Conventions for Defining, Naming, Measuring, Combining, and Mapping Threats in Conservation

An Initial Proposal for a Standard System

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About This Paper

The ideas presented in this paper grew out of a small two-day workshop held in April 2003. Each of the participants in this workshop had been involved in previous efforts to try to define and name threats to biodiversity. Our original goal for the workshop was to compare our respective previous efforts and try to come up with a standard taxonomy of threats. We soon realized, however, that there was potentially great benefit to be gained by trying to develop conventions for not just naming threats, but also measuring and mapping them. So we agreed to keep working together to try to define the problems and then offer our best attempt at solutions to these problems.

We do not expect the conventions proposed in this paper to immediately become "the standard" for conservation. Instead, it is our hope that these conventions catalyze a broader discussion and debate that will ultimately lead to the development and adoption of a set of open-source standards. To this end, we welcome any comments or feedback you might have about this paper. Please send any suggestions that you might have to:

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We are also planning to set-up a website in the near future that will provide a place to discuss these issues further. This current draft is being circulated for peer review prior to its publication. Please check with the authors for the current status of the paper.

Abstract

Although conservation practitioners are ultimately interested in protecting or restoring biodiversity, much of the day-to-day work of conservation involves taking action to counter threats – the human activities that negatively impact biodiversity. Understanding threats is a critical step in many stages of the conservation process such as setting priorities as to where to work, developing strategies to address these problems, coming up with measures to determine whether a given project or program is achieving its desired results, and analyzing and comparing results to promote learning. Despite the importance of threats in the conservation process, there are only a few standardized systems for dealing with threats within conservation organizations and no system in wide use across organizations. To address these problems, in this paper we focus on developing five sets of conventions for describing threats: (a) a framework for defining threats and related factors, (b) a taxonomy for naming direct threats, (c) a system for measuring the magnitude of threats, (d) a procedure for combining threats across targets, threats, and projects, and (e) a method for the spatial mapping of threats. In each section we first define the problem, outline our criteria for the ideal solution, selectively review existing work on this topic, offer a proposed convention, assess it against our ideal criteria, and discuss next steps that might be needed to improve or finalize our proposed convention. Our hope is that our proposed conventions might become the first draft of a system that after sufficient discussion and modification, might be adopted across the conservation community.

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The limits of my language mean the limits of my world…
What we cannot speak about we must pass over in silence.

– Ludwig Wittgenstein, *Tractatus Logico-philosophicus*

1. Why Do We Need Conventions for Describing Threats?

Conservation is an action-oriented discipline. Although conservation practitioners are ultimately interested in protecting or restoring biodiversity, much of the day-to-day work of conservation involves taking action to counter threats – the human activities that negatively impact biodiversity. There is thus a critical need in conservation work to identify and assess the threats affecting the biodiversity of concern. Understanding threats is a critical step in many stages of the conservation process (e.g., TNC 2000, CMP 2003) such as setting priorities as to where to work, developing strategies to address these problems, coming up with measures to determine whether a given project or program is achieving its desired results, and analyzing and comparing results to promote learning.

Despite the importance of threats in the conservation process, there are only a few standardized systems for dealing with threats within conservation organizations (e.g. EPA 1998, TNC 2000, Ervin 2002, Salafsky et al. 2002) and no system in wide use across organizations. To the extent that they consider threats at all, each organization, and even each project team within an organization, seems to have developed their own way of characterizing the threats they are facing. The situation in conservation today is much like the early days of medicine before the advent of standard listings of diseases (e.g., Merck 1899) or the practice of psychiatry before the development of a standard nomenclature and description for mental health problems (American Psychiatric Association 1952). This lack of a standard system causes problems in many steps of the conservation process including:

- **Problems in setting priorities and planning** – Without common definitions and measurements of threats, it is difficult to compare places where a group could potentially take action and set priorities for resource investment. It is also difficult to plan which of these prioritized places should be tackled immediately and which can be deferred until a bit later.

- **Problems in designing projects and programs and developing effective strategies** – Without common definitions and measurements of threats, it is difficult to select which threats to address within a project or program area. It is also difficult to compare the potential leverage obtained by using different strategies and decide which to use.

- **Problems in measuring conservation status and effectiveness** – Without common definitions and measurements of threats, it is difficult to determine and compare the conservation status of biodiversity at one location over time. It is also hard to roll-up status assessments across multiple locations. And it is tricky to determine the relative effectiveness of different conservation actions in relation to threat-based objectives.

- **Problems in learning** – Without common definitions and measurements of threats, it is difficult to compare one practitioner's experiences with others, which is the foundation for any kind of systematic learning about how to effectively and cost-effectively counter each type of threat.

To address these problems, in this paper we focus on developing five sets of conventions for describing threats:

a. A framework for defining threats and related factors
b. A taxonomy for naming direct threats
c. A system for measuring the magnitude of threats
d. A procedure for combining threats across targets, threats, and projects
e. A method for the spatial mapping of threats

In each section we first define the problem, outline our criteria for the ideal solution, selectively review existing work on this topic, offer a proposed convention, assess it against our ideal criteria, and discuss next steps that might be needed to improve or finalize our proposed convention.

Our hope is that at a minimum, our proposed conventions will prompt individuals and organizations to develop an explicit system of their own that can be readily translated into the system that we propose. Ultimately, however, we hope that our proposed conventions might become the first draft of a system that after sufficient discussion and modification, might be adopted across the conservation community.

2. A Framework for Defining Threats and Related Factors

At the moment, different organizations and individuals have overlapping but subtly different ways of referring to threats. These differences include both the specific terms used as well as their relationship to one another.

To solve this problem, we set out to develop a generic framework for referring to threats in which the terms are:

- **Clear** – Terms and their relationship to one another are unambiguous and precise in their definitions.

- **Understandable –** Terms are used in accordance with their general meaning in the English language.
- **Compatible –** Terms are as compatible with the lexicons currently being used by various conservation organizations

Current Practices in Conservation

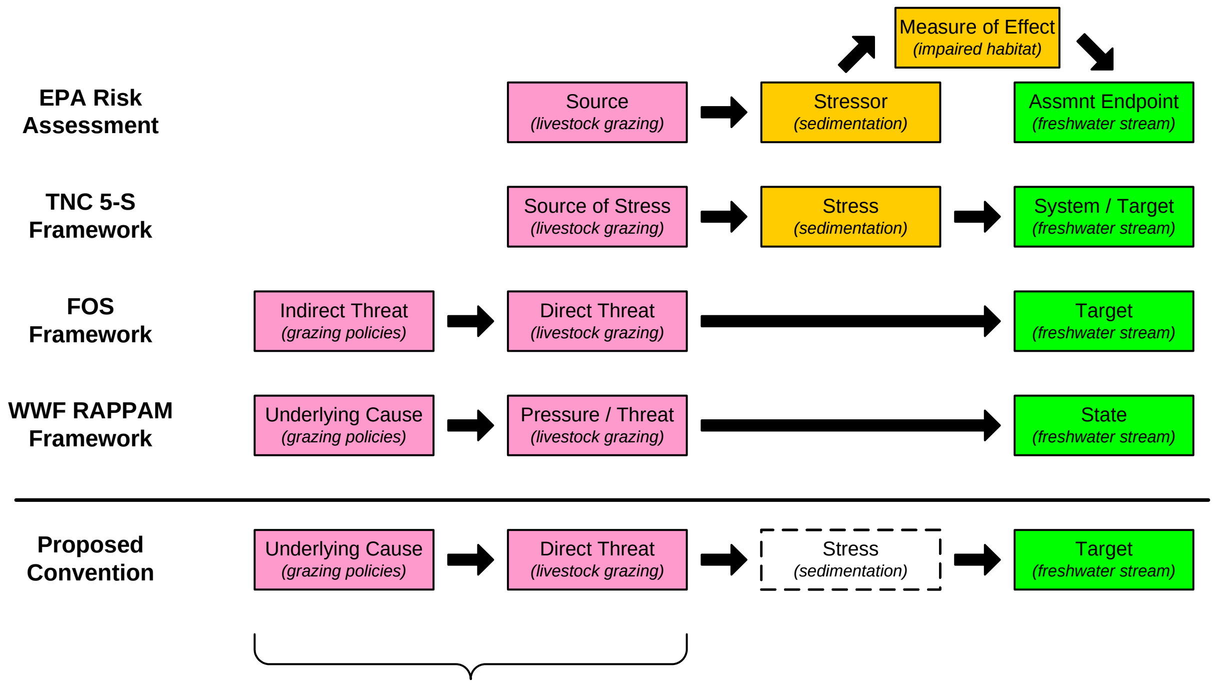
Most conservation organizations currently have some way of describing the threats facing biodiversity. Fig. 1 presents four ways of generically describing the relationship between threats and biodiversity. Each of these descriptions takes place in the context of each organization's broader framework for modeling a conservation project (as defined in Salafsky et al 2002). To this end, the specific way in which each organization describes threats is influenced by how the group chooses to define the target on which they are focusing. It is also influenced by the scale at which the organization conducts its projects.

- **EPA's Ecological Risk Assessment** – As described in EPA (1998), the risk assessment methodology starts by determining specific *assessment endpoints,* which are operationally defined by an ecological entity and its attributes (e.g., salmon reproduction). A *source* is an entity or action that releases a chemical, physical, or biological stressor. A *stressor* causes adverse effects to ecosystem components or functions. Stressors cause a particular impact referred to as a *measure of effect* that in turn, negatively impacts a particular assessment endpoint.

- **TNC's 5-S Framework –** As described in TNC (2000), TNC's methodology for conservation area planning starts by describing the *systems* that the project is focusing on. Systems are synonymous with *conservation targets*. Conservation targets can be single species (e.g., salmon), communities (e.g., specific plant associations or alliances), or ecological systems (e.g., a riparian system that includes aquatic and terrestrial assemblages). Each target has specific *key ecological attributes* related to its size, condition, and landscape context. Conservation targets are affected by *stresses,* which impair or degrade key ecological attributes (for example, alterations to a natural stream flow regime). Stresses are in turn caused by *sources of stress,* which are human (for example, dams or other water control structures) or biological (for example, invasive species) entities that infringe upon a conservation target in a way that results in stress.

- **FOS's Model of a Conservation Project –** As described in Salafsky et al. (2002), a generic model of a conservation project starts by defining the conservation *targets* that the project is focusing on. These targets can range from specific species to entire ecosystems. Targets are negatively affected by *threats*, which can be further subdivided into *direct threats* that are proximate to the targets and *indirect threats* that affect the direct threats. *Opportunities* are things that can positively affect the targets. Threats and opportunities are together *factors.*

Figure 1. Examples of Frameworks for Describing Threats & Targets and the Proposed Convention



- **WWF's RAPPAM Approach** – As described in Ervin (2002), an analysis of threats and pressures is an important component of a rapid assessment of the overall management effectiveness of protected areas within a particular country or region. This system starts by focusing on the *state* of biodiversity, expressed in terms of biodiversity objectives, rather than specific elements of biodiversity. These objectives are linked to *pressures*, which are forces, activities, or events that have already had a detrimental impact on the integrity of a protected area and *threats*, which are potential or impending pressures. Behind the pressures are *underlying causes*.

Other conservation organizations have similar frameworks that they use. For example, the Africa Wildlife Foundation's Heartland Conservation Process (AWF 2003) explicitly incorporates TNC's 5-S approach, but uses the terms *threats* and *source of threat* instead of *stress* and *source of stress*. The Wildlife Conservation Society's Living Landscape's Approach (Sanderson 2002, WCS 2002) defines *threats* as "land-use practices and polices that have direct or indirect effects on the species or habitats that we want to conserve" and refers to *direct threats* and *indirect threats*. Conservation International employs a Pressure-State framework that is similar to the one used by WWF's RAPPAM approach. Another WWF framework (WWF 2000) subdivides the concept of *threats* into *stresses*, *pressures*, and *root causes*. And yet another WWF framework (Stedman-Edwards 1998 and 2000 and Robinson 2000) refers to *proximate causes* and *root causes* of biodiversity loss.

Proposed Conventions

As shown in the bottom portion of Fig. 1, we propose the following generic terms and definitions to describe different types of threats:

- **Threats –** Any human activity or process that has caused, is causing or may cause the destruction, degradation and/or impairment of biodiversity and natural processes. There is often a fine line between a naturally occurring event such as a fire set by lightning and a human-caused threat such as a fire set by a match or even increased intensity of fires due to forest management practices. In general, we would regard the latter two as threats whereas the former is not. In systems that depend on human actions to maintain biodiversity such as the use of prescribed burns, the removal or alteration of these management activities may also constitute a threat. Includes both *direct threats* and *underlying causes.* Synonymous with *pressures.*

- **Direct Threats –** Factors that immediately cause stress to conservation targets by physically causing their destruction or degrading their integrity.

- **Underlying Causes –** A condition or environment, usually social, economic, political, institutional, or cultural in nature, that enables or otherwise contributes to the occurrence and/or persistence of a direct threat. There is typically a chain of underlying causes behind any given direct threat. In a situation analysis, underlying causes can be subdivided into *indirect threats* (factors with a negative effect) and *opportunities* (factors with a positive effect). Synonymous with *drivers.*

In addition to the three generic terms listed above, we also define the following types of threats based on the timeframe on which they occur (note that the Merriam-Webster online dictionary defines a threat as "an expression of intention to inflict evil, injury, or damage" implying that threats can only occur in the future. However, the 3rd Edition of the Shorter Oxford English Dictionary defines threat as "painful pressure, oppression, compulsion; vexation, torment; affliction, distress, misery; danger, peril" indicating that threats can occur both in the present and future):

- **Past Threats –** Threats that have occurred in the past, but are no longer active (although their effects on targets may still persist).

- **Current Threats –** Threats that are actively occurring.

- **Future Threats –** Threats that are not actively occurring, but have some probability of occurring in the future.

Finally, although they are not threats, we also offer two other definitions of related terms:

- **Targets –** The biological entities (species, communities, or ecosystems) that the project is trying to conserve. Synonymous with *conservation targets, biodiversity targets,* and *focal targets.*

- **Stress** – The impairment or degradation to a key ecological attribute of a conservation target that results in reduced integrity of the target. As shown in the diagram, a stress is not a threat in and of itself, but rather a condition of the target. In many situations, defining specific stresses leads to an unnecessary level of detail, especially when the project is operating at a coarse scale. In these cases, it is better to just have the stress be implicit in the arrow leading from the threat to the target. For example, if a threat to a forest in a National Park is illegal clearcut logging, then the project team members will want to act to keep the loggers out of the forest. They don't need to worry about stresses. In some situations, however, it is important to detail the specific mechanisms by which a threat affects a target. For example, the threat to a forest in a managed timber area is legal selective logging, then the team may not be able to completely eliminate the loggers. Instead, the project may wish to ameliorate specific problems caused by the logging such as soil erosion into streams and secondary damage to trees caused by felling practices. In this case, the team members may wish to expand the arrow linking the logging threat to the forest target to show specific mechanisms or stresses.

Overall, we are reasonably satisfied that the set of terms meets our criteria outlined above. We hope that this framework meets the criterion of being *clear*. We also hope that it is *understandable* by English speakers without a technical background in conservation. Finally, it is obviously impossible for this system to be completely *compatible* with all other systems currently in use in the conservation community, but we believe that we have used terms that are currently commonly used.

The next step is for members of the conservation community to decide whether they want to adopt these conventions or propose alternatives. In addition, it will also be important to develop equivalent terms in languages other than English.

3. A Taxonomy for Naming Direct Threats

At the moment, each conservation project team typically gives its own name to the threats affecting biodiversity. For example, one project might speak of "cattle" whereas another might speak of "grazing pressures" and a third "ranching" when they all actually mean the same thing. As discussed above, this lack of common terms makes it difficult to compare one project to another for planning, strategy development, measurement, or learning purposes.

To this end, we tried to develop a classification system for threats that is:

- **Hierarchical** – Creates a logical way of grouping threats that are related to one another.
- **Comprehensive** – Covers all possible threats (at least at higher levels of the hierarchy).
- **Consistent** – All entries at a given level of the taxonomy are of the same type; the hierarchy does not "mix apples and oranges."
- **Expandable** – Is designed so as to enable new threats to be added to the taxonomy as they are discovered.

- **Exclusive** – Any given threat can only be placed in one cell within the hierarchy.
- **Scalable** – The same names can be used for threats at one site and across a continent.

Current Practices in Conservation

There has been some limited work in developing taxonomies of threats facing conservation projects:

- **TNC's Catalogue of Threats –** Gershman (2000) compiled threats from 90 TNC conservation sites. He then provided a hierarchical taxonomy of both stresses and sources of stress. These taxonomies were very detailed with lots of specific stresses and sources of stress; for example listing not only water pollution, but pollution from heavy metals.

- **TNC's 5-S –** In documentation describing the 5-S framework (TNC 2000), TNC staff provided two lists of stresses and sources of stress. These lists were more illustrative than comprehensive.

- **FOS's Taxonomy of Direct Threats –** Salafsky et al. (2002) created a table of direct threats. These threats were organized generically and then by biome. The authors also attempted to separate out threats in terms of the degree of impact that they hard on targets. For example, they listed clearcut logging as being different from selective logging, leading to some confusing repetition within the table. This table also contained threats as well as some "stresses."

- **WWF's Root Causes Analysis –** Stedman-Edwards (1998) and Wood et al. (2002) used an extensive literature review to develop key proximate causes of biodiversity loss and five categories of root causes. The proximate causes of biodiversity loss she identified are habitat alteration and loss, over-harvesting, species and disease introduction, pollution, and climate change. Of these, habitat alteration was identified as the primary cause of biodiversity loss world-wide. The root causes categories she developed are demographic change, inequality and poverty, public policies markets and politics, macroeconomic policies and structures, and social change and development biases.

- **Other –** Other efforts have largely focused on developing lists of threats facing specific ecosystems or biomes (e.g., Geist and Lambin, 2001 for tropical forests; Richter et al., 1997 for freshwater) or cataloguing risks to specific species, including most notably, the compilation of the IUCN Red List.

Proposed Conventions

In considering this task, we quickly recognized that it is difficult to develop a taxonomy of underlying causes that meet our stated criteria since these literally encompass all factors in the universe. We therefore restricted our work in this paper to direct threats.

Furthermore, we recognized that each direct threat has at least two components to it: the action being taken and the actor taking the action. Thus, logging by local people is a different threat than logging by a multinational company. We restricted our work to considering the actions being taken and do not focus on the actors or whether the threats are *internal* or *external* to the stakeholders in a project (Salafsky et al. 2002). We made these two restrictions to keep the focus of this paper at a manageable level; we in no way intend them to imply that practitioners can ignore the underlying causes and actors responsible for direct threats.

Our proposed taxonomy of direct threats is presented in Table 1. In developing this taxonomy, we assume that, as described above, all threats are caused by human activities. General categories of direct threats are presented in the far left-hand column of Table 1:

- **Habitat conversion –** Total loss or destruction of natural habitat.

- **Transportation infrastructure –** Development of long narrow corridors for transporting people, goods, and energy.

- **Abiotic resource use –** Human extraction of non-biological resources.

- **Consumptive biological resource use –** Human harvesting or use of biological resources from an ecosystem that removes the resources from the system.

- **Non-consumptive biological resource use –** Human use of biological resources in an ecosystem in a way that does not remove the resources from the system

- **Pollution –** Human caused introduction and spread of unwanted matter and energy into ecosystems. Includes chemical, biochemical, thermal, radiation, and noise pollution. Can include both point source and non-point source pollution.

- **Invasive species –** Human linked introduction and spread of species from one ecosystem into another. Includes alien or exotic species as well as escaped native ones. Also includes both plants and animals as well as disease causing organisms.

- **Modification of natural processes / ecological drivers / disturbance regimes –** Human caused changes in natural systems. Threats in this category often bleed over into “stresses” within a system. In managed systems, removal or alteration of human management activities such as grazing or prescribed burns may also constitute a threat.

Specific examples of these generic threats in different biome types are then presented in the remaining columns. Similar columns could be added for other biomes or ecosystems. This taxonomy is not meant to be a substitute for having each project team create a specific conceptual model of the threats affecting the targets at their project site. Instead, the taxonomy should serve as a guide to help ensure that practitioners have considered all

Figure 2. An Example of Using the Taxonomy of Direct Threats

A project team is working in a rainforest ecosystem. In developing a conceptual model as part of their situation analysis (Margoluis & Salafsky 1998; TNC 2003) they have identified the following threats:

- **Commercial Logging**
- **Tenure Rights**
- **Cattle Ranching**
- **Hydropower Development**
- **Palm Fruit Over Harvesting**
- **Local Need for Cash**

The team then reviews Table 1 and in the process, realizes that they have not considered some other direct threats that are relevant at their site including:

- **Subsistence Hunting**
- **Subsistence Agriculture**
- **Commercial Hunting**
- **Fire**

The team also uses Table 1 to determine that two of the threats that they have identified (Tenure Rights and Local Need for Cash) are really underlying causes. Finally, although they continue to use the above terms to describe the threats within their project, they also note the "generic" name for each threat so that they can communicate clearly with their home office and with other project teams.

Specific Direct Threat at Project	Generic Name
Commercial Logging	Logging
Cattle Ranching	Grazing
Hydropower Development	Dam Construction
Subsistence Agriculture	Farms
Subsistence Hunting	Hunting
Commercial Hunting	Hunting
Palm Fruit Over-Harvesting	NTFP Collection

relevant direct threats and that they are naming them in a consistent fashion as shown in the example in Fig. 2.

Overall, we feel that our proposed taxonomy meets our criteria of being *hierarchical*. If we compare our system to the Linnaean nomenclature system for living things:

Family = Threat Category (e.g., transportation infrastructure)
Genus = Generic Threat (e.g., roads)
Species = Specific Threat (e.g., secondary dirt road)

Our proposed taxonomy is also *comprehensive* at the level of the threat categories; we believe that all direct threats could be placed in one of the rows of table. It is also reasonably comprehensive at the level of the generic threats, although obviously additional generic threats could be added to various cells of the table. We have not attempted to list the specific threats under each generic threat type. Our proposed taxonomy is also reasonably *consistent*, *expandable*, and *scalable*. The system is not quite as *exclusive* as we would ideally like. This is in large part because many human activities have multiple components to them. For example, mining generally involves the construction of roads, railroads, or other transportation infrastructure. In this case, it is not clear whether this should be one threat (mining) or two threats (mining and roads). Practitioners may have to make this judgment on a case-by-case basis.

The next step is to further test this taxonomy using project sites from around the world and for members of the conservation community to decide whether they want to adopt these conventions or propose alternatives. It will also be necessary to complete Table 1 for all biomes or even for specific ecosystems down to the level of the generic threats and perhaps even the specific threats. Practitioners can then use this taxonomy to describe the threats they are dealing with in a common fashion. Finally, although we have restricted ourselves in this paper to a taxonomy of direct threats, it will be important to follow-up on the WWF Root Cause analysis (Wood et al. 2000) to try to develop some form of taxonomy for underlying causes since it is often more effective to focus project activities on these drivers of the direct threats.

Table 1. An Initial Taxonomy of Direct Threats

This table presents Threat Categories (≈family) and Generic Threats (≈genus); it does not list Specific Threats (≈species).

	GENERIC THREATS IN DIFFERENT BIOME TYPES				
THREAT CATEGORY	**Forests**	**Grasslands / Savannah**	**Desert**	**Freshwater**	**Marine**
Habitat conversion	Housing Industrial development Farms Plantations Ski areas	Housing Industrial development Farms Dam construction Golf courses	Housing Industrial development Farms Golf courses	Docks Farms (e.g., rice) Channelization Dam construction Ship yards	Aquaculture Destructive fishing
Transportation infrastructure	Utility lines Roads Railroads	Utility lines Roads Railroads	Utility lines Roads Railroads	Levees & dikes Dredging	Dredging Shipping lanes
Abiotic resource use	Mining Oil & gas drilling Geothermal energy Water withdrawal	Mining Oil & gas drilling Geothermal energy Water withdrawal Wind farms	Mining Oil & gas drilling Geothermal energy Water withdrawal Wind farms	Mining Oil & gas drilling Water withdrawal	Mining Oil & gas drilling Coral mining Desalizanation plants Wind farms
Consumptive biological resource use	Hunting / NTFP collect Grazing Logging	Grazing Hunting / gathering	Grazing	Fishing	Fishing Trawling
Non-consumptive biological resource use	ATVs / snowmobiles Hiking / biking Scientific research Military maneuvers	ATVs Hiking / biking Scientific research Military maneuvers	ATVs Hiking / biking Scientific research Military maneuvers	Jet skis Boating Scientific research Military maneuvers	Jet skis Boating Scuba / snorkeling Scientific research
Pollution	Acid rain Solid waste Toxins Radio active fallout	Solid waste Toxins Radio active fallout Agricultural runoff	Salizanation Toxins Solid waste	Municipal waste Solid Waste Toxins Agricultural runoff Thermal pollution	Solid Waste Toxins Agricultural Runoff Municipal waste Sonic pollution
Invasive species (alien and native)	Plants Animals Disease & pathogens	Plants Animals Disease & pathogens	Plants Animals Disease & pathogens	Plants Animals Disease & pathogens	Plants Animals Disease & pathogens
Modification of natural processes / ecological drivers / disturbance regimes *	Climate change Loss of key predators Grazing patterns Fire regime	Climate change Desertification Grazing patterns Fire regime	Climate change Grazing patterns	Climate change Sea-level rise Sedimentation Salinity Loss of key predators Flow regimes (dams) Shoreline stabilization	Climate change Sea-level rise Coral bleaching Loss of key predators

* Items in this row could be categorized as "stresses" rather than as "threats" but are important for practitioners to consider.

4. A System for Measuring Threats

There is currently no consistent system for measuring the strength, extent, or magnitude of threats either within a project or across projects. As a result there is no way for a project team to communicate whether a very high threat posed by invasive species is more or less of a problem than a moderate threat posed by clearcut logging. And there is no way to compare the threat posed by hunting in one project area to hunting at another project area. This lack of a consistent measurement system makes it difficult for practitioners to prioritize scarce resources, develop effective strategies to combat threats, decide in what sequence to tackle a series of threats, develop ways of measuring the effectiveness of strategies, and assess the status of biodiversity over large areas.

To this end, we tried to develop a system for measuring the magnitude of threats that is:

- **Measurable –** Based on continuous data or defined categories of impact.
- **Scalable –** Consistently measure threats at different spatial and temporal scales.
- **Consistent –** Provide comparable rankings both within one type of threat and (ideally) across different threats.
- **Combinable** – Designed so that measurements for different threats can be rolled-up to provide an aggregate score for a given conservation area or management unit.
- **Elegant –** Powerful and yet easy for practitioners to understand and use.

Current Practices in Conservation

There are currently a number of different variables used for measuring different dimensions of threats.

- **TNC's 5-S Framework –** TNC (2000) describes four variables used to measure threats. *Scope of Damage* is "the geographic scope of impact to the conservation target expected within 10 years under current circumstances." *Severity of Damage* is "the level of damage to the conservation target over at least some portion of the target occurrence that can reasonably be expected within 10 years under current circumstances." *Contribution* is "the contribution of a source, acting alone, to the full expression of a stress." *Irreversibility* is "the reversibility of the stress caused by a source of stress." Each threat is scored for each variable using a 1-4 ranking and the variables are combined via a series of rules to give an overall score for each threat.

- **WWF's RAPPAM Methodology –** Ervin (2002) describes five variables for measuring threat activities. *Extent* is "the range in which the activity occurs…in relation to its possible occurrences." *Impact* is "the degree, either directly or indirectly, to which the threat affects overall protected area resources." *Permanence* is "the length of time needed for the affected protected area resource to recover with or without human intervention." *Probability* is "the likelihood of the threat occurring in the future." *Trend Over Time* is "increases and decreases in the extent, impact, and permanence of an activity." Each threat is scored for each variable using a 1-4 ranking and then the scores are multiplied to give an overall score for each threat.

- **BSP's Threat Reduction Assessment –** Salafsky and Margoluis (1999) describe three variables to measure threats. *Area* is "the percentage of the habitat(s) in the site that the threat will affect: will it affect all of the habitat(s) at the site or just a small part?" *Intensity* is "the impact of the threat on a smaller scale: will the threat completely destroy the habitat(s) or will it cause only minor change?" *Urgency* is "the immediacy of the threat: will the threat occur tomorrow or in 25 years?" All threats facing a given site are ranked from highest to lowest for each variable and then the scores are summed across the three variables to give an overall score for each threat.

- **TNC's Southeastern Division's Methodology –** TNC Southeastern Division (2003) describe two variables to measure threats. *Severity* is "how severe are the stresses associated with the Source of Stress to the conservation targets?" *Extent* is "what percent of ecoregional target occurrences are affected by the threat at this level of severity?" Rankings are then combined using a rule-based system.

- **WWF's Root Causes Analysis –** D. Montanye (personal communication) describes three variables used to measure threats in the system that they are currently developing: *Scope*, *Impact*, and *Permanence*.

- **WCS's Living Landscapes Approach –** WCS's Living Landscapes Program (WCS 2002) describe five variables uses to assess direct threats: *Severity, Urgency, Proportion of Local Area Affected, Recovery Time*, and *Probability*.

The variables used by the different systems described above are shown in Table 2, in which we have attempted to line up similar variables that were given different names.

Table 2. Specific Threat Variables Used by Different Systems
Variables in each column are used in an analogous fashion.

System	Variables Used By Different Systems						
TNC 5-S	Scope (spatial)	Severity	Contribution	Irreversibility			
WWF RAPPAM	Extent	Impact		Permanence	Probability	Trend	
BSP TRA	Area	Intensity					Urgency
TNC's SE Division	Extent (% targets)	Severity					
WWF Root Causes	Scope	Impact		Permanence			
WCS Living Landscapes	Proportion of Area	Severity		Recovery Time	Probability		Urgency
Table 4 of this paper	Scope	Severity	Contribution	Reversibility	Likelihood	-	Timing

All five methods have developed one variable to measure the scope of the threat and another to measure the severity/impact of the threat and then combined these to get some measure of threat magnitude. In three of the four cases, the measurement of scope focuses on the spatial distribution of the threat across the project area; in the case of TNC's SE Division, however, this measurement counts the percentage of targets in the ecoregion affected by the threat. There is some to no overlap among the other variables.

Proposed Conventions

In considering this task, we soon recognized that it is probably not possible to come up with one measurement of threats that will be useful for all steps in the conservation process. Instead, as shown in Table 3, different steps each require assessing different component variables. For example, a team engaged in global-regional prioritization is going to be comparing all potential places across the domain of their organization where they might work (for a local land trust, this might be all sites within the local community; for a pan-African NGO, this might be all sites across Africa). For each potential site, the team needs to assess the conservation importance of the site, the magnitude of the threats facing the site, the timing of these threats, and the feasibility of that organization being able to address those threats.

Table 4 provides specific definitions and measurement conventions for each of the threat related variables shown in bold font in Table 3. We do not define the other non-threat related variables such as *Conservation Importance of Targets* or *Organizational Resources* as they are beyond the scope of this paper. The basic procedure for measuring threats that we recommend is:

1. **Define Your Information Needs** – Using Table 3 as a guide, define the specific step in the conservation process that you are interested in and the variables that you would like to consider.
2. **Measure Specific Variables** – Using Table 4, assess the specific variables that you have designated. You will have to decide between using the continuous versus categorical measurements depending on the analyses you want to conduct and data availability as discussed below.
3. **Conduct and Use the Analysis** – The most important step is to implement the analyses you have specified and then use the results in your conservation work.

An example of how these proposed conventions might be employed is shown in Fig. 3. Specific issues that need to be considered in defining the variables include:

- **Continuous vs. Categorical Measurements –** Most variables can be assessed either using continuous measurements (e.g., anywhere between 0-100%) or categorical rankings (e.g., > 75%, 50-75%, 25-50%, < 25%). As a rule, the continuous measurements are more precise, but also more difficult and/or expensive to obtain. For many conservation purposes, the categorical rankings should be sufficient.

- **Dependency on Project Scale –** Some of the variables are measured relative to the overall project area. For example, spatial scope is expressed as a percentage of the overall project area. Thus, a threat affecting the entire extent of a conservation project and its targets will have a scope classified in the highest magnitude category, whether the project scale is a small Pacific island or an entire ecoregion. If you want to make prioritization decisions among alternative conservation project areas you will also need to consider other aspects of these projects that determine their overall conservation merit (e.g., actual size in hectares, total number of species present).

- **Scale for Categorical Measurements –** We have proposed 4-point scales for our categorical measurements as these rankings provide sufficient spread, but do not create false precision. For a number of variables, we have deliberately recommended non-linear categories to reflect the non-linear nature of the variable being measured. For example, instead of saying a "localized" threat scope is between 0 and 25% of the project area, it makes much more sense to say it is between 0 and 5%.

- **Absolute vs. Relative Rankings –** For the most part, we have proposed absolute rankings of threats against the scales that we have given. For some steps in the conservation process such as project planning, however, it may make more sense to use relative rankings of threats against one another as outlined in Salafsky and Margoluis (1999).

- **Link to Strategy Development –** We have chosen not to develop variables related to the cost of dealing with a given threat. Variables that could be developed along these lines include *Cost* or *Social Complexity*.

- **Basic vs. Compound Threat Variables –** We distinguish between "Basic Variables" that involve direct assessments of specific threats and "Compound Variables" that involve common combinations of basic variables. As discussed in more detail in Section 5, the compound variables can be constructed using either *arithmetic* or *rule-based* systems. Specific compound variables that could potentially be useful include:

  Threat Magnitude = a combination of *Scope* and *Severity*
  Feasibility = a combination of *Cost* and *Organizational Resources*
  Urgency = a combination of *Conservation Importance* and *Timing*

  Over time, other compound variables may emerge as being useful.

- **Timeframe for Assessments –** In developing our rankings of scope and severity, we found it necessary to put a timeframe on the impact of the threat being assessed. Following TNC (2000) we have suggested a 10-year timeframe. This 10-year window can be applied to analyses of current threats as well as both historical analyses and projections of future threats.

- **All/Nothing vs. Gradual Threats –** Some threats, such as the construction of a dam or the clear-cutting of a forest, either happen or they do not. Other threats, such as subsistence hunting, tend to develop more gradually, fluctuate in their degree of intensity, and tend to have their effects compounded over time. As a rule, conservation projects generally work to prevent the all/nothing threats from happening whereas they generally work to mitigate the effects of the gradual threats.

Overall, we feel that the proposed system for measuring threats meets our criterion of being *measurable* since it does enable assessments based on continuous or categorical data. It is also potentially *scalable* and *consistent*, but only relative to how particular conservation projects are defined and, in some cases, if continuous data are used. It is also *combinable* (see next section). It is debatable whether this system meets our criterion of being *elegant* since it is fairly complex.

In general, since all the systems we examine have used measurements of *Scope* and *Severity*, we are reasonably confident in our proposed method for measuring *Magnitude* as a combination of these two variables. The formulations of specific steps in the conservation process and the measurements of other variables have not been fully vetted and need more work. A good deal of work is also still needed to explore the continuous measurements of the various variables.

Figure 3. An Example of Threat Measurements

The project team at the rainforest site described in Fig. 2 is now at the step in the conservation process of planning their specific project actions. In conducting their situation analysis (Margoluis & Salafsky 1998; TNC 2003) they have identified the specific direct threats shown in the far left-hand side of the table below. Using Table 3, the project team members identify the variables that they need to assess to determine which threats they will initially take on with their conservation actions: Scope, Severity, Timing, and Likelihood. The project team members then use the categorical measurements in Table 4 to rate each threat for each variable. See the next section for a discussion of how to combine these variables.

Specific Direct Threat	Scope	Severity	Timing	Likelihood
Commercial Logging	3 (33%)	3	3	2
Cattle Ranching	2 (10%)	4	4	4
Hydropower Development	1 (3%)	4	1	1
Subsistence Agriculture	4 (60%)	4	4	4
Subsistence Hunting	4 (100%)	1	4	4
Commercial Hunting	3 (50%)	2	2	3
Palm Fruit Over Harvesting	1 (5%)	1	4	4

Table 3. Steps in the Conservation Process Requiring Threat Measurements
Each step of the overall conservation process has different information needs. In this table, we consider some of these steps that require threat measurements. These variables are then defined in Table 4. The list of variables for each step is only one suggested way in which the threat information need might be addressed; different practitioners will undoubtedly customize each "formula" to meet their specific needs. Bold text represents threat-related variables; plain text represents other variables not specifically related to threats and thus not explicitly defined in Table 4. Variables in parenthesis are "optional" in the specific analysis. Variables in brackets are compound variables defined in the text.

Step	**Question(s)**	**Comparison**	**Variables** (see Table 4 for definitions)
Global-Regional Prioritization	Where should we invest our resources?	Across the domain of the organization	Conservation Importance of Targets **Scope & Severity [= Magnitude]** **Timing** **(Likelihood)** **(Reversibility)** Cost & Org Resources [= Feasibility]
Project Planning	Which threats at our project area do we need to address?	Across threats within a project area	Conservation Importance of Targets **Scope & Severity [= Magnitude]** **Timing** **(Likelihood)** **(Reversibility)** **(Contribution)** Cost & Org Resources [= Feasibility] Social Complexity
Strategy Development	What strategy or strategies should we use to abate the identified threats?	Across potential strategies	**Predicted Threat Reduction [Δ Magnitude] for Each Strategy** Cost & Org Resources [= Feasibility] Organizational Fit
Status Assessment (Global & Project)	How is the biodiversity we care about doing?	Across domain of the organization or project over time	Target Status **Scope & Severity [= Magnitude]** **(Likelihood)**
Effectiveness Measurement and Learning	Are our strategies having their intended impact? How do we effectively and cost-effectively counter each type of threat?	Over time or against control (relative to threat-based objectives) Across project sites dealing with the same threat	Target Status **Actual Threat Reduction [Δ Magnitude] for Each Strategy** **(Likelihood)** Cost & Org Resources [= Feasibility] Social Complexity Strategy Implementation

Table 4. Proposed Continuous and Categorical Measurements for Threat Variables
See text for a description of the table.

Variable	Continuous Measurement	Categorical Measurement	Comment
Scope (Spatial) The area of the project site (or target occurrence) affected by a threat within 10 years	Area threatened expressed in hectares or as a % of the total possible project area	4 = Throughout (>50%) 3 = Widespread (15 – 50%) 2 = Scattered (5 – 15%) 1 = Localized (< 5%)	Calculated as % of possible area (i.e., water pollution is % of aquatic habitat at a site, not entire site)
Scope (% of Targets) The number of target occurrences affected by a threat within 10 years	Absolute number of targets or percentage of targets within a project area affected	4 = Most or all (>50%) 3 = Many (25 – 50%) 2 = Some (5 – 25%) 1 = Few (< 5%)	Is an alternative way of measuring scope
Severity The degree to which a threat has an impact on the viability/integrity of targets within the project area within 10 years	Actual measure of reduced target viability/integrity (e.g., nesting success, stream temperature)	4 = Serious damage or loss 3 = Significant damage 2 = Moderate damage 1 = Little or no damage	Independent of area; Different continuous measures needed for each target type
Timing Time until a threat will start having impact on targets	Years	4 = Current (< 1 year) 3 = Imminent (1-3 years) 2 = Near-term (3-10 years) 1 = Long-term (> 10 years)	Refers to onset of the impact, not the duration of the threat
Likelihood The probability that a threat will occur within the next 10 years	Fraction between 0 and 1 or percent between 0 and 100	4 = Existing threat (100%) 3 = High probability (50-99%) 2 = Moderate probability (10-49%) 1 = Low probability (0-9%)	May not be included in most calculations; can also be applied to other variables
Reversibility Degree to which effects of a threat on target occur-rences can be restored	Resources (money, time, ecological capital, etc.) required to reverse a threat	4 = irreversible (e.g., extinction) 3 = reversible with difficulty 2 = reversible with some difficulty 1 = easily reversible	Distinguish between *technical* versus *economic* or *practical* reversibility
Contribution The degree to which a threat causes multiple and cascading threats and/or has widespread ecological impacts	Number of targets and/or target occurrences affected by a threat	4 = Very high 3 = High 2 = Moderate 1 = Low	Has some potential overlap with *Scope*

5. A Procedure for Combining Threats

Once we have developed a series of measurements of different variables pertaining to threats, the next step is to combine or roll-up these variables into overall measurements. There are four basic combinations that are needed:

Type I: How to combine variables in Table 4 to assess a single threat to a single target. For example, what is the magnitude of the threat of logging to Forest Target A?

Type II: How to roll-up assessments of the impact of different threats to a single target. For example, if Forest Target A is threatened by invasive species, logging, and grazing, what is the overall threat status for Forest Target A?

Type III: How to roll-up assessments of the impact of one threat across multiple targets. For example, if industrial development affects Forest Target A, Freshwater Target B, and Grassland Target C, what is the overall ranking of this threat?

Type IV: How to roll-up threat assessments for multiple targets into an overall threat status for a project. For example, Conservation Project X has threat assessment results for four conservation targets; what is the overall threat status of Conservation Project X?

At the moment, there are a number of different procedures for handling the combination or roll-up of threat measurements. As a result, it is hard to compare assessments done by groups using different procedures.

To this end, we tried to develop a procedure for combining threats that is:

- **Meaningful** – Provides combination or roll-up measures that model real world problems.
- **Simple** – Easy to do.
- **Transparent** – Readily understood by most practitioners.

Current Practices in Conservation

There are basically two types of scoring algorithms for combining different variables. Each has its pros and cons.

- **Arithmetic Procedures** – Arithmetic systems involve forming mathematical combinations of different variables. For example, variables can be either added together, multiplied, or averaged as shown in the following example. The practitioner then has the choice of re-ranking the combined rankings either on an absolute or relative scale. These systems have the advantage of being relatively simple and transparent.

Example: Assume that three threats are given a 1-4 ranking for scope and severity as shown in Table 5. The three middle columns show the results of different arithmetic combinations of the rankings. Note, however, that the relative order (shown in parenthesis) does not change.

Table 5. Examples of Arithmetic Calculations of Threat Magnitude

Threat	Scope (1-4)	Severity (1-4)	Additive	Multiply	Average
Logging	3	4	7 (*1st*)	12 (*1st*)	3.5 (*1st*)
Grazing	1	2	3 (*3rd*)	2 (*3rd*)	1.5 (*3rd*)
Hunting	4	1	5 (*2nd*)	4 (*2nd*)	2.5 (*2nd*)

WWF's RAPPAM method (Ervin 2002) represents an example of a multiplicative method for aggregating different threat variables. BSP's Threat Reduction Assessment (Salafsky and Margoluis 1999) represents an example of an additive method. WCS's Living Landscape Approach (WCS 2002) uses a combination of addition and multiplication to combine their threat parameters (*Urgency* + *Recovery time*) * *Proportion of Local Area Affected* * *Severity* * *Probability*.

- **Threshold Rule-Based Procedures** – These procedures involve specifying rules as to how different parameters should be combined as shown in the following example. These systems have the advantage of being able to tailor the combinations in ways that reflect real-world threshold effects.

  Example: The matrix in Fig. 4 from TNC (2000) shows a rule-based procedure for making a Type I combination of the rankings for the *Scope* and *Severity* variables to get a ranking of *Threat Magnitude*. Under these rules, if a threat is rated "low" on either variable, then the magnitude is "low" overall.

Figure 4. A Rule-Based Procedure for Calculating Threat Magnitude
From TNC (2000)

		Scope			
		4-Very High	3-High	2-Medium	1-Low
Severity	4-Very High	4-Very High	3-High	2-Medium	1-Low
	3-High	3-High	3-High	2-Medium	1-Low
	2-Medium	2-Medium	2-Medium	2-Medium	1-Low
	1-Low	1-Low	1-Low	1-Low	1-Low

TNC's 5-S method (TNC 2000) represents an example of a matrix-based method for aggregating different threat variables to conduct a Type I roll-up. See Fig. 5 for another example showing the roll-up for a target (Type II), a threat (Type III) and an overall project (Type IV).

Figure 5. An Example of Type II, III and IV Roll-Ups

The TNC 5-S Framework contains an explicit rule-based procedure for conducting Type II , III and IV roll-ups of threat rankings. The procedure begins by ranking threats on several variables and then using a Type I rule-based roll-up to combine these variables to produce an overall rank of Very High, High, Medium, or Low for each threat on each focal target as described above.

The next step is to create a matrix of threats and focal targets as shown in the table below. Multiple threats to individual targets and multiple target threat scores are summed together using the 3-5-7 rule:

- 3 High ranked threats are equivalent to 1 Very High-ranked threat;
- 5 Medium ranked threats are equivalent to 1 High-ranked threat;
- 7 Low ranked threats are equivalent to 1 Medium-ranked threat

Once multiple threats scores are summed together, the overall threat status for a single target, for a threat, and the overall threat status for the whole project is calculated using the 2-prime rule. This rule requires the equivalent of two Very High rankings (e.g., one Very High and at least three High rankings) for the overall ranking to be Very High and the equivalent of two High rankings for the overall ranking to be High.

For example, in the second row for the Housing threat, there are 3 High rankings (which equals 1 Very High) and 1 Very High ranking. Thus, the overall Threat Rank is Very High. Likewise, in the Upper Watershed Column, there are 6 High rankings, which equal 2 Very High rankings. Thus, the overall rank for this target is Very High. In the TNC Excel Workbook, these rankings are automatically calculated by the software.

In this example, the bottom row contains the overall threat ranking for each target (a Type II roll-up). The far right-hand column contains the rankings for each threat across targets (a Type III roll-up). And finally, the cell in the lower right-hand corner contains the overall ranking for the project (a Type IV roll-up), which is calculated by rolling up the far-right hand column using the 2-prime rule.

Active Threats Across Systems	Vernal pool grasslands	Lower Floodplain	Upper Floodplain: Chinook Salmon	Upper Watershed	Ione Chaparral	Blue Oak Woodland	**Overall Threat Rank (Type III)**
Farms	High	High	High	High	-	Very High	**Very High**
Housing	High	High	-	High	Medium	Very High	**Very High**
Groundwater withdrawal	-	High	Very High	-	-	-	**High**
Levee and dike construction	-	High	Very High	-	-	-	**High**
Mining	-	-	Medium	-	Medium	-	**Medium**
Industrial development	-	-	-	-	High	High	**High**
Fire suppression	Medium	-	-	High	Medium	High	**High**
Invasive/alien species: Plants	High	Medium	-	-	Medium	Medium	**High**
Invasive/alien species: Animals	-	Medium	Medium	High	-	-	**Medium**
Forestry practices	-	-	-	High	-	-	**Medium**
Operation of drainage systems	-	-	-	High	-	-	**Medium**
Grazing	Medium	-	-	-	-	Medium	**Medium**
Recreational vehicles	-	-	-	Low	Medium	-	**Low**
Agricultural runoff	-	Medium	-	-	-	-	**Low**
Overfishing or overhunting	-	-	Low	-	-	-	**Low**
Threat Status for Targets (Type II)	**High**	**High**	**Very High**	**Very High**	**High**	**Very High**	**VERY HIGH**
							Overall Project Rank (Type IV)

Proposed Conventions

Each project or organization will have to decide on its own whether it prefers the simplicity and transparency of a arithmetic roll-up procedure or the ability to meaningfully model real world problems. However, we propose the following conventions:

- **Type I Combinations of Variables –** For combining two or three variables, we recommend either adding up/multiplying the variables or using a simple rule-based matrix. In particular, we recommend calculating *Magnitude* as a rule-based function of *Scope* and *Severity* as described in Table 6. Other rules will have to be developed for other compound threat variables described in the previous section. For combining four or more variables, we recommend adding up the variables.

- **Type II, III, and Type IV Roll-Ups Across Targets, Threats, and Projects –** For developing a combined threat ranking across a target, threat, or overall project, The Nature Conservancy's 5-S Framework is the only system that we are aware of that provides multiple levels of threat roll-up and that has been tested and refined for hundreds of conservation projects throughout the world. It is also instructive to note that the architects of the TNC 5-S system began with arithmetic roll-up procedures and then abandoned them in favor of the rule-based system described above. We are thus proposing a wider adoption of the 5-S rule-based system (TNC 2000). However, we should also continue to explore other roll-up procedures including arithmetic combinations in the context of combining spatial map layers (see next section).

It is also worth noting that depending on how threat variables are measured, some of the types of roll-ups may not be required. For example, if the threat variables are applied to an overall project area rather than specific targets, then there is no need to roll-up across targets to then get an overall project threat ranking; instead this ranking is calculated directly.

Overall, we feel that the proposed procedure for the Type I roll-up meets our criteria of being *meaningful*, *simple,* and *transparent.* The proposed procedure for the Type II, III, and IV roll-ups is *meaningful*. It is also fairly *simple*, especially if an automated program is used. However, the automation comes at some cost of *transparency.*

In general, both sets of conventions have been widely tested by TNC and other organizations and thus the next step is for members of the conservation community to decide whether they want to adopt these conventions or propose alternatives.

6. A Method for the Spatial Mapping of Threats

In addition to having a conceptual understanding of the threats at a given project area, it is also highly desirable, and often critical, to have a spatial map that shows the extent and magnitude of each threat. Spatial depiction enables an analyst/planner to see the relationship between targets and threats, and can facilitate creation of a *threatshed* map, the depiction of a threat and its magnitude over one or more time periods. This threatshed could then be combined with other map layers (such as the location of targets) to help facilitate prioritization, planning, strategy development, measurement, and learning efforts.

We set out to develop a method for the spatial mapping of threats that is:

- **Layered –** Show different threats on different mapping layers.
- **Scalable –** Work at all different spatial scales.
- **Able to Show Magnitude –** Represent the magnitude of the threat at any given location.
- **Able to Display Time –** Represent both current and future threats as well as changes in threat magnitude over time.
- **Able to Link Threats to Targets –** Enable a project to tie specific threats to specific targets.
- **Combinable –** Enable a project to add or otherwise combine threat layers at any given location.
- **Flexible in Data Requirements –** Accommodate both simple and sophisticated data sets as well as both direct and proxy measurements of specific threats.

As in any mapping effort, threat maps can be drawn using simple hand-sketches or by using highly sophisticated computer-based models. Given the rapid development and spread of computer-based technology over the past decade, we assume that most conservation groups would be able to employ at least simple computer-based systems.

Current Practices in Conservation

Many conservation organizations are currently using desktop computer-based geographic information system (GIS) programs to map the project areas they are focusing on. In addition to information layers about the biodiversity, many of these systems also include layers for human population centers, land use patterns, and other actual or potential threats. For example, TNC's current portfolio design methodology calls for creating basic lists of threats for each target. In the past couple of years, however, a few people have begun to combine different data layers to create threatsheds for specific types of conservation problems.

- **Threats to Ecoregions in Central America –** Timothy Boucher (2002) conducted an analysis of the threats facing TNC's ecoregions in Central America. He began with a base map of the ecoregions and then overlaid it with maps of three publicly available data sets: land cover/land use (as a proxy for habitat conversion), protected area status (as a proxy for a wide range of specific threats) and the density and rate of change in human population (used as a proxy for rate of conversion of forest to agriculture). Boucher than added the rankings for each ecoregion to produce an overall measure of the threat to each ecoregion. He then compared the threat status of each ecoregion to TNC and WWF's current priority ecoregions.

- **Threats Across the Brazilian Amazon –** David Oren and Marcelo Matsumoto (2003) conducted an analysis of the threats facing the Brazilian Amazon. They began with a base map of conservation targets represented by PROBIO Polygons. They then overlaid this map with layers representing roads, railways, and navigable rivers (direct measures of transportation infrastructure), nighttime light points (as a proxy for urban areas), and deforestation (a direct measure of habitat conversion). For each type of threat, they also developed defined graded buffer zones around each threat showing the declining impact as one moves away from the threat. They then added the weighted ranking for each threat to produce an overall risk map for the Amazon Basin in Brazil. They then compared this risk map to the map of priority conservation targets and calculated the average risk facing specific ecoregions.

- **Threats to One Ecoregion in the Mid-Atlantic –** Chris Mankoff (2003) conducted an analysis of the threats facing TNC's Mid-Atlantic Coastal Plain Ecoregion. He began with a base map of the ecoregion. He then overlaid this map with layers representing human population density and population change (by county), roads, and percentage of agricultural crops using atrazine, a toxic pesticide. He then added the threat rankings for each cell on the map. Finally, he applied this ranking to each potential portfolio site in the ecoregion by calculating a *threat value* (the ratio of actual threats to maximum potential threat expressed as a percentage).

Other researchers have undertaken similar efforts at different scales (e.g., TNC Northeast Division 2003; Gorenflo 2002).

Proposed Conventions

The specific methodology that should be used to map threats for any given project depends on a number of factors including the scale at which the project is working, the ability of the project team to get either primary or secondary data about the threats of interest, the problems which the threat map will be used to address, and the expertise of team members in doing GIS analyses, among other factors. Almost all threat mapping efforts, however, should use the following general methodology:

1. **Select the appropriate base map –** Ideally this base map will match the scale at which the project is taking place. The base map should not only be the correct scale, but also be the most valuable and meaningful layer of data that is to be depicted and

worked on. The scale of the base map will also define the scale at which you can work. For example, if you are trying to allocate resources across a set of ecoregions, you will want to have your base map showing the ecoregions and the portfolio of conservation areas within them. In some cases, however, a base map at the desired scale may not be available and you will have to use the best available substitute.

2. **Identify the threats to map –** Using a conceptual model or other planning tools, develop a list of the threats facing conservation targets at the project area. This list would ideally follow the naming conventions described in Section 3 of this paper. As a general rule, direct threats will be easier to map than underlying causes; your map should attempt to at least map all direct threats. Underlying causes can be mapped if it is useful to include them.

3. **Determine the range of spatial data available for each threat –** As outlined in the third column of Table 6, some threats are inherently more mapable than others. For example, roads are generally relatively straightforward whereas hunting is much more difficult to define both in scope and magnitude. Furthermore, as outlined in the next two columns, data for some types of threats are more readily available than for others – especially in the developing world. Data availability depends on the type of threat, the scale and degree of accuracy at which you are interested, whether you are working in resource-rich or resource-poor countries, and the amount of money you have to spend. For example, detailed and accurate maps of road networks in many developed countries can be downloaded for free off the internet and are very accurate. However, the best available data for roads in the developing world is usually only available at a 1:1 million scale (ESRI, 1996). For other types of threats, data availability in developing countries might be even more difficult to obtain. For example, data about active logging concessions in a tropical country might only be available on very crude hand drawn maps in a government office or if you are willing to find a proxy measure by using satellite imagery or aerial photography.

4. **Select data you will use and develop map layers** – Once you have the range of data options for each threat, you can select the option that fits your criteria and create the corresponding map layers. In general, there will be a trade-off between accuracy/resolution and cost. As a rule, however, unless the data are so inaccurate that they are misleading, it is better to have some representation of the threat rather than to ignore it altogether – even this means digitizing hand-drawn maps. In developing the map layers, there are a number of technical issues that you will have to consider that are discussed in more detail below.

5. **Assign magnitude rankings to each threat –** The simplest presentations of each threat layer will merely show the presence or absence of a threat at any given point on the map. In more complex presentations, the layer will also show the magnitude of the threat by assigning a ranking to the threat feature and visually depicting it using a gradation of colors on the map. Ideally these magnitude rankings would follow the system described in Section 4 of this paper. In the most complex presentations, the magnitude rankings may vary spatially for a specific threat – for example, hunting impact in a forest might decline with distance from a village.

6. **Combine magnitude rankings** – The next step is to take the individual threat layers and then combine them into overall threat rankings that can be assigned to a point on the map, or assigned to specific features such as protected areas or ecoregions. Ideally, this combination would follow the procedures outlined in Section 5 of this paper.

7. **Use data in analyses** – The final and most important step is to use the threat data in specific analyses that you are interested in. These analyses can occur at all steps in the conservation process. Some of the most useful types of analyses can include the forecasting of future threats such as the spread of urban areas; the impact of current threats downstream or downwind (pollution); or the immediate modeled impact on biodiversity of a fragmented landscape.

There are a few basic issues that emerge across the general method for mapping threats outlined above. These include:

- **Using Vector vs. Raster Data –** Vector-based maps describe features (such as a road or urban area) by specifying a geometrical equation (a point, line, or polygon). Raster-based maps model features by specifying a range of cells on a grid. As a general rule, raster based data are more powerful since (depending on the cell size) they enable mathematical operations on individual cells (Gorenflo 2002) and the establishment of relationships between cells such as the slope and aspect of a threat. This ability to do mathematical operations is particularly useful in trying to analyze and combine threat rankings. There are standard procedures for converting vector data to raster data detailed in GIS program help documents. It should be noted however, that great care should be made when converting vector to raster that the correct scale is chosen for the resulting raster layer.

- **Specifying Buffers –** For each type of threat being mapped, it is generally necessary to specify some sort of buffer to describe how far the threat extends around each feature in the map. In simple systems, there can be one buffer value; in more complex systems the buffer can be set up as a gradation. For example, a team might specify that a paved road has 100% impact on a forest within 10 meters of the road, 50% impact for an additional 100 meters, and then 10% impact for an additional 1000 meters. The width and gradation of the buffer will obviously be different for different threats as well as for the same threat in different ecosystem types. Initially, project teams will have to specify their own buffer conventions. Over time, however, ecologists in the conservation community could ideally begin to establish common conventions for specifying buffer widths and gradations for different threats in different ecosystems. Although at first these conventions might require somewhat arbitrary expert definitions, ultimately, these conventions could be empirically determined through analysis of actual situations. These distances and intensities could also be modeled based on the how land use patterns and threats interact with the land cover.

- **Use of Proxy Indicators –** As a general rule, it is more useful to directly map threats. For example, to show agricultural fields, you would want to map active farms. In many cases, however, although spatial data are not available for specific threats, it is possible to get proxy measurements of the threat. For example, deforestation can be used as a proxy measure of agricultural development. Proxy indicators are often easier to obtain. In addition, one proxy indicator can often represent multiple threats. Disadvantages of using proxy indicators are that they are often not accurate indicators of the actual threats and that they may confuse people as to what the actual threat might be. To this end, we recommend directly mapping threats wherever possible, but also using proxy indicators if no direct data are available. Additional information (other layers) not normally associated with a threat, can also be used to increase accuracy.

- **Adjusting Scales –** Often data are available at scales other than the one on your base map. For example, human population data might be available by state or province and thus not map neatly on to a base map of ecoregions. It is thus vital to find consistent ways of converting data from one format to another. Ideally, over time the conservation community will develop standard conventions for these conversions for widely used data sets. As a rule though, finer scale data can be scaled to a coarser level, but not the other way around. Loss of accuracy, when going from coarse to fine, will jeopardize the validity of the threats analysis. This is not to say that coarse scale data cannot be used in conjunction with fine scale data, just the scale of the data must be taken into consideration when doing any analysis.

- **Data Shelflife –** The best data that are available for a given threat may in many cases have been collected some number of years earlier. It is thus important to be aware of potential discrepancies between the data depicted on the map and the actual situation on the ground. As a general rule, you should use the best data you have, but make sure that the users of the information are aware of when the data were collected and any potential problems that might result.

- **Depicting Past, Current, and Future Threats –** Map layers can be used to depict past and/or current threats as well as the predicted distribution of future threats. It is important to ensure that users are aware of what is being shown on each layer.

Overall, we feel that the method for spatially mapping threats meets our criteria of being *layered, scalable, and combinable,* to the extent that the data a project has will permit. The ability of the method to *show magnitude* and *show time* depends on the specific layers that any project chooses to construct. Overall, while we feel that the general method that we have outlined makes sense, considerable work will be required to refine and perfect it.

Table 6. Mapping of Direct Threats

GENERIC THREAT	Threat Type	Mapability	Data Availability – 1st World	Data Availability – 3rd World	Importance of Mapping	Comments	References/Source
Habitat conversion	Housing Industry/docks/dams Agriculture/aquaculture Plantations Recreation	Very Good Very Good Very Good Very Good Very Good	Actual Presence " " " "	Point, polygon – 1:1 million. Proxy – limited (1km global, 30m local)	V important " " " "	Weighting and buffering may be done	1st – Govt, Census data, etc. 3rd – DCW (ESRI) Land Use maps (imagery based)
Transportation infrastructure	Utility lines Roads Railroads Dredging	Very Good Very Good Very Good Moderate	Actual presence " " "	1:1 million - Major and some minor infrastructure. Digitizing topo-sheets	V important " " "	Weighting and buffering may be done	1st world – Govt/internet 3rd world – DCW (ESRI)/topo sheets
Abiotic resource use	Mining Oil / Gas / Coal Gravel Water Wind	Good Good Moderate Moderate Good	Actual Actual Actual/Proxy Actual/Proxy Actual	Limited Proxy/point Poor Poor Poor Poor	Important " " " "	Local effects, depends on eco-system	1st world – Govt/internet 3rd world – industry
Consumptive biological resource use	Resource extraction Grazing Logging	Moderate Good* Good*	Zoning/declared Actual Actual	Proxy/expert derived Proxy Proxy	V important " "	* Depends on Intensity	1st world – actual/proxy 3rd world – proxy
Non-consumptive biological resource use	Recreation vehicle Hiking / biking Scientific research Military maneuvers	Moderate Moderate Good Good*	Actual Zoning " " "	Poor/proxy " " "	S important " " "	* Depends on security clearance	1st world – Govt/Industry 3rd world – Institutional
Pollution	Acid rain Agriculture/Solid waste Radio active fallout	Moderate Moderate Moderate	Moderate actual " Modeled	Poor/non-existent " "	Important S important S important	Depends on eco-system	1st world – Environ & Ag Agencies 3rd world – ?none
Invasive species (alien and native)	Plants Animals Disease & pathogens	Poor Poor Poor	Proxy/Modeled Point/Modeled Modeled	Poor/non-existent " "	Important Important S important	Difficult to define scale and extent	1st world – Environ & Govt Agencies 3rd world – ?none
Modification of natural processes / ecological drivers / disturbance regimes	Climate change Predators, keystone sp Fire regime	Poor Poor Moderate	Modeled Proxy/Modeled Proxy/modeled	Modeled Poor/Modeled Poor	Important Important V important	Global Local & regional Key for certain ecosystems	1st world – Academic Inst/Govt Agencies 3rd world – none

Description of Columns for Table 6

Threat Type: This is a summation of the majority of different ecosystem threat types from Table 1 (forest, grassland, desert, fresh-water, and marine).

Mapability: How feasible is it to map this threat from currently available data sources? 4 classes – Poor, Moderate, Good, and Very Good

Data Availability – 1st World: A distinction is made between 1st and 3rd world because of the marked difference in availability of data for mapping. Ranges from Actual presence (fine scale, accurate, and up-to-date GIS layers), to using a proxy to indicate a threat presence, and even a modeled occurrence of a threat.

Data Availability – 3rd World: Usually the accuracy and scale of the data is much coarser that that available for the 1st world. Ranges from global data (Digital Charts of the World, ESRI) to some moderate scale level GIS data (digitized topographic sheets), to proxy (defined by imagery), modeled, and in some cases may not exist and is expert derived. Data availability does vary by country, but more detailed information is seldom available for low cost or over the internet.

Importance of Mapping: How important is it to map this threat? This may vary by conservation target, but this column is meant as a general indicator. There are three levels – somewhat important, important, and very important. This indicator could also vary by time and scale.

Comments: Mapping comments applicable to the generic threat type.

References/Sources: Generic sources are indicated here. More detailed references and sources of data will be made available on the internet.

7. General Next Steps

In this paper, we have tried to develop some basic conventions for dealing with threats in the context of conservation problems. In particular, we have proposed conventions for:

a. A generic framework for defining threats and related factors
b. A taxonomy for naming direct threats
c. A system for measuring the magnitude of threats
d. A procedure for rolling up threats across targets, threats, and projects
e. A method for the spatial mapping of threats

In each section, we have outlined specific next steps that could be taken to improve and use these conventions. More generally, next steps that need to occur include:

1. Practitioners test these conventions and propose changes based on their experiences.

2. We refine these conventions based on this feedback.

3. These conventions are then considered by various organizations that can choose to adopt them, or modify them for their own purposes.

4. Organizations and individuals that broadly agree to these conventions develop a steering committee and a website that can be used to coordinate thinking and improvements to each of these conventions.

If some future version of these conventions can be adopted by the conservation community, we feel it will go a long way towards promoting improvements and learning about dealing with the threats facing biodiversity – and ultimately improve our collective ability to counter these threats.

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