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Open Standards for conservation as a tool for linking research and conservation agendas in complex socio-ecological systems

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Disparity between the knowledge produced and knowledge required to address complex environmental challenges, such as biodiversity conservation and climate adaptation, continues to grow. Systems thinking under the Open Standards for Conservation framework can help close this gap by facilitating interdisciplinary engagement, advancing conversations on how environmental systems work, and identifying actions that could be implemented to achieve defined conservation goals. Here, we present a modelling exercise for one of the most endangered forested systems in the world: The Gran Chaco. We focus on unsustainable hunting, a pressing threat to this system. We highlight knowledge gaps that underpin all parts of an adaptive management process from understanding key relationships in social-ecological systems to design and implementation of strategies for Gran Chaco conservation as well as evaluation of outcomes.

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Introduction

It is difficult to imagine a greater challenge than solving the environmental problems of the Anthropocene [1]. Both social and natural scientists play vital roles by developing knowledge that informs environmental decision making. For example, overexploitation of natural resources is one of the leading causes for global biodiversity decline [2]. Switching from overexploitation to sustainable harvest of natural resources can be a monumental task. Among other things, this transition requires understanding socio-economic factors that explain why natural resources are overexploited, the ecological foundations of sustainable harvest rates, and cultural, political, and economic barriers to implementation of sustainable strategies. An interdisciplinary team composed of researchers from different disciplines is key to this process and for an adaptive path forward. Furthermore, knowledge is only one factor that limits solving environmental problems, as worldviews, value systems, and other human perspectives influence decisions at all levels. Social scientists can help decision makers understand and integrate these perspectives into decision-making. However, the ability of researchers to embrace transdisciplinarity (i.e. researchers and non-researchers working as a team) and develop knowledge that can help solve environmental problems remains limited [2,3]. Consequently, the disconnect between knowledge produced and knowledge required to solve environmental problems continues to grow.

Numerous reasons could explain this disconnect [4]; however, two stand out. First, environmental problems are complex (i.e. many components spanning many disciplines). In conservation and related environmental fields, the study of complex systems is uncommon relative to studies that focus on proximate causes of environmental problems [5]. As a result, problems are compartmentalized, interactions among system components are unknown, and significant knowledge gaps are overlooked. Second, decision makers and diverse teams of scientists rarely interact in design and implementation of research programs aimed at producing a knowledge base for conservation. (Note, herein we use the term decision makers for people charged with making natural resource management decisions, ranging from protected area managers and other conservation practitioners to policy makers). As a result, scientific recommendations emerging from research frequently are vague and impractical [6], and critical elements such as feasibility assessments for implementation of recommendations are not incorporated into research [7,8]. Rigorous research that minimizes uncertainties and elucidates underlying mechanisms for problems is a lengthy endeavor. Decision makers often work under time constraints and must take action with the best available information even though understanding of the problem is incomplete. Thus, researchers frequently fail to address critical information needs of decision makers within a useful timeframe, and decision makers sometimes oversimplify problems [9]. Furthermore, information needs of decision makers are dynamic: they are defined by the strategies chosen to address a problem rather than solely emerging from the need to understand the problem. Information needs change as strategies are implemented and evaluated. Without feedback between researchers and decision makers, important information gaps continue to emerge and persist. Co-design of research programs by scientists and decision makers based on adaptive frameworks could help overcome obstacles for applying science to conservation [7,10,11,12•].

The Open Standards for Conservation [13] provides a practical tool to deal with complex systems and facilitates linking researchers and decision makers to solve problems. Major conservation NGOs created the Conservation Measures Partnership with the aim of developing a common framework that could help define conservation goals, take effective conservation actions, and measure progress in reaching goals [13,14]. To this end, the Open Standards for the Practice of Conservation (henceforth, Open Standards; Box 1) was created as a freely available framework based on an adaptive management cycle [15]. This framework integrates design, planning, monitoring, and systematically testing of system assumptions in order to learn and adapt.

Box 1 The Open Standards framework

The Open Standards encompasses five steps that comprise the management cycle of a conservation project [15,16•]: 1) **Conceptualization.** This includes a vision of the desired conservation state and creation of a conceptual model of the system. Conservation work takes place through projects with defined goals and objectives, usually aimed at conserving certain biological entities (e.g. species, communities, ecosystems; [14]) and often the ecosystem services that these provide. These entities can be defined as *biodiversity targets*, subjected to reduction, degradation or modification by human activities, defined as *direct threats* (Figure 1). A chain of social, economic, institutional or cultural factors usually drives the occurrence and/or persistence of direct threats, and these are identified as *contributing factors* (Figure 1). 2) **Plan, actions, and monitoring**. The project team develops desired *goals* and *strategies,* which comprise conservation actions to achieve goals. Goal setting is one of the most important, but perhaps overlooked, steps because it forces consensus on what the team is trying to accomplish. Strategies can be applied to any project component (i.e. conservation targets, direct threats, contributing factors; [14]). In this step, the team also designs a monitoring plan to evaluate effectiveness of strategies and progress towards goals. A critical step in this process is development of *results chains* [17]. A results chain lays out explicit causal linkages between a proposed strategy and desired outcomes through a series of intermediate results ([17]; Figure 2). 3) **Implement actions and monitoring**. Actions proposed in the previous step are implemented and monitored. 4) **Analyze, use, and adapt.** Here, the team analyzes monitoring data to assess effectiveness of proposed actions and adapts the conceptual model and conservation actions, if necessary. The team then uses this information for the last step, 5) **Learning and sharing**. After these steps, the cycle starts over again.

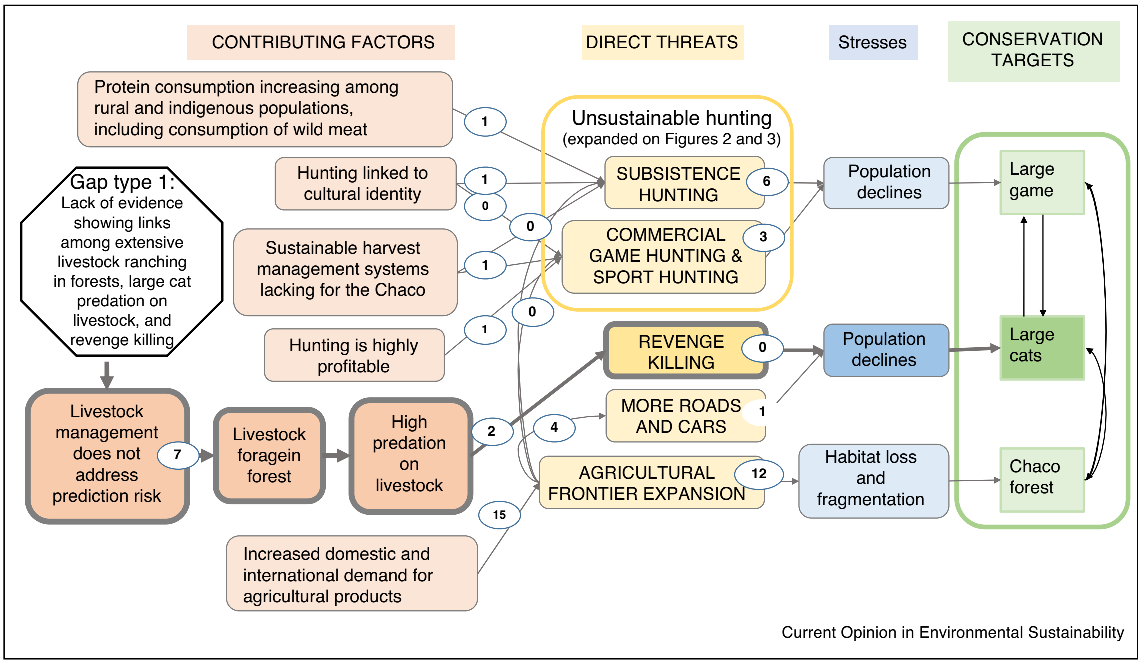
Here, we demonstrate how the Open Standards framework can be used for linking scientific and management agendas in complex socio-environmental systems. We create a conceptual model for a system, identify causal knowledge gaps throughout the system with a literature review, and highlight key types of knowledge gaps. Also, we illustrate interdisciplinary linkages across the domains of social and natural sciences. As an example, we examine threats for large cats and game species in the Argentine Chaco forest.

The Open Standards for conservation as a tool for co-production of social and ecological knowledge for adaptive management

The Open Standards framework can help promote understanding and effective management of complex systems through explicit interventions. This approach has proven useful for projects that range in scope from recovery of target species to conservation of entire ecosystems. For example, Open Standards was used in development of a conservation plan for golden lion tamarins in Atlantic forest of Brazil [18] and for development and evaluation of strategies implemented to conserve tigers and their prey in Lao PDR [19,20]. In the US, this approach supports management of grasslands, woodlands, and freshwater estuaries [21,22], and in Australia, almost 160 million ha of arid shrublands are managed under the adaptive cycle of Open Standards [23•]. Projects based on Open Standards focus on abatement of threats and design and implementation of mitigation strategies (e.g. restoration of indigenous protected areas in Australia [24]). This framework is an effective tool for integrating stakeholders that traditionally are not well represented in planning processes and management. For example, in Australia indigenous knowledge and governance processes are leveraged to manage ancestral lands [25] and restore indigenous protected areas [24]. Although the Open Standards often is applied to projects with a specific geographic scope (e.g. a protected area), this framework also can help address problems that transcend geographic boundaries. For example, Open Standards was key in developing a theory of change for engaging communities in combating illegal wildlife trade [19,26] and for examining political and economic complexities of private sector participation in rhino conservation [27]. Publication of applications of the Open Standards is limited, and we still have much to learn. However, an assessment of the Open Standards after a decade of use shows that, although project teams rarely have completed the full project cycle, users highly value this framework for its ability to integrate components of complex systems and improve conservation practice [16•].

We contend that the Open Standards could be used more broadly in modelling of complex systems to better link design of applied research agendas with conservation practice. In particular, the Open Standards provides a framework for systematically identifying research gaps that hinder design, implementation, and evaluation of conservation strategies. Further, this framework bridges the domains of social and natural science to address problems for biodiversity conservation. As an example, we apply the Open Standards framework to conservation of two biodiversity targets in the Argentine Chaco: top predators (two species of large cats) and large game species. The Gran Chaco ecoregion is the second largest Neotropical forest after the Amazon, spanning roughly 1 200 000 km^2 across Argentina, Paraguay, Bolivia and

Figure 1



Conceptual model and causal knowledge gaps (Gap type 1). We show how conservation targets (far right) are affected by direct threats (middle), which in turn are driven by contributing factors (far left). For this example, we focus on large mammal conservation in the Chaco forest. Our system includes two large cats (jaguars, *Panthera onca*; pumas, *Puma concolor*) and numerous game species that comprise prey for humans as well as these cats (e.g. three species of peccaries, *Pecari tajacu*, *Tayassu pecari*, *Catagonus wagneri*; tapirs, *Tapirus terrestris*; giant armadillos, *Priodontes maximus*, five other species of armadillos, etc.). We illustrate a knowledge gap (octagon) for a causal chain linking livestock ranching to revenge killing of cats and ultimately the population status of cats. Numbers in circles show the number of peered-reviewed articles found that study the causal link between two factors. In this figure, we aim to show an example of how the Open Standards can be used to address complex socio-ecological systems and identify critical knowledge gaps rather than presenting an exhaustive analysis of large cat conservation in the Chaco forest. However, we suggest that similar efforts involving a wider set of stakeholders would be valuable for modelling pressing threats in the Chaco and other endangered ecosystems.

Brazil [28,29,30•,31,32]. As a result of expansion of agriculture and pasture, this region suffers one of the highest deforestation rates worldwide and is among the most threatened regions in the world [33–36]. In northwest Argentina [37,38], the landscape is dominated by soybeans and pastures with remnant forest patches between large agricultural fields [37–39]. Only a few large tracts of old-growth forest persist, separated by broad expanses of agriculture [40]. The Chaco fauna is diverse and high in endemics, particularly for large mammals [41,42]. In addition to rapid landscape change, these large mammals face a multitude of other threats common to tropical forests, such as hunting (Figure 1; [43–45]).

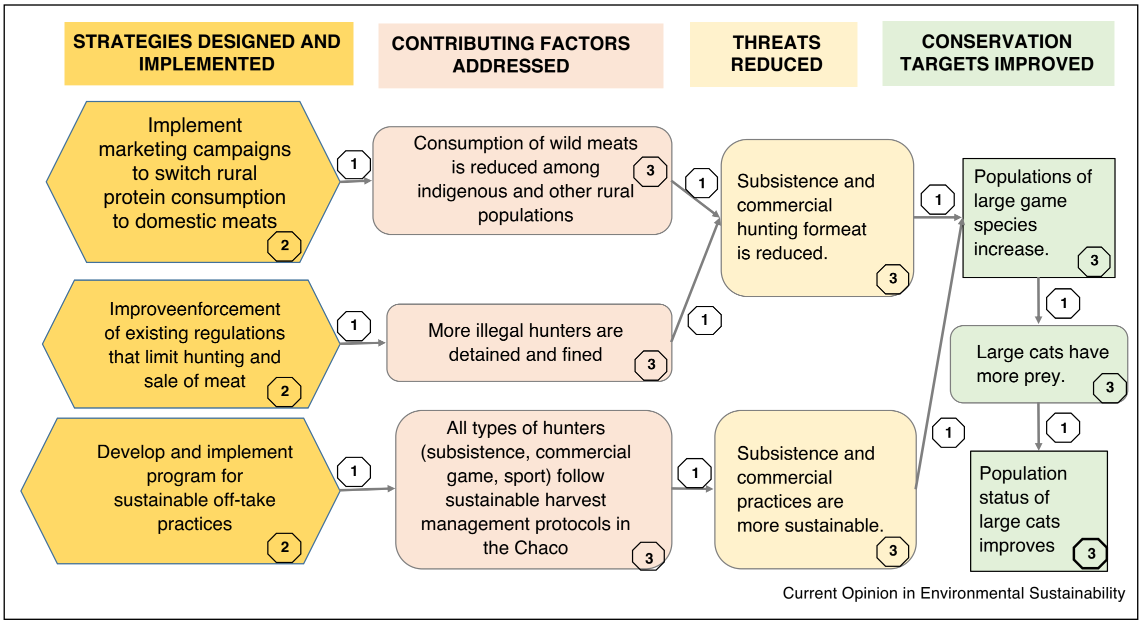
Example model: large cats and large game conservation in the chaco forest

A subset of the co-authors engaged in a workshop to examine conservation problems for large cats and large game species in the Argentine Chaco forest using the Open Standards framework. Our group comprised former government officials from natural resource agencies, foresters, geographers, ecologists, and socio-environmental scientists. Based on participant knowledge, we built a conceptual model and results chains (steps 1 and 2 of the Open Standards, outlined in Box 1). Models within the Open Standards framework generally are not intended to show a complete view of how a system works, but instead are built upon available information and expert knowledge under the premise that models will evolve as new information emerges (i.e. serve as an initial step in adaptive management). The conceptual model comprises causal chains represented by a series of factors linked to a specific threat for biodiversity targets. To identify knowledge gaps, we conducted a systematic search of peer-reviewed literature published since 1990 on Web of Science to identify papers for Chaco that contained key words from results chains. We then reviewed these papers to assess the number that addressed each segment in the causal chains (e.g. 'high cat predation on livestock' leads to 'revenge killing of cats', Figure 1). We also identified potential strategies to address threats, built results chains, and illustrate how information gaps differ among strategies (Figures 1 and 2).

Conceptual model

We began our modelling exercise focusing on the targets of large cats and large game species (Figure 1). Our model shows the targets linked through predator-prey dynamics

Figure 2



Examples of three results chains, or theories of change, with explicit causal links between proposed strategies (orange boxes) and desired outcomes through a series of intermediate results. These causal links are working hypotheses and represent knowledge gaps (Gap type 1, Causal knowledge gaps, see octagon 1). For a single direct threat (i.e. unsustainable subsistence and commercial hunting combined here), we show multiple strategies that could reduce this threat. Knowledge gaps are different for design and implementation of each strategy (Gap type 2, strategy design/implementation gaps). For example, application of a social marketing campaign in the Chaco forest requires understanding of consumption patterns and taste preferences [46]. Effective law enforcement may require knowledge of the routes illegal hunters use for killing game. Development of sustainable harvest programs requires information on reproductive potential of harvested species. Evaluation of the theory of change and final outcomes is a key part of the adaptive management cycle that requires defining indicators. Knowledge gaps regarding appropriate indicators (Gap type 3, indicator gaps) often arise at this stage (e.g. What indicators are sufficiently sensitive, but also feasible, for measuring the amount of hunting or population status of large cats?).

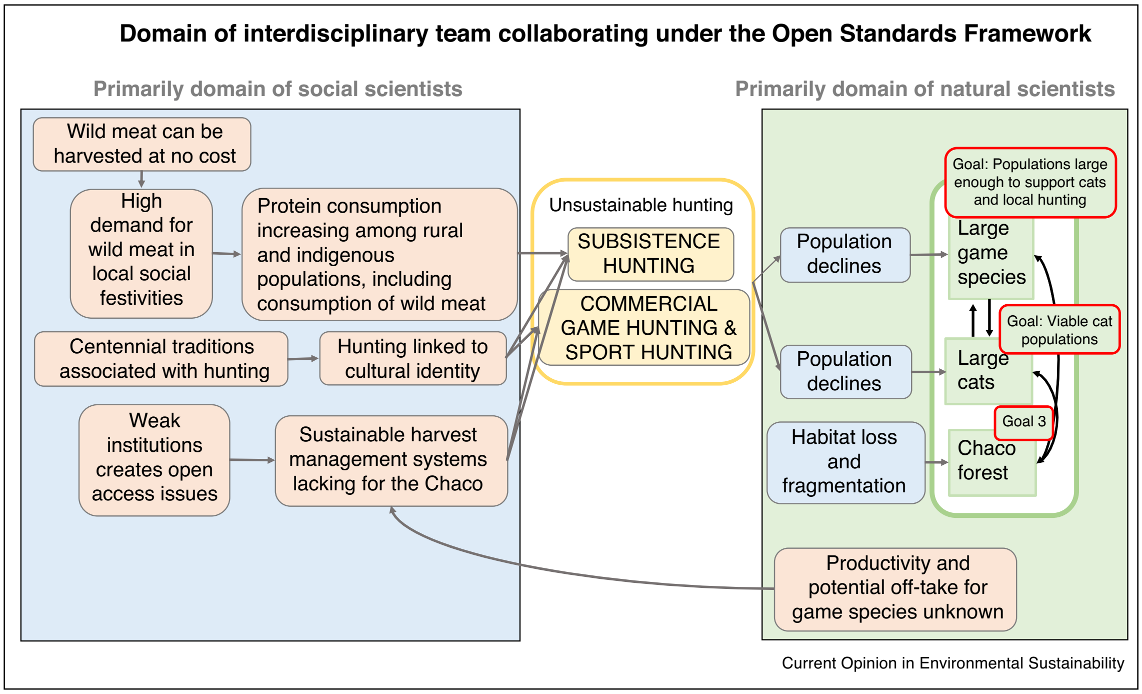
and linkages between targets and Chaco forest resulting from habitat requirements of targets and mammal-mediated processes in Chaco forest such seed dispersal [43]. We identified five direct threats for populations of the large cats and game species: subsistence hunting by rural people, commercial hunting for meat and sport, revenge killing by ranchers, increased roads that lead to mortality from vehicle collisions, and agricultural expansion, which destroys habitat and exacerbates other threats ([46,47]; Figure 1). We then added examples of contributing factors that can influence direct threats to large cats and game species (Figure 1).

Protein consumption by rural and indigenous populations that rely on wild meat [47,48], as well as their strong cultural identity with hunting, promote subsistence and game hunting (Figure 1). Commercial hunting for meat and sport hunting also likely is increasing because of high profitability and lack of sustainable harvest management systems that limit hunting. Expansion of the agricultural frontier reduces habitat for wildlife and probably increases their exposure to hunters [43]. Our model also includes revenge killing as a direct threat to large cats linked to livestock management through a series of intermediate factors [40,49–51] (Figure 1). Most of these linkages represent hypotheses about how the system works, which need to be tested and revised through targeted research projects and monitoring in the adaptive management cycle [18,19,20,25,27]. The structure of the modeled system likely will change through this iterative process. Also, a complete model would show more complex chains of contributing factors. None-the-less, the diversity of factors in this initial conceptual model illustrates the complex socio-ecological context of biodiversity conservation in the Chaco and the need to engage an interdisciplinary team to understand this context, identify threats and contributing factors, and define potential causal relationships among system components that can be evaluated in the process of adaptive management.

Results chains

We illustrate creation of results chains with three strategies that address subsistence and commercial hunting as direct threats to large cats and game species in the Argentine Chaco (Figures 2 and 3). Results chains show a series of explicit causal links between a strategy,

Figure 3



Traditional disciplinary split of scientists addressing complex conservation problems. Here, we expanded the conceptual model for unsustainable hunting shown in Figure 2 to illustrate this disciplinary split. Natural scientists (green domain) most often conduct research on conservation targets and stresses associated with these targets diagramed on the right side of the model (e.g. ecological roles of species, population declines, impacts of forest fragmentation, etc.). Social scientists (blue domain) focus on social, political, and economic factors that contribute to direct threats on the left side of the model (e.g. how subsistence hunting is shaped by the cultural identity of a rural population, social and economic consequences of open access natural resource management, etc.). The horizontal, linked structure of conceptual models developed within the Open Standards framework bridges these domains and illustrates why solving conservation problems and attaining conservation goals (e.g. viable populations of large game species and large cats) requires a transversal approach where scientists address entire causal chains. This framework facilitates working teams that cross disciplinary boundaries and span the divide between science and conservation practice.

intermediate steps, and conservation targets [17] that can be expanded to show mechanisms of change and underlying model assumptions. Results chains represent a theory of change for the system following implementation of a strategy. In the Open Standards, results chains, like conceptual models, are dynamic models that change as complex interactions within the system are understood. For example, because the primary prey for large cats in the Chaco forest are wildlife species that humans hunt, reduction in hunting should increase food availability for cats and improve their population status (right side of results chain, [47] Figure 2). One potential strategy to address hunting is a social marketing intervention with an information campaign and community engagement to switch rural protein consumption to domestic meats (Figure 2; [52•]). This strategy is based on the conjecture that educating local people about negative impacts of hunting or advantages of domestic meat will reduce their consumption of wild game, increase their willingness to consume domestic meat, and ultimately result in a reduction in hunting. Other critical assumptions underlying this strategy are that rural populations have access to domestic meat and that environmental impacts of production of domestic meat do not reduce large mammal populations more than hunting. As with conceptual models, these causal linkages and assumptions represent hypotheses that need to be tested with research and monitoring as part of the adaptive management process. Multiple strategies often are needed to solve conservation problems and each of these requires different types of information (Figure 2). Furthermore, engagement of social and natural scientists is required to address the entire series of critical linkages between strategies, which often are based on changing human behavior, and ultimate impacts on conservation targets that are based on positive changes in biological parameters. The Open Standards provides a framework for creating and integrating teams of social and natural scientists, a universal challenge in addressing, complex socio-ecological systems [16•,17,21,23•,27].

Identification of critical knowledge gaps

Three broad types of knowledge gaps emerged as we applied the Open Standards to the Chaco (Figures 1 and 2). These types of gaps likely are common for many systems, particularly in regions where conservation has not been supported by extensive research. We label the first type of knowledge gap as *causal knowledge gaps*. These gaps occur when relationships between components of a complex socio-ecological system are unknown and, consequently, outcomes from implementation of strategies are uncertain. Our literature review showed that most relationships in the conceptual model for Chaco are either unstudied or supported by very few studies (circled numbers in Figure 1). Knowledge gaps regarding factors that contribute to unsustainable hunting are particularly evident (e.g. multiple linkages with no supporting studies). Within the Open Standards, these causal knowledge gaps would be addressed with monitoring focused on basic questions such as: Does the system change as expected following implementation of a strategy? Were goals reached? If not, where did system behavior depart from the model? For example, based on our conceptual model, if we implement a livestock management strategy to reduce foraging of livestock within forests, we would expect livestock predation to decrease. As a result, ranchers would then kill fewer cats, and populations of cats would increase (Figure 1). This strategy could fail for several reasons. First, reducing foraging of livestock in forests may not reduce predation. Second, ranchers may continue killing cats even though predation is lower. Finally, cat populations may not increase because ranchers convert forest to pasture to reduce livestock predation and consequently reduce habitat for cats and their prey. Filling causal knowledge gaps through research and monitoring is critical for evaluating conservation success and detecting unintended consequences of conservation actions [16•,17]. Importantly, research and monitoring provide a basis for identifying missing and incorrect assumptions, determining where complex interactions have been omitted, and adapting results chains and conceptual models so that they remain living documents within an adaptive management process.

The second type of gap relates to *design and implementation* of strategies. Conservation actions to reduce threats to biodiversity or ecosystem services often are limited by knowledge gaps that emerge in the design of strategies as well as the implementation phase (Figure 2). These gaps highlight the need to collect information for defining and ranking potential strategies, such as feasibility under social, political, economic, and ecological constraints, and for on-the-ground implementation. For example, what factors might facilitate or jeopardize successful implementation of a social marketing campaign strategy to decrease consumption of wild game in the Chaco? What are the critical partnerships and human resources needed for implementation? The participatory nature of the Open Standards can integrate information from socio-ecological research with local knowledge regarding world views, value systems, and other drivers of human behavior to help fill gaps for strategy design and implementation. These gap types often are viewed as most urgent for decision makers.

The third gap type, *indicator gaps*, are methodological gaps that arise when assessing effectiveness of strategies. Specifically, these gaps refer to uncertainties associated with defining monitoring questions (what are the key questions for measuring success?), identification of indicator variables (what do we measure to answer these questions?), data collection (how do we measure indicators?), and interpretation (what should we use as a baseline?, Figure 2). A critical step in the monitoring process, and one often given insufficient attention, is clarification of the questions that indicators are meant to answer. In addition, for monitoring to be useful, mechanisms must be in place for monitoring results to feed back into adaptive management and influence decision-making [20]. Although ecological processes may be relatively well understood, the best way to evaluate management success may not be clear. For example, what is the best way to measure sustainability of hunting in Chaco forests? Also, sometimes identifying an appropriate indicator is easy (e.g. density of harvested game species), but measuring or monitoring this indicator is unfeasible. In that case, how do we establish measures that are rigorous but feasible? Defining questions for monitoring and indicators that provide clear, practical measures of conservation success are key challenges faced by most conservation teams [14].

One important type of knowledge gap that our team did not address relates to goal setting. Team members and other important stakeholders often differ widely in their visions and goals. For example, conserving large stands of forests or healthy populations of large cats may not be a conservation outcome that all stakeholders want to achieve. Impoverished communities or local politicians may see forest conservation as an impediment to increased economic development, and livestock ranchers could view large cats as a threat to their profitability from ranching. A clear understanding of these perspectives is key for developing a shared vision, common goals, and consensus on what constitutes conservation success. Better knowledge about a socio-ecological system does not always lead to consensus on conservation actions because many other factors influence human behavior. However, understanding motivations of key stakeholders is fundamental for building consensus. The Open Standards process of working as a team through the adaptive management cycle can help build understanding and trust among stakeholders, identify and support tradeoffs, and ultimately lead to greater agreement on desired outcomes.

Conclusions and wider implications

The disparity between the knowledge produced and knowledge required to tackle complex environmental issues continues to grow [3]. Here, we show how the Open Standards can help bridge this knowledge disparity by fostering interactions among scientists and decision makers to gain knowledge and develop solutions to environmental challenges in complex systems. One of the most important advantages of the Open Standards framework is its simplicity. Conceptual models within this framework typically do not incorporate complex quantitative links (e.g. for non-linear and multi-directional processes) and other frameworks might be better suited to that end (e.g. quantitative causal diagrams and structured decision making; [16•,50,53,54]). Also, the strong focus on threats sometimes can limit integration of economic and governance factors and worldviews that influence the system. Ignoring these factors can hamper design of effective strategies and ultimately lead to project failure. This problem may occur most commonly when project participants represent a narrow set of disciplines or stakeholders. However, the simplicity of the Open Standards framework makes it accessible to teams comprised of diverse perspectives and expertise, which can help incorporate transdisciplinary drivers, worldviews, and other important perspectives that are not knowledge-based. Also, this approach is particularly valuable for poorly studied systems with few quantitative data, a problem common to regions of the world where environmental problems are most urgent [41,55].

When decision makers, scientists, and other stakeholders jointly identify knowledge needs for solving environmental problems, then consensus on research priorities and application of research findings is more likely to occur [12•]. Also, this collaborative approach serves as a forum for identifying and addressing competing objectives of stakeholders. A primary strength of the Open Standards is that it facilitates conversations among stakeholders on how a system works, what the threats to the system are, and what actions could be implemented to achieve a defined set of conservation goals. This process can help identify research priorities informally (e.g. through discovery of knowledge gaps in conceptual models) or more rigorously by linking research priorities to outcomes of formal assessments within the Open Standards (e.g. threat rating and target viability assessment [15]). For example, under the Open Standards, the three threats in Chaco that directly impact large cats and game (i.e. unsustainable subsistence hunting, unsustainable commercial hunting, and revenge killing) would be ranked by criteria such as severity and geographic extent of their impact. Research on the highest ranked threat, as well as strategies to mitigate this threat might be prioritized. Alternatively, if threat ratings were deemed weak because basic information on all threats is lacking, research on severity and extent of the three threats might be an initial priority. Once a conservation strategy is designed and implemented, priorities for research and monitoring focus on key components of the results chain that indicate whether the strategy is successful (e.g. consumption of wild meat is reduced with a marketing campaign in the Chaco, Figure 2). Evaluation of important assumptions related to unintended consequences of the strategy (e.g. ecological, social or economic consequences) also are priority. For example, if rural people switch to raising more domestic animals, this could result in greater conflicts with large cats and more revenge killing. Other problems arise when stakeholders have competing objectives. For example, interests of local people may be at odds with conservation because conservation strategies negatively impact their livelihood (e.g. in this case, lost income from commercial sale of wildlife meat). The Open Standards can help teams design, implement, and monitor multiple strategies that work together to address competing goals (e.g. development of law enforcement strategies to reduce illegal hunting and ecotourism opportunities to offset lost income of hunters [20]).

The diversity of knowledge gaps that we identified illustrates that, for most cases, these gaps are unlikely to be filled by any single scientific discipline. In the absence of a framework to build collaboration, natural scientists often focus on immediate causes of biodiversity decline, while social scientists study factors contributing to drivers of such declines. This compartmentalization can lead to a disconnect and lack of understanding of linkages across the system (Figure 3). Importantly, the Open Standards framework highlights knowledge gaps that underpin all parts of an adaptive management process. Anchored by construction of well-defined goals, conceptual models, and results chains, the Open Standards process inherently requires collaboration from a broad set of social and natural scientists, policy makers, other conservation practitioners, and communities affected by the conservation action. Tools such as scenario building with diverse stakeholders also can link effectively with the Open Standards framework to help define opportunities and barriers for conservation success [49–51]. We suggest that an integrated approach under the Open Standards framework, through which decision-makers and scientists from diverse disciplines address entire segments of socio-ecological systems (Figure 3), can speed up production of knowledge and generate better understanding of the system. Furthermore, by bringing together scientists and diverse stakeholders to develop plans for conservation actions, the Open Standards process increases the likelihood that this knowledge will be applied to solve pressing environmental challenges.

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Conflict of interest statement

Nothing declared.

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