Conservation Biology

Contributed Paper

Quantifying species recovery and conservation success to develop an IUCN Green List of Species

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Abstract: *Stopping declines in biodiversity is critically important, but it is only a first step toward achieving more ambitious conservation goals. The absence of an objective and practical definition of species recovery that is applicable across taxonomic groups leads to inconsistent targets in recovery plans and frustrates reporting and maximization of conservation impact. We devised a framework for comprehensively assessing species recovery and conservation success. We propose a definition of a fully recovered species that emphasizes viability, ecological functionality, and representation; and use counterfactual approaches to quantify degree of recovery. This allowed us to calculate a set of 4 conservation metrics that demonstrate impacts of conservation*

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Article impact statement*: An objective and ambitious definition of species recovery and a system for recognizing conservation impact inform an IUCN Green List of Species.*
Paper submitted September 1, 2017; revised manuscript accepted March 8, 2018.

Conservation Biology, Volume 0, No. 0, 1–11

DOI: 10.1111/cobi.13112

efforts to date (conservation legacy); identify dependence of a species on conservation actions (conservation dependence); quantify expected gains resulting from conservation action in the medium term (conservation gain); and specify requirements to achieve maximum plausible recovery over the long term (recovery potential). These metrics can incentivize the establishment and achievement of ambitious conservation targets. We illustrate their use by applying the framework to a vertebrate, an invertebrate, and a woody and an herbaceous plant. Our approach is a preliminary framework for an International Union for Conservation of Nature (IUCN) Green List of Species, which was mandated by a resolution of IUCN members in 2012. Although there are several challenges in applying our proposed framework to a wide range of species, we believe its further development, implementation, and integration with the IUCN Red List of Threatened Species will help catalyze a positive and ambitious vision for conservation that will drive sustained conservation action.

Keywords: conservation impact, conservation optimism, recovered species, red lists, *Saiga tatarica*, threatened species

Cuantificación de la Recuperación de Especies y el Éxito de Conservación para Desarrollar una Lista Verde de Especies de la UICN

Resumen: *Detener la disminución de la biodiversidad es fundamental, pero es tan solo un primer paso para alcanzar metas de conservación más ambiciosas. La falta de un objetivo y una definición práctica de* recuperación de las especies *que sea aplicable en grupos taxonómicos causa que los objetivos de los planes de recuperación sean inconsistentes y frustra la posibilidad de informar y maximizar su impacto en la conservación. Hemos ideado un marco para evaluar exhaustivamente la recuperación de las especies y el éxito de conservación. Proponemos una definición de especies* completamente recuperadas*, el cual enfatiza la viabilidad, la funcionalidad ecológica y la representación y utiliza enfoques contrafactuales para calcular el grado de recuperación. Esto nos permite calcular un conjunto de 4 medidas de conservación que demuestran los impactos de los esfuerzos de conservaci ón hasta la fecha (legado de conservación); identifica la dependencia de una especie a las acciones de conservación (dependencia de conservación); calcula las ganancias esperadas a mediano plazo de una acción de conservación (ganancia de conservación) y los requisitos específicos para alcanzar la máxima recuperación posible a largo plazo (potencial de recuperación). Estas medidas pueden incentivar el establecimiento y logro de objetivos ambiciosos de conservación. Ilustramos el uso del marco aplicándolo en un vertebrado, un invertebrado, una planta leñosa y una planta herbácea. Nuestro enfoque representa un marco preliminar para la creación de una Lista Verde Especies de la Unión Internacional para la Conservación de la Naturaleza (UICN), la cual fue ordenada por una resolución de los miembros de la mencionada institución en el 2012. A pesar de que existen varias dificultades para aplicar el marco propuesto en un grupo amplio de especies, creemos que continuar su desarrollo, implementación e integración con la Lista Roja de Especies Amenazadas de la UICN contribuirá a catalizar una visión positiva y ambiciosa de conservación que conducirá a una acción de conservación sostenida.*

Palabras Clave: especies amenazadas, especies recuperadas, impacto de la conservación, listas rojas, optimismo de conservación, *Saiga tatarica*

摘要: *阻止生物多样性的减少十分重要, 但这仅仅是实现更远大保护目标的第一步。由于对 "物种恢复" 的概念缺少一个客观实际、适用于各种类群生物的定义, 致使恢复计划目标不一致, 并且也阻碍了对保护影响力的报告和最大化。因此, 我们设计了一个综合评估物种恢复和保护成功的框架。我们提出了 "完全恢复" 物种的定义, 这个定义强调物种的生存能力、生态功能和代表性, 我们还运用反事实分析法来量化物种恢复的程度。我们可以计算这样四个保护指标, 包括分析至今为止保护行动的影响力 (保护遗产) 、确定物种对保护行动的依赖性 (保护依赖性) 、量化保护行动在中期的预期目标 (保护成效), 以及指明远期要实现最大可能恢复所需条件 (恢复潜力) 。这些指标可以刺激宏远保护目标的建立和实现。我们将此框架分别用于一种脊椎动物、无脊椎动物、木本植物和草本植物, 以说明这些指标的用法。我们提出的方法是《世界自然保护联盟物种绿色名录》的一个初步框架, 这是由 IUCN 成员在 2012 年的一项决议授权下进行的。虽然这个框架在不同物种中大范围的应用还面临一些挑战, 但我们相信它在未来的发展、实施并与《 IUCN 受威胁物种红色名录》的整合, 可以帮助催生出一个积极远大的保护蓝图, 以驱动持续的保护行动。* **【翻译: 胡怡思; 审校: 魏辅文】**

关 键 词: 红色名录, 保护影响力, 恢复物种, 受威胁物种, 保护乐观主义, 赛加羚羊 (*Saiga tatarica*)

Introduction

The goal of conservation is to maintain the diversity of life on Earth. At the species level, this means preventing extinctions, maintaining viable populations, and enabling the recovery of declining and depleted populations. Much conservation has therefore, appropriately, focused on avoiding extinctions and reducing rates of declines. Correspondingly, conservation-relevant metrics, such as the International Union for Conservation of

Nature (IUCN) Red List of Threatened Species (hereafter IUCN Red List), focus on assessing extinction risk. Although efforts that reduce or prevent increases in extinction risk should be celebrated as a conservation success (e.g., Hoffmann et al. 2010), in many cases this is only a first step toward achieving more ambitious conservation goals (e.g., Soulé et al. 2003; Sanderson 2006; Redford et al. 2011).

Although extinct is a well-defined state, the recovered state is often poorly or vaguely defined; no common agreement exists on how to recognize a successful recovery. The default criterion is often an increase in population size or geographical distribution (e.g., Crees et al. 2016). Although some national legislation defines recovery, the absence of an objective, practical, and ambitious definition of recovery that is applicable across taxonomic groups has contributed to inconsistent and inadequate population targets in recovery plans (Tear et al. 2005; Westwood et al. 2014). Some targets are set at or below the current population size or range of threatened species (Neel et al. 2012), making it challenging to document conservation impact, let alone maximize it.

In response, conservationists have tried to define *recovery* and refine methods for setting targets (e.g., Sanderson 2006; Redford et al. 2011; Westwood et al. 2014). These efforts sometimes conflate conservation and recovery goals (e.g., species with long-term viability across their historical range) with the means of achieving those goals (e.g., promoting redundant and connected populations). However, 3 common dimensions of recovery have emerged (e.g., Sanderson 2006; Redford et al. 2011). One is viability as the minimal requirement for recognizing a species as recovered. A fully recovered species is viable. That is, it has the attributes necessary for long-term persistence (e.g., large, stable, healthy, genetically robust, replicated populations, which are demographically sustainable and resilient and have adaptive capacity) and therefore a very low risk of extinction. A second dimension of recovery is functionality. A fully recovered species exhibits the full range of its ecological interactions, functions, and other roles in the ecosystem. A third dimension is representation. A fully recovered species occurs in a representative set of ecosystems and communities throughout its range.

Another body of literature focuses on what conservation success is and how it can be measured in the context of a dynamic social, political, and ecological environment. Butchart et al. (2006), Hoffmann et al. (2010, 2015), and Young et al. (2014) used counterfactual approaches to quantify the difference conservation had made to species status. They considered what the IUCN Red List category of species would have been in the absence of conservation, based on expert judgment. These kinds of post hoc scenarios are difficult to undertake due to the hypothetical nature of the counterfactual and the paucity of information on a suite of species and hence can yield substantial uncertainty around the counterfactual (e.g., Hoffmann et al. 2015). In assessing progress toward achieving species conservation targets, forward projections based on alternative future scenarios are also needed. These are even more challenging because both the with- and without-conservation scenarios are hypothetical; hence, few such analyses have been conducted (Visconti et al. 2016).

We sought to present a framework for quantifying measures of species recovery and conservation success. We started by defining a fully recovered species with respect to the dimensions of viability, functionality, and representation. We then devised a practical approach for quantifying the degree of recovery based on counterfactual and future scenarios. We defined a set of 4 conservation metrics that aim to demonstrate impacts of conservation to date; identify dependence of species' survival on conservation actions; quantify expected gains from conservation action; and quantify species recovery potential to incentivize setting of ambitious conservation targets. These metrics provide a rational basis for focusing conservation actions, countering tendencies to downplay conservation successes that may result from exclusive reliance on threat status (Mallon & Jackson 2017). We applied the framework to 4 species.

Our work serves as a response to a resolution adopted by the IUCN in 2012: "development of objective criteria for a Green List of species, ecosystems, and protected areas" (https://portals.iucn.org/library/node/44008). Our framework will be tested on a variety of species before being finalized as a set of criteria for assessing the recovery status of the species and integrated into the IUCN Red List.

Defining and Quantifying Recovery

To quantify the progress of a species toward recovery, its fully recovered state must be defined, recognizing that for some species, full recovery may not be possible. We consider a species fully recovered if it is viable and ecologically functional in every part of its indigenous and projected range.

Range

To quantify recovery geographically, we considered the total area of the indigenous and projected range of the species. Following The IUCN Guidelines for Reintroductions and Other Conservation Translocations, indigenous range is defined as "the known or inferred distribution generated from historical (written or verbal) records, or physical evidence of the species' occurrence. Where direct evidence is inadequate to confirm previous occupancy, the existence of suitable habitat within ecologically appropriate proximity to observed range may be taken as adequate evidence of previous occupation" (IUCN 2013). For assessments to be comparable across taxonomic groups, estimating indigenous range at a specific past date is a necessity. For recovery objectives to be ambitious and aspirational and to avoid shifting baselines (Papworth et al. 2009), this date should be as early as feasible while still recognizing that going too far back would divorce the definition of a species' indigenous range from contemporary reality. One possible benchmark is 1500, the cut-off date for listing extinct species in the IUCN Red List and approximate start of European expansion. This year is before industrialization and massive human population growth, but historical data may be difficult to obtain. Later dates, such as 1750 (used by IPCC as the start of the industrial era), incur more anthropogenic disturbance, but more documentary evidence is available.

Ranges of many species are shifting or are expected to shift in response to global climate change (e.g., Perry et al. 2005; Chen et al. 2011). Recovery options for some of these species also need to consider areas that will become suitable as a result of these shifts. Projected range includes areas that are expected to become suitable in the next 100 years or so, taking into account range shifts resulting from climate change.

Parts of the Range

Many species occupy small fractions of their indigenous range but still have a low risk of extinction (e.g., saltwater crocodile [*Crocodylus porosus*]; Bobak marmot [*Marmota bobak*]; European oak [*Quercus robur*]). Although these species are not at risk of extinction, at a global level they do not have a favorable conservation status and are not fully recovered from past declines. A fully recovered species occurs in a representative set of ecosystems and communities across its range. A practical way of assessing this condition is to determine the state of the species in each of several spatial units that comprise its range. The spatial units need to be chosen carefully because their number determines how ambitious the fully recovered state is; more units mean more viable and functional populations are needed. Spatial subdivisions can be delineated by subpopulation, ecological and geographical features, and location.

Species-specific subdivisions based on species biology, such as subpopulations (defined in IUCN 2017), are the most relevant options to meet the goals of the framework. Subspecies, stocks, genetic units, flyways, evolutionarily significant units, and discrete population segments are all conceptually related to IUCN's definition of subpopulation. Although not species-specific, divisions based on ecoregions, habitat types, or ecosystem types can also be used to define spatial units because they are defined based on ecological criteria and thus capture the different ecological settings in which a species exists or existed. Geographical features (e.g., watersheds, islands, lakes, mountain ranges) can be proxies for subpopulations. Finally, areas with similar threatening processes ("locations" in IUCN [2017]) can be used to define spatial units.

Viable

Viability can be assessed by any method that estimates extirpation risk in a given spatial unit. One approach considers the population in the spatial unit viable if a regional IUCN Red List assessment (IUCN 2012*a*) of the species in the spatial unit would result in designation of least concern (LC) and the population in the spatial unit is not undergoing "continuing decline" (IUCN 2017). Regional IUCN Red List assessments use the same criteria as global assessments but make provisions for the possibility of recolonization and rescue effects as a result of immigration from other regions (here, other spatial units). They have been used successfully for a range of taxa to assess the category of species at national and regional levels (Miller et al. 2007). Our approach requires only a simplified assessment of whether the species meets criteria for the LC category, rather than considering all red-list categories.

Ecologically functional

Conserving the ecological role or function of species is an important conservation goal, beyond avoiding extinctions (e.g., Soulé et al. 2003; Sanderson 2006). We define functionality of a species as the degree to which it performs its role as an integral part of the ecosystem in which it is embedded. The different facets of this role—the species' ecological functions (Table 1)—include the species' influence on or contribution to ecosystem-level processes (e.g., primary production), interactions with other species (e.g., trophic relationships), structural effects (e.g., ecosystem engineering), and intraspecific processes (e.g., migration).

A species is considered functionally extinct if its abundance is too low, or its demographic structure is unsuitable, for it to fulfill its ecological role. A species may be at low risk of extinction yet functionally extinct, which may be the case for species whose current populations are extremely low relative to historical baselines (e.g., marine species [Jackson et al. 2001]; insects [Vogel 2017]).

Functionality, like viability, is assessed within each spatial unit (i.e., at the population level). This requires assessing each unit relative to functions that comprise the most important roles of the species. Although these functions may not be easy to determine, we believe incorporation of functionality whenever possible is a critical element of an aspirational conservation vision. When a function cannot be identified for a species, a number of proxies can be used to assess functionality, including population density in areas of low human impact or a historical baseline. In cases where these proxies are unavailable, the

Table 1. Types and examples of ecological functions of species.

Type of function of species	*Example*	*Reference*
Species interactions (including trophic functions)	pollination, seed dispersal, predation (including seed predation), host-parasite relationships, facilitation, providing resources (e.g., as prey)	McConkey & Drake 2006; Estes et al. 2010; Anderson et al. 2011; Ripple & Beschta 2012; Galetti et al. 2013; Gordon & Letnic 2016
Structural (landscape) functions	creation of habitat for other species, ecosystem engineering, substrate stabilization, peat formation, bushfire fuel accumulation, facilitation of landscape connectivity, maintenance of heterogeneity	Lips 1991; Casas-Criville & Valera 2005; Sanderson et al. 2008
Ecosystem-level functions	primary production, decomposition, nutrient cycling or redistribution, modification of fire and hydrological regimes	Gende et al. 2002; DeVault et al. 2003; Thrush et al. 2006
Within-species processes	migration, colony formation and other aggregations of individuals, adaptation (evolutionary potential)	Wilcove 2012

maximum category weight (see below) could be set to that of another category.

Quantifying Species Recovery with a Green-List Score

Our definitions allow quantification of degree of recovery based on the defined spatial units. The state in each spatial unit is assessed as 1 of 4 ordinal categories: absent (species does not exist in the wild in the spatial unit), present (species occurs but is not viable), viable, and functional (as defined above). These categories are assigned weights. For demonstration purposes, we used weights of 0 for absent to 3 for functional, although other weighing scales will be tested, including an exponential scale, to determine which best reflects the relative values conservationists attach to presence, viability, and functionality. A green-list score is obtained with

$$G = \frac{\sum_{s} W_{S}}{W_{F} \times N} \times 100, \qquad (1)$$

where s is each spatial unit, W_S the weight of the state in the spatial unit (0 to 3), W_F is the weight of the functional category, and N is the number of spatial units. The denominator is the maximum possible score attained when all spatial units are assessed as functional. The states (e.g., current state) are based on this formula and thus are calculated as a percentage of the fully recovered state. The conservation metrics (e.g., conservation legacy) are calculated as differences between 2 states.

Quantifying Conservation Metrics

We use 4 metrics of recovery progress (Fig. 1): conservation legacy, effect of conservation actions conducted to date; conservation dependence, importance of ongoing and future conservation, with a focus on expected deterioration in the state of the species if all ongoing conservation actions were to cease; conservation gain, expected improvement in state of the species as a result of current and planned conservation actions; and recovery potential, conservation aspiration or ambition (i.e., maximum plausible recovery improvement in the future with sustained conservation efforts and conservation innovation over the long term).

Each metric is calculated as a difference between 2 states (e.g., current and counterfactual). The states, in turn, are calculated in terms of recovery, as a green-list score with Eq. (1). The states can also be calculated in terms of extinction risk, as determined by the IUCN Red List category of the species, although that is not our focus here. Previous researchers calculated an equivalent of the conservation-legacy metric based on IUCN Red List categories (Butchart et al. 2006; Hoffmann et al. 2010, 2015; Young et al. 2014).

Conservation Legacy

To evaluate the difference past conservation has made, it is necessary to assess what would have happened without any conservation action (counterfactual current state) and compare this with the current state of the species. The difference between these two states is a measure of the impact of past conservation (Fig. 1).

Estimating this impact requires determination of the types of actions considered conservation actions. Hoffmann et al. (2015) considered actions that resulted in collateral benefits for species as conservation only if conservation was one of the primary rationales for the action. For example, military or civil conflict may empty an area of people and allow wildlife to persist or even recover (such as in the Korean demilitarized zone), but is not conservation. In contrast, conservation of a forest as an indigenous people's reserve that leads to habitat protection is conservation if the community in the area considered protection of their forest a key motivator.

For some species, the time frame over which conservation has acted is centuries (e.g., in Indian sacred

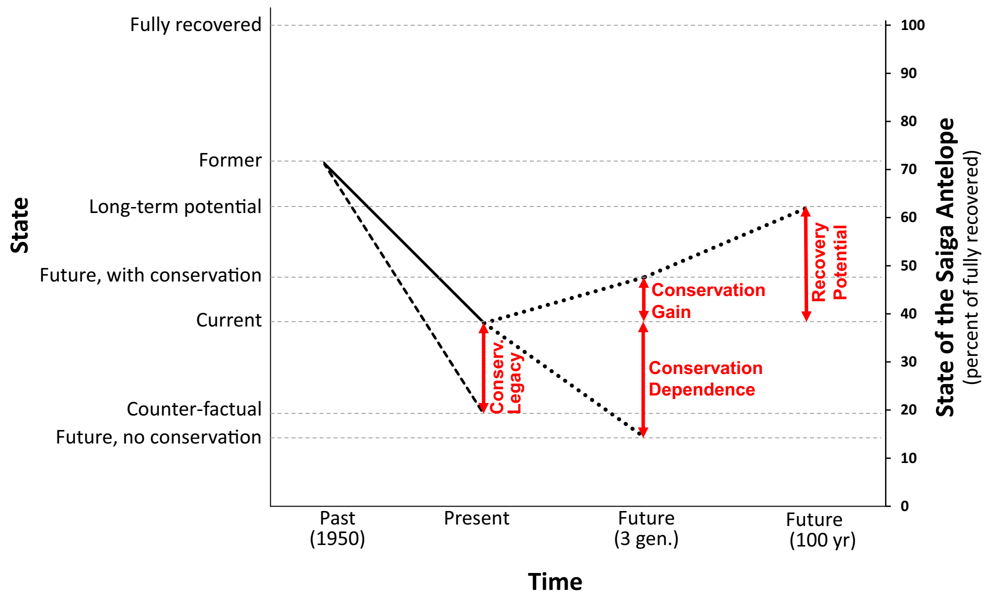

Figure 1. Conservation metrics (vertical arrows) expressed as differences in the species' recovery states (left axis) (solid line, observed change in state of the species; dashed line, past change expected in the absence of past conservation efforts [counterfactual]; dotted lines, future scenarios of change expected with and without current and future conservation efforts). The states are calculated for the case-study species Saiga antelope (right axis) as a percentage of fully recovered state. Similar graphs that incorporate uncertainties (given as intervals in Table 3) are in Supporting Information.

groves), whereas for others conservation action is recent. However, a variable date reduces comparability across species and presents difficulties for species that are poorly known. Therefore, a fixed date of 1950 for all species may be a good compromise. This date captures most of the conservation history for most species and is a relatively good proxy for the birth of modern species conservation (e.g., IUCN was founded in 1948). For application of the framework, it is not necessary to determine the past state of the species (former in Fig. 1), only what the current state probably would have been if no conservation actions had been taken.

Conservation dependence and gain

These 2 metrics indicate the importance of continuing conservation action for the taxon by quantifying a species' conservation dependence or reliance (Scott et al. 2010; IUCN 2017). Conservation dependence is based on what would happen to the state of the taxon in the near future if ongoing conservation actions ceased, and conservation gain is based on how much the state of a taxon would improve with ongoing and planned conservation action.

These metrics indicate the importance of sustaining ongoing conservation. Their use should reduce the perverse incentive to ignore conservation success, represented by reductions in the extinction-risk category of a species, to avoid a perceived risk of losing funding or recognition for the species. Their wide adoption and use would provide a justification for continued conservation action and a quantifiable, realistic, short-term target in the context of current and predicted threatening processes. A suitable time frame for assessing conservation dependence and gain is 3 generations or 10 years, whichever is longer, consistent with the current Red Listing process and providing a realistic time scale for incentivizing conservation action.

These metrics require the development of scenarios for the future state of species with removal of current conservation actions. The uncertainty surrounding future plans for conservation also needs to be considered. Planned actions could be based on recognized species action plans (https://www.iucn.org/theme/species/publications/species-action-plans) and on a nation's Convention on Biological Diversity Biodiversity Strategy and Action Plan for incidental actions (e.g., protected-area establishment that benefits the species). Other sources of information include declarations made by a country (e.g., ban on domestic trade in a species) or expert assessments of the activities of local conservation groups. Assessments need to be based on realistic assumptions about the probability that a given planned action will be implemented and that current or planned conservation actions will result in changed state for the species. In both cases, these assessments need to be done for each spatial unit to calculate the green-list score. The likely benefits expected from these conservation measures are then discounted by these probabilities.

Recovery potential

This metric is about setting an aspirational yet achievable vision for the recovery of a species, estimating the maximum plausible improvement that could be achieved in occupancy, viability and functionality across the (indigenous and projected) range of the species, given its life history and habitat characteristics, and the likely land and resource use and recovery technology over the next 100 years. For many species, the fully recovered state is not achievable because, for instance, parts of the range have been converted to cities and other intensive human uses. Despite such constraints, this metric is used to quantify an ambitious, long-term recovery target such that recovery progress is tracked objectively and realistically. Thus, recovery potential indicates how much the state of the species could potentially be improved with sustained conservation efforts and conservation innovation, taking into account range shifts as a result of climate change, over about 100 years (Fig. 1).

Recovery potential is similar to, and could be based on, the long-term vision of many species recovery plans. It is not meant to replace shorter-term recovery objectives, targets, and goals that are part of the conservation planning process. That process remains the ideal and appropriate venue for setting conservation targets (including the long-term vision) because it brings together all stakeholders.

The main challenge in determining recovery potential is to decide the plausible conservation effort and innovation, considering actions to eliminate threats and opportunities for habitat restoration and increased connectivity. Recovery potential is primarily based on species biology and needs to be realistic, considering the biological limitations of the species (e.g., generation time and maximum rate of population increase) and its habitat (e.g., rates of regeneration). It also needs to be realistic in terms of social and economic factors (e.g., in light of projected trends in urbanization), but the long-term potential should not be limited by current political or budgetary constraints.

Incorporating Uncertainties

As with all data-based biodiversity assessments, availability and uncertainty of information is the largest challenge for the proposed framework. All aspects of the assessment framework involve uncertainties. The IUCN Guidelines for Using the IUCN Red List Categories and Criteria contain detailed advice on handling uncertainty when determining the current category and criteria for a species (Akçakaya et al. 2000; IUCN 2017). The level of uncertainty is higher when setting counterfactual or future states because what would have happened without past conservation or what will happen in the future is unobservable. A 4-step procedure that is particularly effective in eliciting expectations in the presence of uncertainty specifies a lower (minimum) and an upper bound (maximum); a best estimate; and a level of confidence (percentage) that the true estimate lies within the lower and upper bounds (Speirs-Bridge et al. 2010; Burgman et al. 2011). With 2 or more assessors, a structured elicitation procedure is followed in which iterative rounds of expert judgment and inter-rater comparison are used to determine the category a species should be placed in within each spatial unit and the associated uncertainty (McBride et al. 2012). The uncertainties are used to set bounds on the proposed metrics (Supporting Information).

Saiga Antelope Case Study

We applied the framework to the Saiga Antelope (*Saiga tatarica*) (details in Supporting Information). The species was listed as vulnerable when first assessed in 1996, lower risk (conservation dependent) in 2000, and critically endangered in 2002 (Mallon 2008). Its past history, diverse trajectories of its populations in different regions, and the potential it has for further recovery make this species particularly suitable for illustrating the nuances of the 4 conservation metrics. We also estimated the species' past and future IUCN Red List categories under the same scenarios (Supporting Information).

Range and Spatial Units

In 1500 the species ranged over the entire Eurasian steppe from Ukraine to China (Bekenov et al. 1998). The range is divided into 7 spatial units, corresponding to subpopulations: 5 where the species currently occurs (including a subspecies in Mongolia) and 2 (in Ukraine and China) from which it has been extirpated (Table 2). Climate change may cause range shifts within spatial units but is not likely to affect the underlying spatial subdivision.

Functionality

One key ecological function of Saiga populations is long-distance migration, which currently occurs in 2 of its subpopulations (Betpak-dala, Ustiurt). Loss of migration in other subpopulations is due to anthropogenic habitat modification, although the Mongolian subspecies may have always been nomadic rather than migratory. The species naturally occurs in high numbers and at high density in breeding aggregations, which are required for

Table 2. Recovery states of Saiga antelope based on the proposed green-list framework, which proposes metrics to quantify conservation impact based on the differences between recovery states.[a]

Spatial unit	*Note on spatial unit*	*Former*	*Current*	*Counterfactual current*	*Future with conservation*	*Future without conservation*	*Long-term potential*
		(minimum, medium, maximum recovery score)					
Ukraine	extirpated	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 1
Russia	northwest of the Caspian sea	2, 3, 3	1, 1, 1	0, 0, 1	0, 1, 2	0, 0, 1	2, 2, 3
Ural	in western Kazakhstan, with some movement into Russia	2, 3, 3	2, 2, 2	0, 1, 1	2, 2, 3	0, 1, 1	2, 2, 3
Ustiurt	in Kazakhstan and Uzbekistan	2, 3, 3	1, 1, 1	0, 1, 1	1, 1, 2	0, 0, 1	2, 2, 3
Betpak-dala	large area contained within Kazakhstan	3, 3, 3	2, 2, 2	0, 1, 1	2, 3, 3	0, 1, 1	2, 3, 3
Mongolia	separate subspecies	1, 2, 3	1, 2, 2	1, 1, 1	2, 2, 2	0, 1, 1	2, 3, 3
China	extirpated	1, 1, 2	0, 0, 0	0, 0, 0	0, 1, 1	0, 0, 0	1, 1, 2
Total score		11, 15, 17	7, 8, 8	1, 4, 5	7, 10, 13	0, 3, 5	11, 13, 18
Total[b] (% of fully recovered)		52, 71, 81	33, 38, 38	5, 19, 24	33, 48, 62	0, 14, 24	52, 62, 86
		Extinction risk (IUCN Red List) category –(minimum, best estimate, maximum)[c]					
Global			CR	CR, CR, CR	LC, LC, LC	EX, CR, CR	LC, LC, LC

[a] *Recovery states (former through long-term potential, as in the vertical axis of Fig. 1) assessed based on the score in each spatial subunit from 0 (for absent) to 3 (for functional). Uncertainty in score expressed as minimum, medium, and maximum estimates.*
[b] *Total score expressed as a percentage of the maximum score (21, with all 7 units functional).*
[c] *Categories: EX, extinct; CR, critically endangered; LC, least concern.*

functionality. The species was presumably once the dominant grazing ungulate and a major influence as a biomass consumer on the steppe ecosystem.

Conservation Metrics

By 1950 the species had declined throughout its indigenous range; was recovering from severe overhunting in the 19th century in 5 spatial units it currently inhabits; was extirpated in 1 spatial unit (Ukraine); and was rapidly declining in another (China). In 1950 it was 71% recovered (uncertainty interval, 52–81%) (Table 2).

The current state of the species in the 7 spatial units ranges from absent in 2 units to between present and viable in 5 units; the current state is thus 33–38% of its fully recovered state (Table 2). See Supporting Information for the state in each spatial unit and Fig. 1 for a graphical representation of the 4 metrics.

It seems unlikely the species would have gone extinct in the absence of conservation, given its large range and high fecundity. Its counterfactual state is 5–24% of its fully recovered state (Table 2). Conservation legacy (i.e., the difference between this value and current state) is 19% (Fig. 1) and 10–33% with uncertainties (Table 3). Therefore, although the species is currently listed as critically endangered and its state has deteriorated since 1950, our framework shows that past conservation efforts for this species had a moderate positive effect on its state.

If conservation actions were to cease in the future, the species would either lose viability or become extinct in each of its currently inhabited spatial units. Given the high value of products derived from the species in traditional Chinese medicine markets, its very rapid population decline in the last 20 years due to poaching, and the continuing increase in threats from other sources (infrastructure, disease), there is risk of global extinction within a 3-generation time frame in the absence of conservation (Table 2). Even in spatial units where it may persist, it is not likely to be viable or functional. Thus, the future-without-conservation state is 0–24% of the fully recovered state (Table 2). Conservation dependence (i.e., the difference between this value and current state) is 24% (Fig. 1) and 10–38% with uncertainties (Table 3). Therefore, the Saiga antelope is moderately to largely dependent on future conservation actions, without which its state would deteriorate substantially.

The species is very resilient, and the rapid increase in one subpopulation under conservation programs over the last 10 years shows that it can increase rapidly once threats abate. In the near future, the species state could improve in response to conservation such that it could be listed as LC globally; could be viable or even functional in 5 of the 7 spatial units; could be present in 1 of the units where it is currently absent (China); and could remain absent in Ukraine (Table 2). Thus, the future-with-conservation state is 33–62% of its fully recovered state (Table 2). Conservation gain (i.e., the difference between this value and current state) is 10% (Fig. 1) and –5% to 29% with uncertainties (Table 3). Therefore, the Saiga antelope stands to gain from future conservation efforts

Table 3. Comparison of case studies of species to which the green-list framework was applied to calculate 4 proposed conservation metrics.[a]

	Saiga tatarica	*Dryococelus australis*	*Rutidosis leptorrhynchoides*	*Grevillea caleyi*
Species characteristic	widespread mammal	narrow-range insect	widespread annual herb	narrow-range shrub
spatial units	7 subpopulations	2 islands	7 units, based on ecoregions (and 3 disjunct occurrences in 1 ecoregion)	3 habitat patches
function	migration, biomass consumption, breeding aggregations	biomass consumption, nocturnal food source	primary production, insect food source during mass flowering	prolonged flowering in high densities provides early postfire food source
Conservation metric				
conservation legacy[b]	19% (10–33%); moderate	17% (0–17%); moderate	24% (0–29%); moderate to large	33% (11–33%); substantial
conservation dependence[c]	24% (10–38%); moderately to largely dependent	17% (0–17%); moderately dependent	24% (14–29%); moderately to largely dependent	33% (22–33%); highly dependent
conservation gain[d]	10% (–5–29%); modest improvement	50% (17–67%); likely to gain substantially	33% (–14–62%); likely to gain substantially	0% (–11–0%); not likely to gain
recovery potential[e]	24% (14–52%); potential to achieve substantial recovery	67% (50–83%); potential to recover to a large extent, perhaps even achieve full recovery	62% (43–76%); potential to recover to a large extent, perhaps even achieve full recovery	11% (11–33%); potential to achieve partial recovery

[a] *Conservation metrics are calculated as percentage of fully recovered state. Uncertainty ranges are in parentheses. For details, see calculations in Supporting Information.*
[b] *Effect of conservation actions conducted to date: current state – counterfactual current state.*
[c] *Expected future change in the state of the taxon if ongoing conservation actions ceased: current state – future-without-conservation state.*
[d] *Expected improvement in the state of the taxon with current and future conservation actions: current state – future-with-conservation state.*
[e] *Maximum plausible long-term improvement in the state of the taxon: current state – long-term-potential state.*

and should improve modestly in state in the next 3 generations (9–12 years).

With sustained long-term conservation, it would be possible to have functional populations in 5 of the 7 spatial units and a viable population in 1 other. Thus, the long-term potential state is 52–86% of its fully recovered state (Table 2). Recovery potential (i.e., the difference between this value and current state) is 24% (Fig. 1) and 14–52% with uncertainties (Table 3). Therefore, even though the species currently has a very high risk of extinction, with sustained conservation efforts it could undergo substantial recovery.

Three additional examples of the application of our framework (Button wrinklewort [*Rutidosis leptorrhynchoides*], Caley's grevillea [*Grevillea caleyi*], Lord Howe Island Phasmid [*Dryococelus australis*]) are presented in Supporting Information. Across the 4 case studies (Table 3), spatial units were interpreted as islands, habitat patches, and subpopulations, and species functions ranged from migration, to critical food sources, to biomass consumption. *Grevillea caleyi* has the highest conservation legacy and dependence but the lowest (short-term) conservation gain, whereas *Dryococelus australis* has the highest conservation gain and recovery potential (Table 3 & Supporting Information).

Discussion

Our green-list framework is a practical approach to achieving several goals, including defining and quantifying species recovery, quantifying the benefits of conservation investment, recognizing conservation success, and incentivizing conservation ambitions to go beyond extinction avoidance. This is an important development in light of the increasing recognition of the importance of aspirational goals and reporting of success in engaging society in conservation (Young et al. 2014; Balmford 2017).

Our definition of a recovered species incorporates viable and ecologically functional densities across the species' indigenous and projected range in a representative set of its ecosystems and communities. To our knowledge, this is the first attempt at a general, ambitious, and practical definition of a recovered species. Further testing is underway. If the approach proves applicable to a wide range of taxa, it will open up many opportunities for quantifying different aspects of the recovery process. As demonstrated with the Saiga antelope, it will allow quantification of the conservation dependence of a species, the legacy of past conservation efforts (even when the state of the species may be deteriorating), and expected gains from current and future conservation actions.

Our definition of species recovery and the metrics we propose are applicable to taxa recovering as a result of conservation, to taxa that have not declined, and to taxa that are not the focus of conservation so far. Some of these taxa may have high conservation dependence, for example, because of expected future impacts or byproduct benefits from conservation of other species; these taxa could be identified through our framework, which is designed to recognize both prevented and reversed declines.

Our case study is instructive because it demonstrates that even though Saiga antelope is critically endangered and is facing ongoing challenges, conservation actions have kept the species viable in several spatial units where it might otherwise have been extirpated or present in much lower numbers. It also demonstrates that without ongoing conservation interventions, it is likely that no subpopulations would remain viable and that 2 be extirpated. The conservation dependence of this species is clearly articulated by the proposed framework, providing a strong incentive for ongoing conservation. That there is potential to improve the species' state toward broad functionality provides an aspiration.

Exclusive reliance on the current IUCN Red List category of a species in funding decisions risks creating a perverse incentive for conservationists to downplay their successes and focus on the dire state of their species in order to continue to qualify for funding and garner political and practical support for future conservation actions (Mallon & Jackson 2017). In contrast, our green-list framework provides incentives for funders and decision makers to promote high conservation impact by focusing on species with high conservation dependence and high potential for conservation gain, providing a more effective means of valuing their investments. Likewise, evaluating future scenarios of conservation interventions supports actions to prevent population declines, which are likely to be more cost-effective than recovery from low numbers and a severely contracted range. However, the proposed metrics are informative, not prescriptive. Just as the IUCN Red List "is not the sole means of setting priorities for conservation measures" (IUCN 2012*b*), the metrics we propose are designed for objective assessment of the recovery state of species; prioritization is left to those responsible for the conservation of species.

We believe development and implementation of this system will lend to The IUCN Red List of Threatened Species a positive vision for conservation, encouraging optimism (Balmford 2017). Our proposed green-list approach is not intended as an alternative to the IUCN Red List. Rather, the metrics discussed here will be fully integrated into IUCN's metrics of extinction risk and thus allow a more complete assessment of a species' conservation state, prospects, and impact. After the new metrics have been tested, they will appear on the IUCN Red List webpage of each assessed species alongside its extinction risk category. To effectively communicate these metrics, they may need to be converted into categories, similar to how the IUCN Red List system divides the continuum of extinction risk into broad categories of threat (Collen et al. 2016; IUCN 2017). For example, a species may be assessed as endangered and conservation dependent with low conservation legacy and high conservation gain. Thus, both extinction and recovery aspects of the species status (i.e., the red-list category and the proposed metrics) will be presented together as a unified and comprehensive assessment of its conservation status.

We suggest future work on this system include testing the proposed system by applying it to a set of species with varying characteristics, such as life history, threats, range size, levels of knowledge and uncertainty, and biogeographic realm; further development of robust and replicable methods and standards for counterfactual and scenario analysis under different conditions of data availability, type, and quality; integrating assessments with species conservation planning and monitoring to harmonize approaches to setting conservation targets; determining general methods to identify the ecological functions of a species and population attributes that allow these functions to occur; developing guidance for choosing ecologically meaningful spatial subunits; improving understanding of when fully functional species become invasive or problematic native species; developing effective ways of communicating and graphically representing the results of the assessments to diverse audiences; and establishing strong policy linkages (e.g., linking future with- and without-conservation scenarios with those used by IPBES and IPCC). Parallel efforts are underway to develop and apply a similar framework to ecosystems and to protected areas. We invite contributions to this effort and feedback on this framework.

Acknowledgments

We thank the participants of the workshops and meetings of the Task Force on Assessing Conservation Success convened under the auspices of the IUCN SSC Red List Committee; WWF-US and Environmental Agency Abu Dhabi for funding several of the meetings; and P. Cardoso and 3 anonymous reviewers for helpful comments. National Science Foundation DEB-1146198 supported H.R.A. NERC Knowledge Exchange Fellowship supported M.K.G.

Supporting Information

How the system incorporates and presents uncertainties (Appendix S1), additional case studies (Appendix S2), application of the proposed framework to *Saiga tatarica* (Appendix S3), *Rutidosis leptorhynchoides* (Appendix S4), *Grevillea caleyi* (Appendix S5), and *Dryococelus* *australis* (Appendix S6), and the translation of the paper to Spanish (Appendix S7) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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