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A comparative approach to assess drivers of success in mammalian conservation recovery programs

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Abstract: *The outcomes of species recovery programs have been mixed; high-profile population recoveries contrast with species-level extinctions. Each conservation intervention has its own challenges, but to inform more effective management it is imperative to assess whether correlates of wider recovery program success or failure can be identified. To contribute to evidence-based improvement of future conservation strategies, we conducted a global quantitative analysis of 48 mammalian recovery programs. We reviewed available scientific literature and conducted semistructured interviews with conservation professionals involved in different recovery programs to investigate ecological, management, and political factors associated with population recoveries or declines. Identifying and removing threats was significantly associated with increasing population trend and decreasing conservation dependence, emphasizing that populations are likely to continue to be compromised in the absence of effective threat mitigation and supporting the need for threat monitoring and adaptive management in response to new and potential threats. Lack of habitat and small population size were cited as limiting factors in 56% and 42% of recovery programs, respectively, and both were statistically associated with increased longer term dependence on conservation intervention, demonstrating the importance of increasing population numbers quickly and restoring and protecting habitat. Poor stakeholder coordination and management were also regularly cited by respondents as key weaknesses in recovery programs, indicating the importance of effective leadership and shared goals and management plans. Project outcomes were not influenced by biological or ecological variables such as body mass or habitat, which suggests that these insights into correlates of conservation success and failure are likely to be generalizable across mammals.*

Keywords: conservation evidence base, evaluation, extinction, intervention, recovery program

Una Estrategia Comparativa para Evaluar a los Conductores del Éxito en los Programas de Recuperación y Conservación de Mamíferos

Resumen: *Los resultados de los programas de recuperación de especies han sido mixtos; la recuperación de poblaciones de alto perfil contrasta con las extinciones a nivel de especie. Cada intervención de conservación tiene sus propios retos, pero para informar de manera más efectiva al manejo es imperativo evaluar si se pueden identificar los correlativos del éxito o el fracaso de programas de recuperación más amplios. Para contribuir al mejoramiento basado en evidencias, realizamos un análisis cuantitativo a nivel mundial de 48 programas de recuperación de mamíferos. Revisamos la literatura científica disponible y llevamos a cabo*

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entrevistas semi-estructuradas con profesionales de la conservación involucrados en diferentes programas de recuperación para investigar los factores ecológicos, administrativos y políticos asociados con la recuperación o declinación de las poblaciones. Identificar y remover las amenazas estuvo asociado significativamente con la tendencia poblacional creciente y la disminución de la dependencia a la conservación, lo que enfatiza que las poblaciones probablemente sigan en peligro en la ausencia de una mitigación efectiva de amenazas y en necesidad del monitoreo de amenazas y del manejo adaptativo en respuesta a amenazas nuevas y potenciales. Se citaron, respectivamente, a la falta de hábitat y al tamaño pequeño de las poblaciones como factores limitantes en 56 % y 42 % de los programas de recuperación, y ambos estuvieron asociados estadísticamente con la creciente dependencia a largo plazo a las intervenciones de conservación, lo que demuestra la importancia de aumentar rápidamente los números poblacionales y de restaurar y proteger el hábitat. El pobre manejo y la poca coordinación entre los accionistas también fueron citados regularmente por los entrevistados como debilidades clave en los programas de recuperación, lo que indica la importancia de un liderazgo efectivo y de planes y objetivos de manejo compartidos. Los resultados de los proyectos no fueron influenciados por las variables biológicas o ecológicas, como la masa corporal o el hábitat, lo que sugiere que este conocimiento sobre los correlativos del éxito y el fracaso de la conservación es probablemente generalizado entre los mamíferos.

Palabras Clave: base de evidencias de la conservación, evaluación, extinción, intervención, programa de recuperación

Introduction

Vertebrate populations for which long-term data are available have on average declined globally by 52% since 1970 (WWF 2014), and at least 25% of mammal species are threatened with extinction (Schipper et al. 2008). Wide-scale and long-term attempts to mitigate anthropogenic impacts have not halted or reversed global biodiversity loss (Butchart et al. 2010). Threatened species recovery is considered an important example of microscale conservation (Sodhi et al. 2011), but the outcomes of such interventions remain mixed. In one recent analysis, the conservation status of only 24 species improved from 1996 to 2008, whereas the status of 171 species deteriorated (Hoffmann et al. 2011).

High-profile recent mammalian conservation successes include population recovery of southern white rhinoceros (*Ceratotherium simum simum*) (Amin et al. 2006) and black-footed ferret (*Mustela nigripes*) (Miller et al. 1996), whereas well-publicized losses include extinction of the Yangtze River dolphin (*Lipotes vexillifer*) (Turvey 2008) and the Vietnamese subspecies of Javan rhinoceros (*Rhinoceros sondaicus annamiticus*) (Brook et al. 2014). These mammals were all the focus of recovery programs, and it is not immediately clear why certain conservation strategies succeeded and others failed. A species' biology, its ecological, political, and social environment (i.e., operating environment), and threat type all interact to create unique conservation challenges requiring diverse, often bespoke approaches and responses. However, some of these factors may transcend context and predispose a project to certain outcomes. It is therefore imperative to learn lessons from past successes and failures in species' recovery to maximize effectiveness of future interventions and minimize ongoing biodiversity loss (Ferraro 2009).

Evaluation of conservation effectiveness is a small but growing area of conservation science, and there have been recent industry-wide efforts to establish guidelines for project evaluation (Kapos et al. 2008; CMP 2013; Hopkins et al. 2015). Previous qualitative evaluations of single or contrasting case studies have highlighted specific factors driving past conservation successes and failures (Miller et al. 1996; Martin et al. 2012). Although these are useful on a case-by-case basis, it is unclear whether such factors are context specific or have wider applicability (Hutchings et al. 2012). Conversely, several reviews of multiple conservation projects have largely focused on integrated conservation and development programs and paid limited attention to correlates of successful species recovery (Waylen et al. 2010; Brooks et al. 2013). Few studies have included a large enough sample size to conduct quantitative analyses that could reveal the effect of different operating environments on species recovery outcomes, but this approach would contribute greatly to the current scientific evidence base for informing conservation planning.

As species recovery programs have now been underway for several decades, ample data are potentially available for long-term analyses of their efficacy. Statistical analyses of a wide range of projects can permit identification of common factors associated with varying degrees of project success or failure (e.g., Abbitt & Scott 2001). These factors may be intrinsic (e.g., species biology) or extrinsic (e.g., project management). Such analyses could constitute a powerful tool for determining likely success of future conservation programs operating under different scenarios. This in turn could help managers and policy makers choose appropriate strategies to maximize likely effectiveness of potential recovery activities.

We aimed to provide a new baseline of conservation evidence by conducting a global-scale quantitative analysis of a large set of mammalian recovery programs, representing a wide range of species, life histories, and conservation challenges. We sought to determine whether it was possible to identify common factors associated with population recovery or decline, and thus improve future conservation strategies under different operating environments.

Methods

To understand the relationships between causal factors and conservation outcomes and identify potential determinants of conservation success, we generated a list of possible interventions and variables through focus-group discussion with conservation scientists and practitioners. This list was subsequently refined by J.J.C., H.M.R.M., and S.T.T.

Project Selection

Conservation interventions vary enormously in scope. To avoid comparing projects with substantially different aims, we chose recovery programs that aimed to increase population size of the focal species. We defined a recovery program as a coordinated initiative of linked conservation actions that seek to directly mitigate threats to a species and increase its population (or the populations of interest). To minimize taxonomic variation within our sample, we investigated only conservation activities for mammals, a well-studied group that has been the focus of numerous recovery programs.

We selected projects by contacting International Union for Conservation of Nature (IUCN) Specialist Group coordinators and chairs of the IUCN Species Survival Commission and requesting information on species within their group that were subject to recovery programs as defined above, and by using the IUCN Species Information Service database. We included only species with sufficient information in the literature to complete a case study or for which we were able to interview a relevant conservation professional. Our final data set comprised 48 recovery programs focused on an entire threatened species, subspecies, or specific population, and included a wide range of species and locations (Table 1).

Response Variables

Numerous methods have been proposed for evaluating conservation success (Kapos et al. 2008; Howe & Milner-Gulland 2012). However, success is frequently determined through achievement of project goals (Saterson et al. 2004). We therefore assessed population trend (overall trajectory of population or species since the start of the recovery program) as a primary measure of success, defining it as a binary variable (1, extinct or in decline; 2, stable or increasing) (Table 1).

Most recovery programs also aim to ensure that target populations are self-sustaining (i.e., need for long-term direct management is minimal) (Redford et al. 2011). We therefore included the additional variable of conservation dependence, which quantified the degree to which a focal population required ongoing conservation intervention to maintain recovery. We considered this a secondary measure of success and described it on a scale from 1 to 5 (1, extinct; 2, intensively managed; 3, lightly managed; 4, conservation dependent; and 5, self-sustaining) (Table 1) based on definitions in Redford et al. (2011). A sixth category, captively managed, was excluded because our data set contained no species in this category.

Explanatory Variables

We organized our final set of explanatory variables into 6 categories (species biology or ecology; geopolitical environment; threats; baseline information; stakeholders and management; and funding) and developed a standardized questionnaire based on these categories. Each question represented a potential variable (Supporting Information). Life-history data were obtained from Jones et al. (2009), habitat types were from IUCN (2013), biogeographic realms were defined according to Olson et al. (2001), and Human Development Index data were from United Nations Development Programme (2013). We obtained information on recovery programs from the peer-reviewed conservation literature and from semistructured interviews conducted verbally or through correspondence with relevant contacts involved (currently or in the past) with specific recovery programs. Due to time constraints on data collection, a maximum of 2 people were interviewed per recovery program. To account for potential differences in informant perspectives on factors associated with project outcomes, we gathered information from both the literature and interviews where possible, or used multiple, independent literature sources when interviews were not possible. All statistical and descriptive analyses preserved respondent anonymity. We also gathered extensive qualitative data on examples of good and bad practice in species recovery during the interviews.

Data Analyses

We used initial exploratory tests (Pearson's correlation and chi-square) to eliminate variables that were correlated or lacked substantive explanatory power, resulting in a set of 20 explanatory variables (Table 2). To explore factors influencing recovery program outcomes, we modeled the response variables of population trend and conservation dependence against explanatory

Table 1. Species recovery programs examined to investigate correlates of species recovery or decline.

Scientific name	*Common name*	*Order*	*Location of assessed population*	*Population trend*	*Conservation dependence*	*Project length (years)*
Ailuropoda melanoleuca	Giant panda	Carnivora	China	→	LM	34
Arvicola terrestris	Water vole	Rodentia	United Kingdom	↑	LM	16
Beatragus hunteri	Hirola	Artiodactyla	Kenya	↓	IM	19
Bettongia penicillata	Woylie	Diprotodontia	Australia	↓	LM	18
Brachylagus idahoensis	Columbia Basin pygmy rabbit	Lagomorpha	United States	→	IM	13
Bubalus mindorensis	Tamaraw	Artiodactyla	Philippines	→	CD	35
Bunolagus monticularis	Riverine rabbit	Lagomorpha	South Africa	→	CD	16
Canis lupus baileyi	Mexican gray wolf	Carnivora	United States	↑	IM	32
Capra falconeri jerdoni	Sulaiman markhor	Artiodactyla	Pakistan	↑	CD	29
Ceratotherium simum simum	Southern white rhinoceros	Perissodactyla	South Africa	↑	CD	56
Coleura seychellensis	Seychelles sheath-tailed bat	Chiroptera	Seychelles	↑	LM	17
Cynomys ludovicianus	Black-tailed prairie dog	Rodentia	United States	→	IM	16
Dasyurus geoffroii	Chuditch, western quoll	Dasyuromorphia	Australia	→	LM	23
Dicerorhinus sumatrensis	Sumatran rhinoceros	Perissodactyla	Indonesia and Malaysia	↓	IM	30
Equus zebra zebra	Cape mountain zebra	Perissodactyla	South Africa	↑	IM	64
Gorilla beringei	Mountain gorilla	Primates	Uganda, Rwanda, and Democratic Republic of Congo	↑	CD	23
Hapalemur alaotrensis	Alaotran gentle lemur	Primates	Madagascar	↓	LM	24
Hypogeomys antimena	Malagasy giant rat	Rodentia	Madagascar	↑	CD	12
Lasiorhinus krefftii	Northern hairy-nosed wombat	Diprotodontia	Australia	↑	IM	22

Continued

Table 1. Continued.

Scientific name	*Common name*	*Order*	*Location of assessed population*	*Population trend*	*Conservation dependence*	*Project length (years)*
Leontopithecus chrysopygus	Black lion tamarin	Primates	Brazil	↑	IM	27
Leontopithecus rosalia	Golden lion tamarin	Primates	Brazil	↑	IM	31
Lipotes vexillifer	Baiji, Yangtze River dolphin	Cetacea	China	EX	EX	28
Lycaon pictus	African wild dog	Carnivora	South Africa	↑	IM	16
Lynx pardinus	Iberian lynx	Carnivora	Spain	↑	IM	12
Macrotis lagotis	Greater bilby	Peramelemorphia	Australia	↓	IM	23
Marmota vancouverensis	Vancouver Island marmot	Rodentia	Canada	↑	IM	26
Monachus schauinslandi	Hawaiian monk seal	Carnivora	Hawaii (United States)	↓	LM	34
Muscardinus avellanarius	Common dormouse, hazel dormouse	Rodentia	United Kingdom	↓	LM	20
Mustela nigripes	Black-footed ferret	Carnivora	United States	↑	IM	27
Myrmecobius fasciatus	Numbat	Dasyuromorphia	Australia	↑	LM	29
Neotoma floridana smalli	Key Largo wood rat	Rodentia	United States	→	IM	26
Nomascus hainanus	Hainan gibbon	Primates	China	→	IM	11
Onychogalea fraenata	Bridled nailtail wallaby	Diprotodontia	Australia	↓	IM	23
Orcaella brevirostris	Irrawaddy dolphin	Cetacea	Cambodia	↓	CD	13
Panthera pardus orientalis	Amur leopard	Carnivora	Russia	→	LM	18
Petrogale penicillata	Brush-tailed rock wallaby	Diprotodontia	Australia	→	IM	18
Phocarctos hookeri	New Zealand sea lion	Carnivora	New Zealand	↓	CD	19
Pipistrellus murrayi	Christmas Island pipistrelle	Chiroptera	Christmas Island (Australia)	EX	EX	10
Porcula salvania	Pygmy hog	Artiodactyla	India	↓	IM	19
Potorous gilbertii	Gilbert's potoroo	Diprotodontia	Australia	→	IM	20
Puma concolor coryi	Florida panther	Carnivora	United States	↑	IM	33

Continued

Table 1. Continued.

Scientific name	Common name	Order	Location of assessed population	Population trend	Conservation dependence	Project length (years)
Rhinoceros sondaicus annamiticus	Javan rhinoceros	Perissodactyla	Vietnam	EX	EX	16
Rhinoceros unicornis	One-horned rhinoceros, Indian rhinoceros	Perissodactyla	Nepal	↑	CD	55
Saguinus oedipus	Cotton-top tamarin	Primates	Brazil	→	LM	29
Sarcophilus harrisii	Tasmanian devil	Dasyuromorphia	Australia	↓	IM	10
Trichechus manatus latirostris	Florida manatee	Sirenia	United States	↑	LM	38
Urocyon littoralis	Island fox	Carnivora	Channel Islands (United States)	↑	LM	15
Vulpes velox	Swift fox	Carnivora	United States	↑	SS	20

EX, extinct; IM, intensively managed; LM, lightly managed; CD, conservation dependent; SS, self-sustaining (based on Redford et al. 2011).

variables under univariate analysis using, respectively, binomial logistic regression and ordinal logistic regression in the R package "ordinal." We included significant variables in full models and applied model simplification, deleting variables with the highest p values to produce a minimum adequate model (Crawley 2007). To assess significance of changes in deviance resulting from removal of terms, we compared models with F tests rather than chi-square tests due to overdispersion in our data (Crawley 2007). All analyses were undertaken in R version 2.15.2 (R Core Team 2013).

Results

Of the 48 mammalian populations in our study for which conservation action had been undertaken, 33 were stable or increasing and 15 were declining or extinct (Table 1). The commonest intensive conservation interventions (where individual animals were manipulated or managed to some degree) were ex situ conservation breeding and translocation, whereas the commonest nonintensive interventions (where only the environment was manipulated or managed) included community engagement and habitat protection or restoration. Although we treated intervention type as a single variable, we could not include it as a predictor variable because all projects had >1 intervention and our overall sample was too small to account for this. Average project length was 24.3 years (SD 11.4) and was not a significant predictor of improved conservation outcome. No explanatory variables related to species biology or ecology, geopolitical environment, baseline information, or funding were significantly related to either response variable. We did not encounter conflicting informant responses associated with specific project outcomes.

Threat reduction was significantly associated with both increasing population trend and decreasing conservation dependence under univariate analyses and was retained under both multivariate models (Table 3). The commonest threat was habitat loss (reduction, degradation, and fragmentation); human-induced mortality, primarily hunting and persecution, was also a major threat. Emergence of novel threats (e.g., dam development for Irrawaddy dolphins [*Orcaella brevirostris*]; increase in disease prevalence in mountain gorillas [*Gorilla beringei*] through tourism) was associated, although not significantly, with increased likelihood of population decrease or extinction (Table 3). Although 85% of focal populations were protected by national-level legislation, this did not predict recovery program outcomes. However, low levels of law enforcement were significantly associated with increased likelihood of population decrease or extinction (Table 3). Lack of habitat and small population size were cited as limiting factors for 56% and 42% of recovery programs, respectively, but were not statistically

Table 2. Independent variables investigated as possible predictors of mammalian recovery program outcome.

Variable	*Category*
Biology or ecology	
Order	Artiodactyla, Carnivora, Cetacea, Chiroptera, Dasyuromorphia, Diprotodontia, Lagomorpha, Peramelemorphia, Perissodactyla, Primates, Rodentia, and Sirenia
Body mass (g)	4–2,285,939
Habitat[a]	forest, savannah, shrubland, grassland, desert, wetland, rocky, marine, and mixed
Geopolitical environment	
Biogeographical realm[b]	Nearctic, Palearctic, Afrotropic, Indomalaya, Australasia, Neotropic, and Oceania
Human development index (HDI)[c]	0.463–0.938
Political support	conflict or no support; passive, partial, or intermittent support; active or continuous support
Threats	
Threat reduction	none, some, most, and all
Threat escalation	none, moderate, and substantial
Novel threat emergence	no or yes
Law enforcement	ineffective or weak across range, partial in protected areas (PAs) only, partial inside and outside PAs, effective in PAs only, and effective across range
Lack of habitat as limiter to recovery	no or yes
Small population as limiter to recovery	no or yes
Baseline information	
Length of time since project start	number of years
Data confidence	none or status unknown, low, reasonable, or high
Number of publications since start of the recovery program	1–259
Stakeholders and management	
Management structure	informal collaboration between stakeholders, formal collaborative recovery team or working group, formal recovery team led by government or other body
Stakeholder agreement	weak, partial, and general
Community support	persistent conflict, intermittent conflict or polarized support, none or neutral, general support, and strong support
Funding	
Continuity of funding	1 year or less, 1–3 years, over 3 years
Actions delayed due to funding	never or rarely, occasionally, regularly, and always

[a] *International Union for Conservation of Nature (IUCN 2013) habitat classification scheme.*
[b] *Olson et al. (2001).*
[c] *United Nations Development Programme (UNDP 2013).*

associated with population recovery or decline. However, both were associated with increased conservation dependence under univariate analysis; small population size remained a significant predictor of long-term conservation dependence in multivariate analysis (Table 3).

Neither response variable was statistically associated with predictor variables around stakeholders or management structure. However, >55% of all projects with stable or increasing populations were associated with general stakeholder agreement; 21% were associated with weak stakeholder agreement. By contrast, 33% of projects with extinct or declining populations were associated with general stakeholder agreement; 40% were associated with weak stakeholder agreement (Fig. 1).

Discussion

Our study constitutes a novel step toward developing a global quantitative comparative framework to identify mechanisms that improve likelihood of species recovery under different operating environments.

Identifying and Mitigating Threats

The importance of accurate identification and removal of threats to improve population trajectories in both the short and long term was demonstrated strongly in our analysis. Although seemingly intuitive, this result highlights that even if certain aspects of a recovery program (e.g., community engagement and captive breeding) are successful, wild populations will continue to be negatively affected by threats if they are not reduced or eliminated. Recent species or population extinctions in our data set (e.g., Yangtze River dolphin and Vietnam rhinoceros) were closely associated with a lack of effective mitigation of continuing external threats. Although threat abatement is insufficient to ensure recovery (Hutchings et al. 2012), it is clearly a necessity that must be acknowledged from the outset of conservation planning.

Table 3. Results of logistic regressions and ordinal logistic regressions used to investigate potential predictors of population trend and conservation dependence in mammalian recovery programs ($n = 48$).

	Estimate	*SE*	*z*	*p*
Univariate regressions				
Population trend				
(Intercept)	−0.981	0.677	−1.449	<0.10
Threat reduction (some)	2.280	0.819	2.785	<0.01
Threat reduction (most)	2.590	1.288	2.011	<0.05
Threat reduction (all)	18.547	2284.101	0.008	
(Intercept)	1.386	0.456	3.037	<0.05
Novel threats (yes)	−1.269	0.667	−1.903	
(Intercept)	−1.179	1.080	−1.659	
Level of enforcement (partial protected areas [PAs] only)	2.197	1.414	1.554	
Level of enforcement (partial across range)	19.358	2284.102	0.008	
Level of enforcement (effective PAs only)	3.045	1.345	2.263	<0.01
Level of enforcement (effective across range)	3.127	1.191	2.625	<0.05
Conservation dependence				
Threat reduction (some)	2.091	0.910	2.298	<0.05
Threat reduction (most)	2.368	1.283	2.516	<0.05
Threat reduction (all)	3.229	1.283	2.516	<0.05
Habitat limitation (yes)	−1.579	0.583	−2.708	<0.01
Small population (yes)	−1.386	0.595	−2.329	<0.05
Multivariate regressions				
Population trend				
Intercept	−0.981	0.677	−1.449	
Threat reduction (some)	2.280	0.819	2.785	<0.01
Threat reduction (most)	2.590	1.288	2.011	<0.05
Threat reduction (all)	18.547	2284.101	0.008	
Conservation dependence				
Threat reduction (some)	2.315	0.935	2.477	<0.05
Threat reduction (most)	2.062	1.143	1.803	<0.10
Threat reduction (all)	3.261	1.313	2.482	<0.05
Small population (yes)	−1.573	0.626	−2.511	<0.05

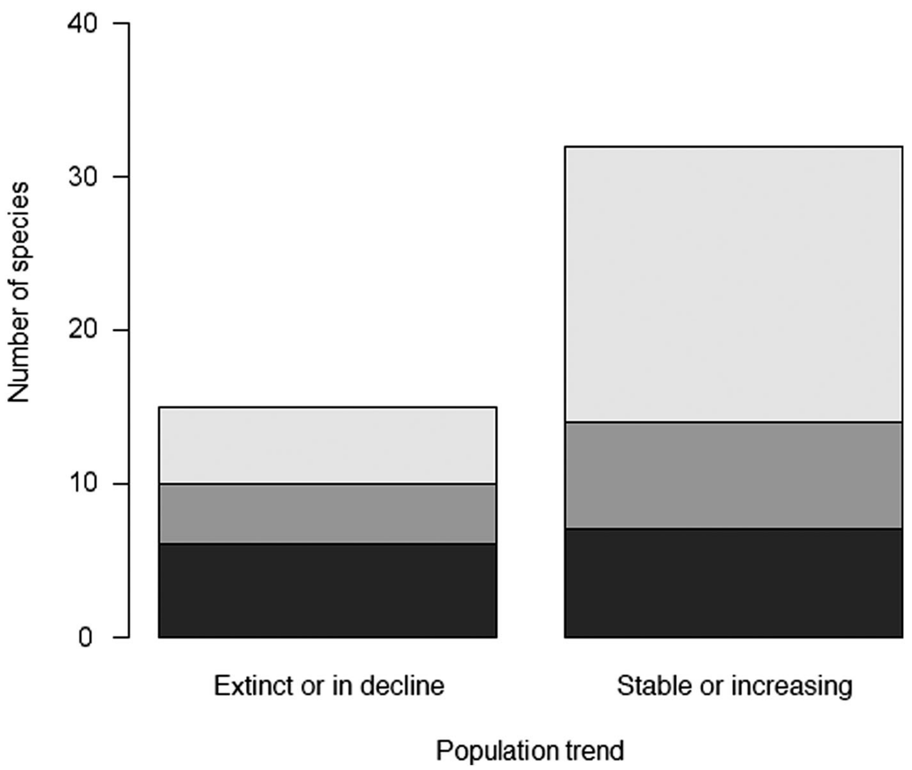

Figure 1. Level of stakeholder agreement and population trend relative to number of species recovery programs (dark gray, weak agreement; medium gray, partial agreement; pale gray, general agreement).

We argue that the association between emergence of a novel threat and population decline demonstrates the need to undertake thorough threat analysis during project planning, to continue monitoring threats, and to adapt strategies in response to new and potential threats. Monitoring (and acting on monitoring-derived data) is a key part of conservation evaluation (Stem et al. 2005), but its usefulness within conservation, and the resources it should be allocated, is debated (McDonald-Madden et al. 2010; Geupel et al. 2011). Many conservation programs have inadequate monitoring and evaluation systems (Stem et al. 2005), often due to the absence of measurable goals (Lindenmayer & Likens 2009; Stephenson & Ntiamoa-Baidu 2010), and some populations or species, such as the Christmas Island pipistrelle (*Pipistrellus murrayi*), have been "monitored to extinction" (Martin et al. 2012). Our results emphasize that threat identification and monitoring should be incorporated into project monitoring and evaluation plans and that these data should be used regularly in adaptive management (McCarthy et al. 2012).

Although most focal populations were protected by national-level legislation, our case studies included numerous examples of considerable weakness in practical law enforcement. For example, Brook et al. (2014) specifically attributed the extinction of Javan rhinoceros in Vietnam to "poaching, facilitated by weak enforcement of anti-poaching and anti-trafficking laws," and inadequate protection is linked to rhinoceros declines elsewhere in Asia and in Africa (Amin et al. 2006). Conversely, increased investment in antipoaching enforcement has successfully protected populations of rhinoceros and other species (Amin et al. 2006; Hilborn et al. 2006). As a further example, the Alaotran gentle lemur (*Hapalemur alaotrensis*) is threatened by illegal burning of marshland for rice cultivation and access by fishers around Madagascar's Lake Alaotra, a temporary protected area and Ramsar site, but despite closed fishing seasons there is little enforcement, partly due to lack of government funding (Copsey et al. 2009). As one informant noted, "the future is not that bright for this species unless there are radical changes in the way that environmental rules and laws, whether traditional local ones or national ones, are enforced." We therefore strongly recommend that resources for enforcement be fully integrated into recovery plans where illegal activity is a known primary limitation to population recovery.

Short-Term Versus Long-Term Recovery Goals

Young et al. (2014) found that a minimum of 11 years is needed for a species' conservation status to improve. In our study, project length was not associated with population trend or conservation dependence, and our data set included young projects showing population recovery and well-established projects struggling to increase populations and vice versa. Although recovery time is likely linked to focal species life history, our results suggest that other factors may be more important than project length.

Small population size and habitat limitation were not associated with population recovery but were associated with long-term conservation dependence, which suggests that it may be helpful to distinguish and apply different phases in recovery programs (Linklater 2003). The first phase is removal of a species or population from immediate danger of extinction by increasing numbers as quickly as possible; this tends to be the primary goal of most recovery programs and is a fundamental principle of conservation theory (Frankham & Ralls 1998; Courchamp et al. 2008). The second phase is a longer-term process of recovery to achieve multiple robust, healthy, and self-sustaining populations that require minimal conservation input. This distinction may be beneficial in conservation recovery planning because different phases may require distinct goals and timelines to be anticipated and managed proactively rather than reactively.

Where habitat limitation is a barrier to recovery, restoring, protecting, and increasing habitat should be a key conservation action; otherwise, species may recover from near extinction only to exist in captivity or in wild populations that are not viable or that lack ecological function. Several of our case studies showed that long-term management may also require reevaluation of species' habitat requirements and recognition that areas where surviving individuals occur may constitute suboptimal habitat. For example, remnant populations of Cape mountain zebra persisted in montane fynbos-dominated areas assumed to constitute appropriate habitat. However, subsequent research has shown that zebras would naturally have migrated up and down mountains to find suitable grazing and only recently became restricted to isolated fynbos patches (Faith 2012). Even where metapopulation management is the explicitly stated recovery strategy, expanding habitat or creating habitat corridors should still constitute a key conservation action in such situations if species are not to remain heavily conservation dependent.

Stakeholders and Management

Informants commonly cited stakeholder conflict as a major reason for project failure, from obstructive individuals, to recovery teams unable to agree on common management approaches, to conflicts with political figures stalling conservation efforts at a policy level. Neither response variable was statistically associated with any predictor variables around stakeholders or management structure, possibly due to difficulties with capturing this complex information in a quantitative measure (Black et al. 2011). However, all projects where species became extinct and two-thirds of those where species were declining were characterized by partial or total lack of coordinated management and by stakeholders with differing agendas. This invariably led to lack of clear aims and delays in implementing conservation interventions.

In contrast, over half of projects associated with general stakeholder agreement had increasing target populations (Fig. 1). In these instances, an active centralized working group generally facilitated effective conservation efforts, with species managed as a coordinated whole rather than as separate populations for long-term recovery. Effective working groups tended to meet at least annually and to have regular informal updating. Regularity of contact also facilitated adaptive management, with changes in recovery program trajectory evaluated and updated as necessary with everyone's agreement. Elsewhere in the conservation literature, the establishment of special working groups has been correlated with increased innovation in translocation programs of rare species but not with increased organization or decreased conflict as found in our study (Reading et al. 1997). The relationship between working groups and effective conservation is therefore likely to be complex and context dependent. However, effective leadership and management practices are likely to improve project performance, for example, through appropriate working-group coordination (Black et al. 2011, 2013). Effective stakeholder coordination may also be related to different capacity levels of partners that affect their ability to influence conservation decision making. For example, lack of investment and subsequent limited capacity in many government wildlife agencies was regularly cited as a key problem by informants. It was interesting that funding was not related to conservation outcomes in our study, particularly because links between increased funding and improved conservation status have been found elsewhere (Kerkvliet & Langpap 2007). However, our informants regularly made the important distinction that continuity of funding was more important to effective long-term recovery program management than simply amount of funding, a concern that has not been commonly discussed in the conservation literature.

Conflict with government or policy makers was also a commonly reported issue. One informant, reflecting on a difficult political relationship with a national government, commented, "We were right to go on record and say there's a problem [. . .] you have also got to realise that the people who run the country, run the country; we are just an NGO and you need to work with them to get anything done [. . .] I think really careful political engagement is absolutely vital, and we'd be a lot further along if we'd been more adept at that." We suggest that many projects could benefit from involvement of specific politically adept individuals to help liaise with governments, and this may be worth considering in difficult cases. Although this is not a commonly acknowledged challenge in the conservation literature, Martin et al. (2012) argue that institutional accountability was a vital prerequisite for avoiding species extinctions, notably lacking for the Christmas Island pipistrelle. Key decision makers must be identified early and political engagement managed carefully. This could constitute an essential step toward successful conservation outcomes (Phillis et al. 2013).

Future Directions

Our global-scale quantitative approach revealed several common predictors of recovery or decline across a wide sample of recovery programs, some of which have received relatively little attention in the conservation literature. No biological variables affected project outcomes, so we would expect that recommendations based on our results could be applied to other recovery programs. This could reflect the strong understanding of mammalian biology and ecology that usually forms part of the evidence base for species recovery; alternatively, external factors may simply be more influential in project outcomes. An interesting next step would be to repeat this study for other taxonomic groups to identify whether these patterns hold more widely.

Although we had a reasonable geographical spread of projects, >37% were from the United States and Australia. This was partly due to legislation in these countries supporting identification of threatened species and establishment of recovery programs, meaning that there were more existing projects in these countries than in most others. However, to tackle potential bias, future analyses could focus on specific geographical or political regions. This would also yield more localized insights into factors influencing recovery program outcomes and improve the ability to apply lessons learned in a targeted manner. Perhaps most importantly, it would be useful to generate larger project sample sizes for purposes of statistical analysis, including comparable-sized sets of conservation successes and failures, to help identify stronger associations between explanatory variables and project outcomes.

Recovery programs must be planned (including the use of proper threat and stakeholder analysis), implemented, and monitored according to best practices, as well as tailored to suit specific situations. Other factors that we did not explicitly consider, such as project cost-effectiveness (Naidoo et al. 2006), must also be incorporated into decision making for recovery programs. However, our findings demonstrate the importance of considering management strategies such as robust threat monitoring, long-term habitat protection, and effective stakeholder coordination. Above all, the conservation community must recognize the importance of regular evaluation and take lessons from past experiences to replicate successful strategies and avoid repeating potentially grave and irreversible mistakes.

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Supporting Information

The questionnaire (Appendix S1) is available online. The authors are solely responsible for the content and functionality of this material. Queries (other than absence of the material) should be directed to the corresponding author.

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