Determinants of bird conservation-action implementation and associated population trends of threatened species

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Abstract: Conservation actions, such as habitat protection, attempt to halt the loss of threatened species and help their populations recover. The efficiency and the effectiveness of actions have been examined individually. However, conservation actions generally occur simultaneously, so the full suite of implemented conservation actions should be assessed. We used the conservation actions underway for all threatened and near-threatened birds of the world (International Union for Conservation of Nature Red List of Threatened Species) to assess which biological (related to taxonomy and ecology) and anthropogenic (related to geoeconomics) factors were associated with the implementation of different classes of conservation actions. We also assessed which conservation actions were associated with population increases in the species targeted. Extinction-risk category was the strongest single predictor of the type of conservation actions implemented, followed by landmass type (continent, oceanic island, etc.) and generation length. Species targeted by invasive nonnative species control or eradication programs, ex situ conservation, international legislation, reintroduction, or education, and awareness-raising activities were more likely to have increasing populations. These results illustrate the importance of developing a predictive science of conservation actions and the relative benefits of each class of implemented conservation action for threatened and near-threatened birds worldwide.

Keywords: birds, conservation actions, conservation planning, extinction risk, IUCN Red List

Determinantes de la Implementación de Acciones para la Conservación de Aves y Tendencias Poblacionales Asociadas de Especies Amenazadas

Resumen: Las acciones de conservación, como la protección del hábitat, intentan detener la pérdida de especies amenazadas y ayudar a que sus poblaciones se recuperen. La eficiencia y efectividad de las acciones han sido examinadas individualmente. Sin embargo, las acciones de conservación generalmente ocurren simultáneamente, de manera que se debe evaluar al conjunto de acciones de conservación implementadas. Utilizamos las acciones de conservación que están en marcha para todas las especies de aves del mundo amenazadas o casi amenazadas (Lista Roja de Especies Amenazadas de la Unión Internacional para la Conservación de la Naturaleza) para determinar los factores biológicos (relacionados con la taxonomía y ecología) y antropogénicos (relacionados con la geoeconomía) asociados con la implementación de diferentes clases de acciones de conservación. También identificamos que acciones de conservación estaban asociadas con los incrementos de población en las especies atendidas. La categoría en riesgo de extinción fue el predictor individual más robusto del tipo de acciones de conservación implementadas, seguida por el tipo de masa

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continental (continente, isla oceánica, etc.) y el período generacional. Las especies atendidas mediante el control de especies no nativas o por programas de erradicación, conservación ex situ, legislación internacional, reintroducción o actividades de educación y concientización tuvieron mayor probabilidad de incrementos poblacionales. Estos resultados ilustran la importancia de desarrollar una ciencia predictiva de acciones de conservación así como los beneficios relativos de cada clase de acción de conservación implementada para especies de aves amenazadas y casi amenazadas globalmente.

Palabras Clave: acciones de conservación, aves, Lista Roja UICN, planificación de la conservación, riesgo de extinción

Introduction

Due to human activities, the rate of species extinction is higher now than at any other time in the past 65 million years (Barnosky et al. 2011; Pimm et al. 2014). Conservation efforts aim to slow, stop, and reverse threats to species and thus the current loss of biodiversity. However, the extinction risk to species continues to rise (Butchart et al. 2010; CBD 2014). This does not mean conservation efforts have failed. Indeed, conservation efforts have circumvented at least 20% of projected increases in aggregate extinction risk to birds and mammals over the last 4 decades, as measured by changes in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (hereafter, red list) (Hoffmann et al. 2010). For ungulates, increases in aggregate extinction risk since 1996 would have been 8 times greater in the absence of conservation actions (Hoffmann et al. 2015).

Targeted actions to recover birds have been particularly successful. For example, from 1994 to 2004, conservation efforts likely prevented at least 16 bird species from going extinct (Butchart et al. 2006; Rodrigues et al. 2006). The implementation of conservation actions for threatened species is critical if species recovery is to be supported as agreed in Aichi Target 12 of the 2010–2020 Strategic Plan for Biodiversity (Convention on Biological Diversity 2010).

Research on the suite of parameters that affect extinction risk for threatened species, including biological and geoeconomic factors and threats, has made great progress toward predicting extinction risk (e.g., Owens & Bennett 2000; Davies et al. 2006; Purvis et al. 2006). Although such studies provide information on the extinction risk and threats facing species, it is only through the implementation of conservation actions that the status of threatened species has improved. Thus, just as there is an emerging predictive science of extinction risk, there is a need for a predictive science of conservation actions, which would illuminate how, why, and where conservation actions are best implemented for threatened species and could be used to assess their efficiency.

Such a predictive science of conservation actions has not been completely overlooked. Hayward (2011) used a subsample of 144 threatened mammals from the red list that improved or declined in status from 2004 to 2008 to assess the links among threats, conservation actions, and population trends. Brooks et al. (2009) examined the effectiveness of the conservation actions implemented in tropical rainforests. Chapman et al. (2016) surveyed experts about whether conservation actions had been successful. Most comprehensively, in a literature review, Williams et al. (2012) assessed the efficiencies of each of the IUCN conservation-action categories for birds. Building from these attempts to assess implemented conservation actions and using data for birds from the red list, we analyzed the biological and geoeconomic parameters that influence conservation-action implementation and are associated with increasing population trends. Specifically, we assessed which factors predicted implementation of conservation actions and examined which actions were associated with different directions of population trends for threatened and near-threatened bird species (i.e., bird categorized as critically endangered, endangered, vulnerable, or near threatened). We examined which factors were associated with the implementation of each category of conservation action and which conservation actions were most likely to be associated with increasing population trends.

Methods

We examined the conservation actions underway for bird species assessed by BirdLife International as threatened (i.e., critically endangered, endangered, or vulnerable) or assessed as near threatened by IUCN (BirdLife International 2014a). Birds are an excellent study group to investigate such questions because birds occur in most areas and all countries worldwide, are easily identifiable, and practical to monitor and research and there are large numbers of people in networks studying birds, compiling information about them, and implementing conservation actions for them (Brooks et al. 2008). Moreover, all birds have been comprehensively assessed with IUCN’s Red-List categories and criteria multiple times. As of July 2012, when all biological data were extracted from the Species Information Service, there were 1313 species threatened and 880 species near threatened (i.e., 22% of the world’s 10,425 bird species are considered of elevated conservation concern) (BirdLife International 2014a). We excluded critically endangered species tagged as possibly
Types of conservation actions underway that were assessed in association with population trends. (which included 142 species). We used data on conservation actions underway as documented in the Species Information Service, the database comanaged by IUCN and BirdLife International, which underpins the red list. The aim of these conservation actions is to stop and reverse the decline of the populations of the target species. The fields for conservation actions underway largely represent a subset of the actions in the conservation-actions classification scheme developed by Salafsky et al. (2008) and relate to those actions for which meaningful data can be compiled for the majority of species on the red list (Table 1). Conservation actions included in the database represent those that are ongoing or took place within the last decade. We excluded the action of identification of “important sites” for species because nearly all (>95%) of threatened and near-threatened bird species have important bird and biodiversity areas identified for them (BirdLife International 2014b). Thus, this parameter would have had little explanatory power in our analysis. We included monitoring, which is not technically a conservation action according to Salafsky et al. (2008) but is instead a research need, yet monitoring tends to be a critical component in terms of assessing population trends as related to conservation actions.

### Table 1. Types of conservation actions underway that were assessed in association with population trends.

| Conservation action          | Definition                                                                 | IUCN classification scheme                   |
|------------------------------|---------------------------------------------------------------------------|-----------------------------------------------|
| Action plan                  | an action or recovery plan exists research needed for the species         | research needed conservation planning         |
| Monitoring Protected area    | species subject to systematic monitoring                                  | research needed monitoring                     |
| Invasive species control     | species occurs in at least one protected area                             | invasive or problematic species control       |
| Reintroduction               | species being (or has been successfully) reintroduced or introduced benignly for conservation purposes | species reintroduction                        |
| Ex situ                      | species subject to ex situ conservation                                    | ex situ conservation                           |
| Education or awareness raising | species subject to ongoing (or recent) education and awareness programs species listed in international legislation (e.g., on appendices of CITES, CMS, or their agreements and instruments) | education and awareness                        |
| International legislation    | legislation (e.g., on appendices of CITES, CMS, or their agreements and instruments) | law and policy                                |
| International trade management | species subject to international management or trade controls               | livelihood, economic, and other incentives    |

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extinct or possibly extinct in the wild from our analysis (16 of the 2193 species) because these species require targeted searches to determine whether any individuals survive before identifying the most appropriate conservation actions, which left 2177 species in the analysis. We used data on conservation actions underway as documented in the Species Information Service, the database comanaged by IUCN and BirdLife International, which underpins the red list. The aim of these conservation actions is to stop and reverse the decline of the populations of the target species. The fields for conservation actions underway largely represent a subset of the actions in the conservation-actions classification scheme developed by Salafsky et al. (2008) and relate to those actions for which meaningful data can be compiled for the majority of species on the red list (Table 1). Conservation actions included in the database represent those that are ongoing or took place within the last decade. We excluded the action of identification of “important sites” for species because nearly all (>95%) of threatened and near-threatened bird species have important bird and biodiversity areas identified for them (BirdLife International 2014b). Thus, this parameter would have had little explanatory power in our analysis. We included monitoring, which is not technically a conservation action according to Salafsky et al. (2008) but is instead a research need, yet monitoring tends to be a critical component in terms of assessing population trends as related to conservation actions.

**Factors Associated with Implemented Conservation Actions**

We examined both biological and anthropogenic factors as independent predictor variables of conservation-action implementation. Biological factors considered encompassed IUCN Red-List Category, taxonomic order, body mass, clutch size, generation length, landmass type, habitat, biogeographic region, number of countries in species range, and size of breeding range (Table 2). For species’ habitat, we considered only the IUCN’s broad level-1 classes (http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3) coded as being of major importance during the breeding season. To simplify the analyses, we summed the 4 marine habitat subcategories, neritic, intertidal, marine coastal, and oceanic, to create a general marine category (which included 107 species) and pooled the categories for caves and rocky areas, introduced vegetation and artificial terrestrial or aquatic habitats, other habitats, and unknown habitats into a class we termed other (which included 142 species). We placed species that inhabit multiple geographic realms in a multiple category and species in multiple landmass types in a separate multiple category as well.

**Geoeconomic factors, which describe the economic development of the places where species live, can also be an important determinant of conservation implementation. Geoeconomic factors considered encompassed proportion of range in Group of 20 (G20) countries, proportion of range in Organization of Economic Co-operation and Development (OECD) countries, and gross domestic product (GDP) of countries within species’ ranges (Table 2). To calculate the per capita area-weighted GDP for a species, we used 2008 GDP estimates (the most recent complete data set) and weighted the GDP for each country of occurrence by the proportion of the range occurring in that country (Rodrigues et al. 2014). The GDP is calculated as per capita in 1990 international Geary–Khamis dollars and from the World Economic Outlook (2014). One hundred and eighty-eight countries belong to the International Monetary Fund. For the few that do not belong, we used estimates of GDP from the CIA Factbook (CIA 2013).**
We fitted binomial regression models to explain the presence of each of the 9 conservation action categories for 2177 bird species. Missing data, among 4 variables with 0.05–5.9% missing (see Supporting Information for details of missing data), were input singly (Fig. 1).

Best models were selected using a combination of the Akaike information criterion corrected for small sample size (AICc) and an assessment of the generalized variance inflation factor to ensure low collinearity among predictors. Collinearity among predictors was judged acceptable when the generalized variance inflation factor was below $\sqrt{3}$ (Zuur et al. 2010). If the generalized inflation factor was $>\sqrt{3}$, that model was not considered valid. After a final model was selected, Pearson residuals were binned and examined to ensure no patterns emerged that would suggest an important predictor was left out of the model. Residuals were plotted against all predictor variables, both those included and excluded from the model, to ensure that important predictors had not been removed. We used the MuMIn package in R (R statistical software, version 3.0.2, Vienna) (Barton 2015) to conduct model averaging on the best models so that the cumulative Akaie weight was $\geq 0.95$ (Johnson & Omland 2004) for each of the 9 conservation actions, which resulted in one average final model for each conservation action. The best models are used for averaging in Supporting Information, and the averaged parameter estimates, unconditional standard errors, and confidence intervals are reported in Supporting Information. To determine the importance of variables, we calculated the 90% (SE 1.64) and 95% (SE 1.96) confidence intervals around the model-averaged parameter estimates (Kittle et al. 2008). If the confidence interval did not contain 0, we concluded that the parameter had an effect on the dependent variable (i.e., the estimate was different from 0).

Conservation Actions Associated with Population Trends

In a separate analysis, we used a binomial regression model (AICc and the generalized variance inflation factor as detailed above) to explore which conservation actions were associated with increasing population trends for threatened and near-threatened bird species. Population trend was a categorical variable based on ongoing trend data over the last several years. Coefficients for binomial regression were interpreted as the odds ratio (i.e., the antilog of the raw coefficients). Numerical results are reported as mean and SE unless otherwise noted. All tests were conducted using R statistical software (version 3.0.2, R Core Team 2014).

Results

Factors Associated with Implemented Conservation Actions

In total, 5424 conservation actions were documented as being implemented for the 2177 threatened and near-threatened bird species on the IUCN Red List (mean of 2.55 [SE 0.028] conservation actions/species). The most frequent conservation action was implementation of a
protected area to cover a population of the species (74% of species). There were international trade regulations and action plans for 23% and 18% of threatened and near-threatened bird species, respectively. Other conservation actions were implemented for <10% of species. Predictive models for international trade regulations, international legislation, invasive species control, and action plans all had relatively high explained deviance (McFadden’s pseudo $R^2$ averaged over all of the models): 0.67, 0.54, 0.53, and 0.54, respectively (McFadden 1973). Predictive models for other conservation actions, ex situ conservation, monitoring, reintroduction, education, and population protection had lower predictive power; explained deviances were 0.36, 0.36, 0.27, 0.22, and 0.20, respectively.

Red-list category of extinction risk was the predictor occurred most frequently in the best models for conservation-action implementation. More severely threatened species were more likely to be targeted by more conservation actions; critically endangered and endangered species had significantly more conservation actions than vulnerable and near-threatened species ($F_{3,2173} = 45.56, p < 0.001$).

Species that live in Europe or multiple regions had the most conservation actions implemented, whereas species in western and central Asia, North Africa, and Antarctica had the fewest ($F_{13,2163} = 21.69, p < 0.001$). Species that breed in more countries had more conservation actions implemented ($F_{1,2175} = 240.4, p < 0.001$). For every 1% increase in the area of a species range within G20 or OECD countries, the number of conservation actions increased by 0.00196 ($F_{1,2175} = 9.54, p = 0.002$) and 0.0093 ($F_{1,2175} = 148.8, p < 0.001$), respectively. As the area-weighted GDP of species increased, so did the likelihood that the species would have conservation actions in place ($F_{1,2175} = 81.51, p < 0.001$).

Species’ biology was also associated with the implementation of conservation actions. Species with longer generation times were more likely to have more conservation actions. For every year increase in generation length, the number of conservation actions implemented increased by 0.13 ($F_{1,2175} = 482.6, p < 0.001$), and generation length was an important contributing factor for all conservation actions except action plans and international legislation. Species with marine habitats and inland wetland habitats had more conservation actions in place than species in other habitats ($F_{7,2169} = 20.28, p < 0.001$). Specifically, species in these habitats tended to have more monitoring, protected areas, invasive nonnative species control or eradication, ex situ conservation, and international legislation. The type of landmass where a species occurred was an important predictor variable for all implemented conservation actions except education and ex situ conservation; more actions were implemented for species inhabiting oceanic islands ($F_{3,48} = 9.22, p < 0.001$).

Taxonomic order was a predictor in all the best models for education and awareness raising, action plans, ex situ conservation, international legislation, and trade control. The taxonomic orders Anseriformes (ducks, geese, and swans), Falconiformes (raptors), Gaviiformes (divers/loons), Phoenicopteriformes (flamingoes), and Psittaciformes (parrots) had the highest numbers of conservation actions, whereas Caprimulgiformes (nightjars), Columbiformes (pigeons), Cuculiformes (cuckoos), Passeriformes (perching birds), and Piciformes

Figure 2. Estimated odds ratio (points) and 95% confidence interval (whiskers) for a species showing an increasing population trend when each conservation action (y-axis) is in place.
(woodpeckers) had the fewest ($F_{23.2153} = 21.68$, $p < 0.001$) (see Supporting Information for associations between taxonomic orders and specific conservation actions).

**Conservation Actions Associated with Population Trends**

Among threatened and near-threatened species, 83% had decreasing population trends, 3% increasing, and 11% stable, and 2% had unknown population trends (BirdLife International 2014b). Species with increasing populations had more conservation actions in place (4.01 [SE 0.19]) than those with decreasing (2.51 [SE 0.03]), stable (2.47 [SE 0.09]), or unknown population trends (0.98 [SE 0.14]) ($F_{3.2173} = 34.31$, $p < 0.001$). The best generalized binomial regression model that explained an increasing or decreasing population trend based on the conservation actions in place included education and awareness raising, international legislation, reintroduction, ex situ conservation, and invasive alien species control or eradication (Table 3). Species with these conservation actions showed increased odds of having a positive population trend of 2.16, 2.62, 2.82, 3.09, and 10.63, respectively (Fig. 2).

**Discussion**

Our results depict both the biological and anthropogenic environment in which conservation actions are most likely to be implemented and are most likely to yield population increases for their target species. More severely threatened species received more types of conservation actions, presumably because the conservation of more severely threatened species is seen as more urgent or because more threatened species face a wider range of threats. Species with increasing population trends had 1.6 times more conservation actions in place than those with stable or decreasing populations, suggesting that implementation of multiple conservation actions may be more effective at reducing extinction risk. In particular, the implementation of invasive nonnative species control or eradication, ex situ conservation, international legislation, reintroduction, and education and awareness raising were most frequently associated with positive population trends. Knowledge of the circumstances in which conservation actions are implemented as well as which ones are most successful, such as we describe here, could tremendously benefit the future of species conservation and have implications for future resource allocation for conservation actions and assessments of the potential success of different types of actions.

Biological factors important in predictive models of biodiversity threats, such as generation length, clutch size, taxonomic group, and habitat, were also important in the predictive models of conservation-action implementation. In particular, generation length was a predictor in all of the models for 6 of the 9 conservation action types assessed and is an important predictor in extinction risk models (Owens & Bennett 2000; Fisher & Owens 2004). Many of the biological factors in the models are correlated with taxonomy, and closely related species within taxonomic groups are generally susceptible to similar threats (Gaston & Blackburn 1995; Owens & Bennett 2000; Mace 2004); consequently, they tend to receive similar conservation actions.

Taxonomic order was an important factor associated with education and awareness raising, action plans, ex situ conservation, international legislation, and international trade regulations, suggesting that these 5 classes of conservation action tend to be applied in a taxonomically selective way. Species in taxonomic groups that are particularly threatened by overexploitation, such as Anseriformes, which are threatened by hunting (Green 1996), Psittaciformes, which are threatened by trapping for the pet industry (Collar & Juniper 1992; Wright et al. 2001), and Falconiformes, some of which are threatened by trapping for falconry (Butchart et al. 2005), receive a disproportionate number of conservation actions compared with species in other orders. Species in these orders tend to be particularly palatable, colorful, carnivorous, or otherwise charismatic, explaining both their attractiveness for harvest and conservation attention (Leader-Williams & Dublin 2000).

Whether a species lives on an oceanic island, continental island, continent, or multiple landmass types was an important predictor for 7 of the 9 conservation actions. Being on an oceanic island was a strong predictor of the existence of invasive-species control or eradication implementation, reintroduction programs, and action plans. Invasive species have been a leading cause of extinction for native species on islands (Clavero & Garcia-Berthou 2005). However, eradicating invasive species is an increasingly applied and successful conservation tool (Veitch et al. 2011; Jones et al. 2016). Our finding that the odds of populations of threatened and near-threatened species are over 10 times more likely to be increasing when invasive species control or eradication is implemented is a strong signal that this conservation action has a positive impact on such species. With ongoing declines in oceanic seabird populations, international legislation has been strengthened to reduce threats to these species because they typically cross national borders and often use areas beyond national jurisdiction while foraging or migrating (Wolf et al. 2006; Croxall et al. 2012).

The implementation of conservation actions requires adequate resources (McCarthy et al. 2012), which explains the importance of geoeconomic factors as predictors of the implementation of many conservation actions. Geoeconomic factors were important in models for each conservation action, and species in more economically developed countries were more likely to receive conservation actions. This appears to be consistent
Table 2. Variables used to predict conservation-action implementation based on research that showed these variables are important in predicting extinction risk.

| Predictor variables | Definition | Variable type | Number of levels | Citation |
|---------------------|------------|---------------|-----------------|---------|
| Threat category     | IUCN Red-List category | categorical | 4 | Mace 2004 |
| Taxonomic order Mass | taxonomic order body mass | categorical | 24 | Gaston & Blackburn 1995; Owens & Bennett 2000; Fisher & Owens 2004 |
| Clutch size         | clutch size generation length | continuous | | |
| Generation length   |            | continuous | | |
| Landmass type       | landmass type | categorical | 4 | Davies et al. 2006 |
| Habitat type        | habitat type | categorical | 8 | Owens & Bennett 2000; Purvis et al. 2006; Cooper et al. 2008 |
| Region              | biogeographic region | categorical | 14 | |
| Country count       | number of countries in species range | continuous | | |
| Breeding range      | size of breeding range | continuous | | |
| G20                 | proportion of range in G20 countries | continuous | | |
| OECD                | proportion of range in OECD countries | continuous | | |
| GDP2008             | GDP of countries within species range | continuous | | |

Table 3. Akaike information criterion (AICc) models for conservation actions associated with increasing population trends of threatened and near-threatened species as listed on the International Union for Conservation of Nature Red List.

| Implemented conservation actions\(^a\) | -logLL | K\(^b\) | AICc | ΔAICc | Weight | Explained deviance (McFadden's pseudo \(R^2\)) |
|------------------------------------------|--------|--------|------|-------|--------|----------------------------------|
| Education + international legislation + reintroduction + ex situ conservation + invasive species control Action plan | -250.90 | 5 | 513.85 | 0 | 0.35 | 0.210 |
| Protected populations | -249.39 | 7 | 514.85 | 1 | 0.21 | 0.215 |
| International trade regulations | -249.09 | 8 | 516.27 | 2.42 | 0.1 | 0.216 |
| International trade regulations + monitoring | -249.00 | 9 | 518.13 | 4.27 | 0.04 | 0.216 |

\(^a\)All groups of actions include all those listed in the previous entry (i.e., only the additional action is listed in each row after the first).

\(^b\)K is the number of parameters in the model.

with the Kuznets curve, which predicts that there is a hump-shaped relationship between wealth and environmental quality (Mills & Waite 2009), whereby improving population trends for threatened and near-threatened species coincided with wealthy countries. However, there are criticisms of the Kuznets curve model because as poorer countries increase their wealth it can lead to increased threats, which can create a complex relationship between a country’s financial resources and the conservation of biodiversity (Mills & Waite 2009). Another complication with economic predictive variables is that finances often flow across international borders, which can lead to the transfer of funds for conservation efforts as well as the transfer of threats, such as logging and the harvesting of species (Lenzen et al. 2012; Weinzierl et al. 2013). Furthermore, some of the richest countries...
have shown poor results with regard to species recovery, whereas many of the best successes have come from countries with small per capita GDPs (Rodrigues et al. 2014), illustrating that finances alone cannot explain the implementation or efficiency of conservation actions.

Reintroduction, ex situ, invasive nonnative species control or eradication, education and awareness raising efforts, and international legislation were all significantly associated with increasing population trends among species of conservation concern. Action plans, monitoring, protected populations, and international trade regulations were positively associated as well, but not significantly. The reasons for these differences are not clear. Certainly, reintroduction and invasive nonnative species control or eradication are highly targeted actions, which can often yield dramatic positive results. Conversely, action plans and monitoring are preconditions to other conservation actions and alone are insufficient to ensure population increases. Furthermore, the existence of an action plan does not necessarily imply that it is being implemented adequately or at all. Unfortunately, trade controls can often be ineffective, and illegal trade is a widespread issue for utilized species (Magnin 1991). Some conservation actions may have interactive effects that increase opportunities for population recovery. For example, invasive species eradications coupled with reintroductions may increase the likelihood of population recovery more than one of these conservation actions alone.

Future research should investigate the alignment of effectiveness with efficiency for a more holistic view of the best approaches to species conservation. For example, we found that more threatened species received more conservation actions either because threats to them are more intense or because their situation is more urgent. However, it may not be cost-efficient to focus on these species if budgets are limited and the aim is to maximize the number of species persisting (Possingham et al. 2002; Di Fonzo et al. 2016). On the contrary, cultural factors and others could also be important in terms of conservation efforts rather than conservation efforts solely based on predicted efficiency. In the end, it is important to try to save all threatened species not just those for which it seems efficient.

A predictive science of conservation-action implementation and effectiveness should increase the future success of conservation efforts. Although our models accounted for many of the biological and anthropogenic factors thought to be associated with threats to species and hence potentially with conservation-action implementation, additional factors are likely to play a role. Climate change is an important variable we did not account for; however, all of the conservation actions we assessed can be implemented in a climate-smart manner and remain relevant in the presence of climate change (McClanahan et al. 2008; Stein et al. 2014). Future efforts should also look at the relationship between particular threats and the implementation of conservation actions, specifically to measure the alignment between them and to use the alignment as a predictor for positive population trends. Future research should investigate similar questions in other taxa and refine our results to pinpoint the correlates of successful conservation actions and help improve the overall effectiveness of conservation action for species of conservation concern.

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Supporting Information

The AICc model selection with the top models and predictors of conservation-action implementation for each class of conservation action and models with Akaike weight summing to at least 0.95 used to calculate model averaged estimates, standard errors, and confidence intervals for each conservation action (Appendix S1) 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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