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An evaluation of species recovery under the U.S. Endangered Species Act

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FOREWORD

I have prepared my thesis following the integrated thesis format; each chapter was produced as an independent manuscript. Consequently, some of the introductory and methodological content may overlap in chapters one and two. As well, the first person plural active voice is used throughout, rather than a third person singular passive voice. I have also tried my best to keep the main body of the document short, with additional details provided in appendices.

STATEMENT OF AUTHORSHIP AND CONTRIBUTIONS

I was responsible for completing the majority of work described in this thesis; however, I did receive the following assistance. I proposed and developed the research questions and study design in co-operation with David Currie and Scott Findlay. Species' data collection was conducted with assistance from staff at the Center for Biological Diversity (Tucson, Arizona), led by Noah Greenwald and Kieran Suckling. I also directed two data-collection projects for students enrolled in BIO3115: Introduction to Conservation Biology at the University of Ottawa. I was responsible cleaning and organizing the assembled data. I conducted all of the analyses presented and wrote all first drafts of each of the chapters, general introduction and conclusion, and appendices. Revisions of first drafts were conducted by David Currie and Scott Findlay.

ABSTRACT

The U.S. Endangered Species Act (U.S. ESA) is one of the oldest pieces of legislation to protect endangered species. The bodies responsible for administering the U.S. ESA have published species Biennial Recovery Statuses (BRSs) in *Reports to Congress on the Status of Endangered and Threatened Species.* We found that expert assessments of species recovery trends match BRSs reasonably well; however, there appears to be a weak relationship between the BRSs and available data tracking species abundance and range trends. We aimed to establish whether the recovery trends of species examined were detectably associated with their threats, the general U.S. ESA tools, or recovery actions. We found positive associations between species recovery and two U.S. ESA tools – mean annual funding and peer-reviewed scientific information. However, correlations with other variables differ greatly depending on how recovery is defined. Species threats and recovery actions are also moderately related to their abundance and range trends.

RÉSUMÉ

Le Endangered Species Act des États Unis (U.S. ESA) est l’une des plus vielles actes législatifs pour protéger les espèces menacées d'extinction. Les organisations responsables de mise en application du U.S. ESA publient bi-annuellement un rapport au Congrès sur l’état de rétablissement des espèces en péril (BRSs). Nous avons pu déterminer que les biologistes ayant une expertise sur ces espèces ont une opinion positive des BRSs, et que leurs propres évaluations des tendances du rétablissement des espèces correspondent raisonnablement bien avec les BRSs. Cependant, ils semblent y avoir une relation faible entre les tendances rapportées dans les BRSs et celles estimées par des données quantitatives d’abondance ou de distribution des espèces. Nous avons ensuite cherché à déterminer si les tendances de rétablissement de ces espèces sont associées à l'ensemble des activités qui les exposent au risque ainsi qu’aux outils généraux ou actions ciblées mis en place pour promouvoir leur rétablissement. Nous avons trouvé des associations positives entre le rétablissement de ces espèces et deux outils généraux - le financement annuel et les renseignements scientifiques. Pourtant, des corrélations avec d'autres variables dépendent fortement de la métrique utilisée pour caractériser le rétablissement. De plus, les activités qui exposent les espèces au risque ainsi que les actions ciblées pour leur rétablissement sont modérément liées aux tendances de l'abondance et de la distribution des espèces.

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General Introduction

The loss of biodiversity is often cited as one of the most significant environmental threats facing the world (Myers et al. 2000). The degree of consensus on this issue among conservation biologists has even been said to exceed support for anthropogenically-driven climate change among climate scientists (Rudd 2011). In response, numerous international, national and sub-national policies and regulations to protect species at risk of extinction have been implemented (e.g. Convention on International Trade in Endangered Species, Migratory Birds Treaty Act, European Union Habitats and Birds Directives, Canadian Species At Risk Act, Ontario Endangered Species Act). However, a largely outstanding question is the extent to which such instruments are proving in protecting and recovering species.

The United States Endangered Species Act (U.S. ESA 1973) is considered one of the oldest, most powerful and controversial pieces of environmental legislation in the world (Gosnell 2001; Schwartz 2008; Gibbs & Currie 2012). Its overall purpose is to provide for the conservation of endangered and threatened species, as well as their habitats (U.S. ESA 1973 (sec. 2b)). Critics have argued that the U.S. ESA has failed because only 1 percent of protected species have achieved a 'recovered' status (Hastings 2011). Supporters of the Act contend, however, that as many species have not been listed long enough to achieve full recovery, this measure of success will underestimate the Act's impact. As an alternative, others have suggested that a more appropriate measure of success might be the number of extinctions prevented (e.g. Suckling et al. 2012). Neither detractors nor proponents of the Act are reticent about voicing their opinions, but the empirical foundations of these opinions are shaky. And as Scott & Goble note in their 2005 letter to Conservation Biology, "*Anecdote, rhetoric and even logic are poor substitutes for data*".

The majority of scientists and conservation practitioners recognize that responding to the loss of biological diversity will require greater efforts in long term monitoring and modelling of species and the determinants of their endangerment and recovery (Rudd 2011). However, the evidence suggests that conservation managers are rarely able to use empirical data in their management decisions (Cook et al. 2012). The absence of monitoring and evaluation of implemented actions is a consistent problem in conservation biology (Pullin & Knight 2001). Even where evidence of impact is available, there is often no requirement to ensure it is used in subsequent management decisions (Pullin & Knight 2001).

As conservation knowledge is limited, uncertainty concerning expected outcomes of policy, regulatory or management interventions is often large (Fazey et al. 2004). Taking an adaptive management approach to conservation has been one proposed way to deal with this high uncertainty (Campbell et al. 2002). Following an evidence-based approach to conservation alone, actions are only taken following the guidance of prior evidence (Fazey et al. 2004). Given the urgency with which we are threatened by biodiversity loss, relying solely on this method is not possible. An adaptive management approach, however, allows evidence to be acquired while actions are being implemented through the continuous review of their outcomes (Fazey et al. 2004). Applied to statutory, regulatory or policy instruments that are designed to protect species at risk of extinction, an adaptive approach requires that there be periodic assessment of whether they are contributing to their intended effect – which is that species are recovering, and that recovery is due to the instrument(s).

The need for greater monitoring and evaluation of conservation actions is clear. A survey of conservation managers' data requirements revealed they need a broader understanding of biodiversity management when making decisions; including information relevant to managing individual species and ecosystems, as well as information leading to the prioritization of management actions (Cook et al. 2012). However, the same survey revealed that while conservation managers highly value empirical evidence on which to base their decisions, the availability of this data was poorer than other types of evidence (e.g.

experiential evidence) (Cook et al. 2012). Better empirical understanding of the threats faced by species, their recovery trends and the actions that affect recovery will strengthen conservation efforts (Campbell et al. 2002, Hutchings et al. 2012). Pullin and Knight (2001) go so far as to suggest that funding (through government, charity or other means) should not be provided for carrying out biodiversity conservation actions that have weak evidentiary basis – unless experimentation and follow-up monitoring are built in as a requirement.

Because of its long history and the large and diverse group of species it is intended to protect, the U.S. ESA provides the best opportunity for assessing the effectiveness of actions aimed at conserving endangered species. This thesis aims to evaluate the recovery trends of species listed under the U.S. ESA. Here we examine the degree to which species recovery trends as defined by their statuses published in the U.S. ESA biennial reports to Congress (U.S. FWS 1990-2012, NMFS 1991-2013), reflect the trends described by their available quantitative abundance or range data. Using these data we attempt to determine what factors (threats, recovery actions or legislated tools) are able to distinguish improving vs. declining recovery trends of listed species. Through this project we hope to highlight the importance of monitoring species recovery trends, and demonstrate the value of these data for evaluating their causes of endangerment, as well as directing and managing conservation actions.

LITERATURE CITED

Campbell, S., J. Clark, L. Crampton, A. Guerry, L. Hatch, P. Hosseini, J. Lawler, and R. O'Connor. 2002. An assessment of monitoring efforts in endangered species recovery plans. Ecological Applications 12(3):674-681.

Cook, C.N., R.W. Carter, R.A. Fuller, and M. Hockings. 2012. Managers consider multiple lines of evidence important for biodiversity management decisions. Journal of Environmental Management 113:341-346.

Fazey, I., J. G. Salisbury, D. B. Lindenmayer, J. Maindonald, and R. Douglas. 2004. Can methods applied in medicine be used to summarize and disseminate conservation research? Environmental Conservation 31(3):190-198.

Gibbs, K. E., and D. J. Currie. 2012. Protecting endangered species: Do the main legislative tools work? Plos One 7(5):e35730.

Gosnell, H. 2001. Section 7 of the endangered species act and the art of compromise: The evolution of a reasonable and prudent alternative for the Animas-La Plata Project. Natural Resources Journal 41(3):561-626.

Endangered Species Act (U.S. ESA). 1973. Public Law No. 93–205, 87. US statutes at large 884 (Dec.23, 1973). Available http://www.fws.gov/ENDANGERED/esa-library/pdf/ESAall.pdf. Accessed 2014 June 25.

Fish and Wildlife Service (U.S. FWS). 1990 - 2010. Report to Congress on the recovery of threatened and endangered species: fiscal years 1990, 1992, 1994, 1996, 1997–1998, 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007-2008, 2009-2010. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.fws.gov/endangered/esa-library/index.html#recovery. Accessed 2014 May 09.

Hastings, D. 2011. "Excessive Endangered Species Act litigation threatens species recovery, job creation and economic growth." Press release by Doc Hastings, Chairman of the Committee on Natural Resources, U.S. House of Representative, December 6, 2011.

Accessed November 29 2012 from http://naturalresources.house.gov/News/DocumentSingle.aspx?DocumentID=271408

Hutchings, J. A., S. H. M. Butchart, B. Collen, M. K. Schwartz, and R. S. Waples. 2012. Red flags: correlates of impaired species recovery. Trends in Ecology & Evolution 27(10):542-546.

Myers, N., R. Mittermeier, C. Mittermeier, G. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403(6772):853-858.

National Marine Fisheries Service (NMFS). 1991 - 2013. Report to Congress on the recovery of threatened and endangered species: fiscal years 1989-1991, 1992-1994, 1994-1996, 1996-1998, 1998–2000, 2000–2002, 2002–2004, 2004–2006, 2006-2008, 2008-2010, 2010-2012. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.nmfs.noaa.gov/pr/laws/esa/biennial.htm. Accessed 2014 May 09.

Pullin, A. S., and T. M. Knight. 2001. Effectiveness in conservation practice: Pointers from medicine and public health. Conservation Biology 15(1):50-54.

Rudd, M. A. 2011. Scientists' opinions on the global status and management of biological diversity. Conservation Biology 25(6):1165-1175.

Schwartz, M. W. 2008. The performance of the Endangered Species Act. Annual Review of Ecology, Evolution, and Systematics 39:279-299.

Scott, J., and D. Goble. 2005. A database for the ESA. Bioscience 55(4):299-299.

Suckling K., N. Greenwald, and T. Curry. 2012. On Time, On Target. How the Endangered Species Act is saving America's wildlife. Available: http://www.esasuccess.org/report_2012.html. Accessed 2014 May 9.

CHAPTER ONE:

AN EVALUATION OF RECOVERY METRICS FOR SPECIES LISTED UNDER THE U.S. ENDANGERED SPECIES ACT

1.1. ABSTRACT

For legislation designed to protect species at risk of extinction, adaptive management requires there be periodic assessment of whether the instrument is having its desired effect – that species are recovering, and that recovery is due to the instrument. To date, most evaluation of the success of the U.S. Endangered Species Act (U.S. ESA) has been based on species recovery statuses published by the U.S. Fish and Wildlife Service in their biennial reports to Congress. However, there are concerns about quality of these data and, consequently, the validity of any inferences drawn concerning the effect of the U.S. ESA. To evaluate the Biennial Recovery Statuses (BRSs), we surveyed species experts for their opinion of the reliability of the scores, and for their own assessment of species recovery trends. We also collected metrics of species recovery trends developed by the IUCN and NatureServe, and we searched for published estimates (in peer-reviewed literature or government reports) of change in species abundance or range through time. We found that most experts think well of the BRSs, and the BRSs are moderately well correlated to experts' assessments of species recovery. However, the BRSs, the IUCN and NatureServe metrics, and data describing species' recovery trends gleaned from the literature are not strongly correlated with one another. This empirical uncertainty in estimates of recovery limits ability to evaluate the true effectiveness of the U.S. ESA in achieving its stated objectives.

1.2. Introduction

The current decline in biodiversity has been described as a silent epidemic and is one of the most significant environmental threats facing our world (Pimm et al. 1995, Loreau et al. 2001). Conservation biology is in many circumstances a crisis discipline (Soulé 1986). As such, in contrast to other areas of scientific investigation, it can be necessary to take action before the available data is sufficient to justify doing so; and in many situations the risks of non-action may exceed those posed by incorrect action (Soulé 1986). The need to address this crisis is critical: it has been estimated that species are going extinct at 1,000 to 10,000 times the natural background rate (EU Environment Commission 2014), and as a result, an estimated 21,000 known species are faced with imminent extinction (IUCN 2013).

Legislation and policy instruments are one set of tools that are increasingly used to coordinate and regulate actions aimed at conserving biodiversity. For legislation designed to protect endangered species, adaptive management requires periodic assessment of whether the instrument is having its desired effect – that species are recovering, and that recovery is due to the instrument. However, there is no consensus on how effective existing instruments have been. Various indices of species recovery exist (e.g. The International Union for the Conservation of Nature (IUCN) Red List, and NatureServe Conservation Statuses), as do instrument-specific measures (e.g. U.S. Endangered Species Act biennial reports to Congress, and the status assessments of the Canadian Committee on the Status of Endangered Species)); however, the extent to which these measures correlate with actual species recovery is unknown.

1.2.1. The United States Endangered Species Act

Established in 1973, the United States Endangered Species Act (U.S. ESA 1973) is considered one of the most powerful and controversial pieces of environmental legislation, and is one of the oldest instruments to specifically address the conservation of biodiversity

(Abbitt & Scott 2001, Gosnell 2001, Schwartz 2008, Gibbs & Currie 2012). Currently, 1,525 species, sub-species, and distinct populations segments (collectively referred to hereafter as "species") in the United States, its territories and waters are listed under the U.S. ESA (U.S. NMFS 2014). The overall purpose of the U.S. ESA is to provide for the conservation of listed endangered and threatened species, as well their habitats (U.S. ESA sec. 2(b)). To this end, the U.S. ESA mandates two types of actions: those to prevent extinction, and those to promote recovery (defined as the process by which the decline of a listed species is arrested or reversed, or threats to its survival neutralized so that its long-term survival in nature can be ensured (U.S. FWS 2014a)). Because of its long history and the large and diverse group of species listed, the U.S. ESA provides perhaps the best opportunity to evaluate the effectiveness of legislation aimed at conserving endangered species.

1.2.2. U.S. ESA biennial reports to Congress and species recovery statuses

The United States Fish and Wildlife Service (U.S. FWS) and the National Marine Fisheries Service (NMFS) administer the U.S. ESA, and together they systematically report on the recovery status of listed species (Schwartz 2008). Since 1989, these agencies have been mandated with the task of producing a biennial *Report to Congress on the Recovery Status of Endangered and Threatened Species* (U.S. FWS 1990-2012, NMFS 1991-2013). These reports describe progress made in species conservation over the two-year reporting period, and contain information on species' Recovery Plans, listing classification and recovery status. In particular, they contain Biennial Recovery Status (BRS) designations which are qualitative measures of species' recovery trends. A BRS is meant to communicate how U.S. FWS experts interpret a species' overall recovery trajectory since the previous biennial report to Congress. This status classifies a species' recovery trend as either 'Improving', 'Stable', 'Declining', 'Uncertain', 'In Captivity', 'Presumed Extirpated, or 'Presumed Extinct.

To know if the U.S. ESA and the various policies and actions it enables are working, one must be able to assess the extent of recovery of listed species. To date, most evaluations of the success of the U.S. ESA have used metrics based on BRSs as the dependent variable (i.e. outcome of interest). These studies have then assessed the extent to which variation in BRSs is associated with various tools enabled by the U.S. ESA. These analyses have yielded mixed results. For instance, Taylor et al. (2005), Male & Bean (2005) and Kerkvliet & Langpap (2007) all came to various, and at times conflicting conclusions regarding whether recovery trend was significantly related to the tools enabled by the U.S. ESA (e.g. listing period, critical habitat designation, funding, and Recovery Plan status). Gibbs & Currie (2012) found that these tools, combined, explain less than 13 % of the variation in recovery statuses among species, regardless of whether their effects were statistically significant.

The use of BRSs in a number of published studies on the effectiveness of the U.S. ESA (Abbitt & Scott 2001, Hatch et al. 2002, Male & Bean 2005, Taylor et al. 2005, Kerkvliet & Langpap 2007, Gibbs and Currie 2012) notwithstanding, there are concerns about the degree to which BRSs accurately reflect species' population trends. This concern arises from two sources. First, the U.S. FWS in their most recent biennial report to Congress (U.S. FWS 2012), cautions that BRSs are "*a combination of population numbers and threats … relative to the previous reporting year's outcome. It is not a long-term trend, and thus does not necessarily reflect progress towards recovery*". This combination of (a) population trends, and (b) (perceived) trends in threats has several implications, most notably that its utility in assessing actual recovery (in terms of population size or geographical distribution) depends on the extent to which (a) dominates (b) in the index. Secondly, there are concerns about the degree to which the BRSs are objective and systematic. The U.S. FWS has limited resources to devote to species status monitoring (Campbell et al. 2002); therefore species' BRSs will, almost invariably, have considerable uncertainty and may only be based on the best sense of a reviewer (Boersma et al. 2001, Male and Bean 2005). On the other hand, BRSs represent the only comprehensive initiative to describe the recovery trends of most U.S. ESA listed species over a relatively long time period (≤ 20 years). Thus, if the BRSs do reflect species' actual recovery trends (even if imperfectly), they represent a valuable dataset for further investigations into the effect of the U.S. ESA at recovering species.

1.2.3. Study objective

Our objective is to determine how well the BRSs and other indices reflect the recovery of species listed under the U.S. ESA. To do so, we ask:

1. Do species experts feel that trends characterized by the BRSs accurately reflect their own impressions of species recovery trends?
2. How well do BRS trends correlate with assessments of species recovery carried out by other organizations?
3. How well do BRS trends correlate with publicly available quantitative abundance and/or range data describing species recovery trends?

To answer the these questions, we distributed an online questionnaire to experts familiar with particular U.S. ESA listed species to solicit their opinions on the BRSs and species recovery trends. We then compared the BRSs to the qualitative assessments of changes in species recovery status produced by the IUCN and NatureServe. Finally, we compared BRSs to quantitative estimates of species abundance and/ or range size change, obtained from the published literature and a database of species recovery narratives produced over the past several years at the Center for Biological Diversity (Tucson AZ).

1.3. Methods

The average predicted time to delisting from the U.S. ESA for species for which Recovery Plans have been completed is 46 years (Suckling et al. 2012). If the U.S. ESA is capable of promoting species recovery, its effects should, on average, be most pronounced for species listed the longest. For our analyses, we included species listed under the U.S. ESA before 1981, (i.e. species that have been protected for > 30 years). We excluded island endemic species, species that were considered to be extinct before listing and species that have been subsequently delisted due to errors in their original listing decision (U.S. FWS 2014b).

1.3.1. The index of biennial recovery statuses (BRI)

We developed an index of recovery, the Biennial Recovery Index (BRI), using species' BRSs published in the biennial reports to Congress. Following methodology from Male & Bean (2005) and Gibbs and Currie (2012), we assigned a value of -1, 0 or 1 to each status of 'Decreasing', 'Stable' or 'Increasing', respectively. These values were then summed over time to create a scalar index of recovery. Statuses of 'Uncertain', 'In Captivity', 'Presumed Extinct', and 'Presumed Extirpated' were not scored in the index. BRSs from reports published between 1990 and 2010 were considered in the evaluation; thus, the possible range of species' BRI scores is -11 (declining in all reports) to +11 (increasing in all reports). To account for unknown or missing statuses in the datasets, final BRI scores were adjusted by dividing by the proportion of known statuses, such that all scores are based on the same time frame. As done by Gibbs and Currie (2012), this adjustment assumes unknown or missing statuses are on average equal to the known statuses. We, and Gibbs and Currie (2012) tried several variations of this index (e.g., weighting recent assessments more heavily). None materially changed the results we present below.

1.3.2. Expert opinion of the BRI and of species recovery trends

Using FluidSurveys software, an online questionnaire was developed to obtain information from species experts on the recovery trends of listed species (Appendix A). The survey was conducted at the level of individual species and the questionnaire was e-mailed to approximately 250 experts whose coordinates were obtained through a database of species experts maintained by the Center for Biological Diversity, and through additional literature reviews. Permission was obtained from the Deputy Director of the U.S. FWS to distribute the survey to their employees, allowing employees to complete the survey as part of their work activities. The survey was distributed on September 16 2013 and closed December 1 2013. Survey respondents were able to select any of the pre-1981 species to review, and were asked to rate their own knowledge of the conservation and recovery status of their selected species. They were then asked to compare their personal assessment of reviewed species' recovery trend to its set of BRSs and overall BRI score. Comparisons were made on an ordinal scale from -3 to + 3 (with wording *Extremely dissimilar, Dissimilar, Somewhat dissimilar, Neutral, Somewhat similar, Similar, Extremely similar, and Unsure*). We compared the distribution of responses between government vs. non-government employees using a χ^2 test. To do so, three response categories were created: Category 1 = responses of "similar"; Category 2 = responses of "dissimilar" and "neutral"; and Category 3 = responses of "Unsure".

Respondents were also asked to provide an overall rating of their reviewed species' recovery trend since listing, based on an ordinal scale from -3 to + 3 (with wording *Declining sharply, Declining, Declining slightly, Stable, Increasing slightly, Increasing, Increasing sharply*) as well as individual ratings for each decade between 1970 and 2010 (i.e. 1970-1980, 1980-1990, etc.). With these data, two expert opinion indices were created: the first uses the overall rating or the mean of the decadal (1970 to 2010) ratings as a long-term trend; the second uses the mean of the decadal 1990 to 2010 ratings as a short-term trend. Spearman's rank correlations (ρ) were calculated to compare each species' long-term and short-term ratings to its BRI score. For species reviewed by multiple experts, their mean trend was calculated.

1.3.3. Comparison of the BRI to other trend assessments

We also compared the BRI to qualitative trends generated by two large, well-known conservation organizations: the International Union for the Conservation of Nature (IUCN) and NatureServe (NS). We limited our comparison of BRI, NS and IUCN trend assessments to the set of species listed pre-1981 considered in our study. Short-term trends (representing 10 years or 3 generations (whichever is longest)) were extracted from NatureServe's Explorer database (explorer.natureserve.org). Short-term trends are described by NatureServe as the *"degree of past directional change in population size (for species), extent of occurrence, area of occupancy, number of occurrences, and/or viability or ecological integrity of occurrences"* (NatureServe 2013). 'Increasing', 'Stable' and 'Decreasing' trend values were assigned scores of +1, 0 and -1, respectively (NatureServe 2013). Unknown statuses, or statuses overlapping any of the three trend values, were not scored. We then ran a one-way ANOVA using NatureServe trend scores as a fixed factor and BRI scores calculated for the full 1990-2010 period. Population trends were also extracted from IUCN Red List v. 2013.1 assessments (IUCN 2013), which are an indication of the species' current population trend. 'Increasing', 'Stable' and 'Decreasing' trend values were assigned scores of +1, 0 and -1, respectively. Assessments older than 10 years that require updating include a 'needs updating' annotation alongside the Red List assessment. Species with unknown statuses and statuses needing updating were not included in the analysis. We then ran a one-way ANOVA using IUCN trend scores as a fixed factor and BRI scores calculated for the full 1990-2010 period.

1.3.4. Comparison of the BRI to trends in species abundance and range data (Recovery Slope)

We searched for quantitative estimates of changes in species abundance or range size (see Appendix B for metadata). Estimates were obtained from the Center for Biological Diversity who is developing a database of species recovery narratives containing local and population-wide estimates of changes in species population size or occupied range across time (Suckling et al. 2012). These data were obtained through consultations with expert biologists, reviews of U.S. FWS and NMFS documents, grey literature obtained from U.S. FWS and NMFS personnel, consulting agencies, and from the published academic literature. Additional estimates of abundance and range were obtained through literature reviews conducted by a group of undergraduate biology students from the University of Ottawa. Eighteen participants were divided into two groups to search for abundance or range estimates for 54 species for which range and population data were still incomplete or lacking. The first group searched U.S. FWS Recovery Reports and Five-Year Reviews, as well as literature cited in their associated bibliographies. The second group searched grey and published academic literature found through online searches using ProQuest's databases (See Appendix for C for search instructions and search key-words). All extracted data were referenced to a specific document. Within both groups, each species was randomly and anonymously assigned to at least two students to review independently. Students were provided with a database and associated set of metadata (Appendix D), the latter providing explicit instructions on how to codify retrieved abundance and range information and enter these data into their copy of the database. All student copies of the database were returned to the database manager who then compared the independent reviews of the same documents to check for discrepancies. If the independent extractions returned identical data, they were assumed to accurately reflect the content of the corresponding report. Discrepancies were resolved by referring directly to the document in question. When documents retrieved through online searches were reviewed by only one student, the database manager completed the second review.

Using the abundance and range estimates obtained from the various literature sources, a measure of recovery was calculated by fitting the model *log* (*Estimate + 0.5* * [*Minimum*

Estimate]) ~ *Time* for each species' dataset(s) ("*Minimum Estimate*" is the smallest observed estimate of abundance or range size). The regression slope was used as a quantitative estimate of species' recovery trend, termed Recovery Slope (RS). Searches often turned up multiple datasets for a particular species, representing different locations or populations, different measures of abundance or geographical distribution, or different sampling/ enumeration techniques (Appendix B). In such cases, a separate RS was estimated for each dataset.

For each RS, we calculated BRI over the same interval of time. We then regressed matching RS on BRI, weighted by the inverse of the standard error of the RS estimates.

We observed considerable scatter in the relationship between BRI and RS. We therefore tested to what extent concordance between BRI and RS scores (characterized as the square root of the unsigned residual from the RS ~ BRI regression) could be explained by (1) the precision (r^2) of the fitted RS regression, (2) the amount of information used to derive recovery metrics (defined as the number of data points (years) used in the RS calculation, and the number of data points (biennial reports) used in the BRI calculation), (3) whether RS was one of many for the same species, (4) whether the RS estimate was based on temporal changes in abundance versus temporal changes in range, (5) taxonomic designation (birds, fishes, herptiles (amphibians and reptiles), invertebrates, mammals and plants), and (6) a coarse spatial index of species range size (estimated by the number of U.S. states in which the species is present (according to the U.S. FWS ECOS database)).

Finally, NatureServe, IUCN, Expert long-term and short-term recovery measures were matched to species' datasets included in the analysis of the relationship between matching BRI and RS scores, and Pearson or Spearman correlations among pairs of indices were estimated.

Analyses were also conducted using a single RS and BRI score for each species, which were respectively calculated as the mean, weighted by inverse standard error, of a species' set of RSs, and the mean of overlapping BRI scores. Results of the correlations between recovery measures did not change substantially (Appendix E).

1.4. RESULTS

1.4.1. BRI AND EXPERT OPINION OF SPECIES RECOVERY

Fifty-nine completed questionnaires were received from respondents of various professional backgrounds, most of whom were government scientists. Assessments were provided for 42 species. All respondents rated themselves as being knowledgeable about the conservation and recovery status of the species they chose to review. See Appendix F for further characterization of the questionnaire respondents. Of the 33 species experts surveyed who felt confident in comparing their perception of the recovery trend of their selected species to that characterized by the corresponding set of BRSs and the resulting BRI score, most (73 %) felt that the latter provided an adequate representation (Figure 1.1). A comparison of responses from government vs. non-government employees revealed they do not differ significantly (χ^2 p-value = 0.41). Both expert long-term (1970-2010) and short-term (1990-2010) ratings of recovery trends were provided for 29 of the species evaluated in our questionnaire, which were moderately correlated with BRI scores (Table 1.1). For the 11 species reviewed by two experts, we found high intra-class correlation (Raudenbush & Liu 2000) (ICC = 0.78; 95 % CI = [0.40, 0.93]), with 12 % of the total variance in experts' overall recovery ratings attributable to within-species variation.

1.4.2. BRI, IUCN AND NATURESERVE ASSESSMENTS OF SPECIES RECOVERY

Of the 218 species that met the our inclusion criteria, we retrieved short-term trends from the NatureServe Explorer database for 106 species, and IUCN Red List population trends for 64 species. Both institutional assessments showed moderate correlation to BRI (Figure 1.2).

1.4.3. BRI AND RECOVERY SLOPE TRENDS

Time series of abundance and range measures were retrieved for 127 of the 218 species, from across 7 broad taxonomic groups (birds, fishes, herptiles (amphibians and reptiles), invertebrates, mammals and plants). The resulting database includes 205 datasets of 2,983 individual estimates of various indices of abundance and range. Estimates were collected from multiple source types, most often from governmental reports (61%) and journal publications (10%). Estimates were not often found in more than a single publication. In instances where they were, estimates were attributed to the original source. (See Appendix G for further characterization of the sample of abundance and range data.)

Treating each dataset as an individual observation, RS (weighted by the inverse of its standard error) and BRI are weakly positively correlated (r^2 = 0.13; p< $10^{-5;}$ n = 139) (Figure 1.3). To address potential problems associated with multiple datasets per species, we also fitted regression models weighted by ((*1 / number of datasets per species*) * (*1 / SE of RS*)). In this way, each species contributes equivalent amounts of information to the model (essentially 1 "unit" of information as set by (*1 / number of RSs per species*)), weighted by their associated dataset standard errors. The modified regression yields a similar result (r^2 = 0.12; p < 10^{-5}; n = 139). For the 23 species for which we were able to calculate multiple RS scores, we found comparatively low intra-class correlation (Raudenbush & Liu 2000) (ICC = 0.07; 95 % CI = [-0.15, 0.35]), with about 63 % of the total variance attributable to within-species (i.e. among datasets) variation in estimated RS. To address potential issues associated with the assumption that unknown or missing BRSs are on average equal to the known statuses, we also fitted regression models weighted by the proportion of known BRSs out of the number of possible BRSs for the time period of a given dataset. In this way, species' with more complete datasets are weighted more heavily than species with patchy BRS datasets. The modified regression, again, yields a similar result (r^2 = 0.13; p < 10^{-5-}; n = 139).

Concordance between BRI and RS scores was not detectably related to any of the explanatory variables estimating data quality (R^2 of full model = 0.04).

Results of our correlation tests comparing the relationships of NatureServe, IUCN and Expert long and short-term measures of recovery to species' matching BRI and RS scores (Table 1.2) suggest that qualitative BRI relates better to other qualitative measures than they do to quantitative RS, although all correlations are moderate at best. Of the assembled measures, Expert long and short-term assessments relate best to both BRI and RS.

1.5. Discussion

The combined results of our evaluation of species' BRSs published in the biennial reports to Congress paint an unclear picture. Experts view the BRSs positively, and their own assessments of species recovery trends match BRSs reasonably well. BRI is also moderately related to assessments of species recovery made by the IUCN and by NatureServe. However, there appears to be a weak relationship between a species' BRI score and its abundance or range size trend, as estimated by RS.

Because a species' actual recovery trend is unknown, it is impossible to tell whether any of the recovery metrics tested are accurate. Had we found strong relationships among our metrics, we would be confident in asserting that they reflect the same measure of species recovery (or are ultimately based on the same data). However, the fact that we do not find strong correlations is perhaps unsurprising given that each of the compared indices is based on a different scale. In our analyses, both BRI and RS are treated as continuous metrics, whereas the NatureServe, IUCN and Expert Opinion metrics are measured from ordered categorical values. The differences in scales alone lead to weakened correlations.

All of the recovery metrics we examined are subject to some degree of uncertainty. For the sample of species with multiple datasets of abundance or range estimates, almost 63 % of the variation in estimated RSs falls within species groups. Within-species variation in RS could result from differences in the populations, timeframes or sampling methods represented. For example, since RS estimates were calculated to exactly match BRI in time frame, estimates for datasets within a species may not represent the same period of time. As well, for species reviewed by multiple experts, 12 % of the total variation in Expert Opinion indices is within species (i.e. among experts). Thus, depending on the index, there may be considerable imprecision associated with species recovery trends. In combination with the issues caused by differences in scale of the compared metrics, correlations between them all are likely to only be moderate at best.

It is also important to bear in mind that in our analyses, in order to obtain the best possible correlation estimate between the metrics we compared directly, we included as many species as possible for which we had data, and which met our study's inclusion criteria. This means that the sets of species included in each metric comparison differ. For this reason, correlation estimates between sets of metrics are not strictly comparable.

Of the recovery metrics tested, our quantitative RS measure has the advantage of being a direct measure of recovery, as we know precisely what information it reflects. However, for reasons that could range from species' biology (e.g. cryptic behaviour, wide range) to administrative issues (e.g. lack of funding or available personnel), long time series of abundance or range estimates are rare for endangered species (Gerber et al. 1999). Often the data to support population estimates are only infrequently gathered, and for only a portion of the entire population, whose trends may or may not be representative of the species overall (González-Suárez et al. 2012). As such, abundance and range data are often regional or site specific, so that estimates to the entire population or range involve considerable extrapolation. Moreover, there are potential biases associated with selective monitoring (Nakagawa & Freckleton 2008). Not all species are monitored, and those that

are often possess some desirable trait which sets them apart (e.g. wider distributions, diurnal activity, longer life spans) (González-Suárez et al. 2012).

The BRSs have some advantages as an index of recovery. Since their production is mandated by the U.S. Congress, they are, in principle, available for all listed species, allowing broad comparative studies; for example, those examining the effect of general U.S. ESA tools on species recovery trends (Taylor et al. 2005, Kervliet & Langpap 2007, Gibbs and Currie 2012). The information leading to the determination of the BRSs is provided by U.S. FWS field staff who are very knowledgeable about the species in question (Debby Crouse, U.S. FWS, pers. comm.). Finally, the BRSs are intended to reflect species as wholes, rather than component populations.

Of the experts we contacted who provided their opinions of species recovery, comparisons to the BRSs are generally positive, and do not appear to be biased by their area of employment. Interestingly, Expert Opinion indices appear to be reasonably well correlated to both BRI and RS metrics, which could suggest some aspect of the species reviewed in our survey to experts may be related to concordance of BRI and RS metrics. Visual inspection (Appendix F: Table 1) indicates that many of these species are high-profile and well-studied (e.g. California Condor, Gray Wolf, Attwater's Greater Prairie Chicken). When we restrict the linear regression of RS to BRI weighted by the inverse of RS standard error, to only the species reviewed in our survey, their correlation doubles ($r^2 = 0.24$). One explanation for this is that each of the RS, BRI and Expert Opinion metrics for these species could be informed by much of the same data. Many of the species reviewed in the survey are intensively monitored by the U.S. FWS and NMFS; while (a) many of the survey respondents were U.S. FWS or NMFS employees, (b) much of the data used to generate the RS metrics were obtained from U.S. FWS and NMFS sources, and (c) all of the BRSs are created by the U.S. FWS and NMFS. There is a finite pool of empirical data from which all of the metrics evaluated must draw. As such, the extent to which the set of data used to produce each index is similar will determine the correlation. However, since we do not explicitly know what information went into the BRS assessments, we cannot determine how much information overlaps with our retrieved abundance and range data.

As described earlier, much of the discrepancy between metrics likely arises from the difference in their scales; although there are other associated uncertainties. Regarding the correlations of NatureServe and IUCN metrics to BRI, observed correlations could be weakened by the fact that NatureServe and the IUCN metrics may take into consideration trends of species' populations which occur outside the range of the continental U.S. (IUCN 2001, NatureServe 2013). As well, both IUCN and NatureServe metrics take only changes in species' abundance or range estimates (or their proxy) into consideration when assigning recovery trends (IUCN 2013, NatureServe 2013), while the BRSs are intended to reflect changes in population size and/or threat levels (U.S. FWS 2012). Like the BRSs, we do not explicitly know what information went into each of these assessments; thus, we cannot determine how much of their differences are related to these issues.

Regarding the correlation between RS and BRI metrics, it is possible that the BRSs reflect different or additional population or range data than was used to formulate RS, thereby reducing the correlation. Although the vast majority of our abundance and range data were obtained through reviews of government documents (Appendix G: Figures 1 and 2), most of which were published by the U.S. FWS and NMFS, it is possible that grey literature or unpublished data which we could not access in our reviews were used in informing the BRSs. Overcoming publication biases by searching for private or unpublished data is important for any systematic review (Pullin and Knight 2001). It is for this reason that the Center for Biological Diversity has been contacting researchers to assemble species data that are not publicly accessible. However, even if these two metrics were based on the same empirical data, there are a number of factors that might reduce their correlation, including: (a) uncertainty in the RS estimates themselves, as indicated by the associated standard error (b) within-species variation in RS (i.e. variation among different datasets) and the fact that BRI is a species-level score; (c) the fact that BRSs integrate trends in both threats and population abundance, whereas RS is concerned only with the latter; and (d) the possibility that non-biological (i.e. political) considerations may enter into the assigned BRSs.

One major concern with the BRSs is their mixing of both species population numbers and threats in determination of status. The identification of species' threats and the degree to which they are directly impacting recovery is inherently challenging to measure and quantify (e.g. Bolten et al. 2011). Ultimately, the only evidence that some activity or circumstance is threatening a species is its impact on species dynamics. The fact that something is perceived as a threat does not necessarily mean it actually is. As well, the degree to which any inference that some activity or circumstance is a threat to a species is based on strong evidence varies dramatically among threats, as well as among species for a given threat. As a result, determining species' threats and their relative importance is fraught with difficulty (Mace and Lande 1991, Wilcove et al. 1998, Hayward 2009). Therefore, basing BRSs or any other measure of recovery trend on them can lead to incorrect evaluations. Since there is no way of dissecting the BRSs and assigning their statuses to assessments of threats or population information, re-evaluating them in light of new information concerning threats is impossible. It is perhaps for this reason that organizations such as NatureServe and the IUCN produce an evaluation of species population trends separate from a recovery metric that considers threat levels (IUCN 2001, NatureServe 2013). Changes to species abundance or range can be accurately measured, are much less subject to interpretation, and can be assessed not only to the previous assessment, but relative to all other assessments, when aspects such as effort and sampling technique are taken into consideration.

Researchers who, at present, wish to use any of the existing metrics of recovery (BRS, IUCN, NatureServe, etc.) to explore patterns of recovery or test hypotheses concerning factors contributing to, or impeding species recovery, must be aware that their results may well depend critically on which index is used. As such, good practice would be to use multiple indices whenever possible, and to focus on robust patterns or results that are at least qualitatively similar across different metrics.

According to the U.S. FWS, BRSs will no longer be produced in future biennial reports to Congress. The rationale for this decision provided by the U.S. FWS is that, in their view, the BRSs may not necessarily reflect progress towards recovery, and that they have often found them to have been misunderstood or misused (U.S. FWS 2012), albeit (unhelpfully) in unspecified ways. They thus point to the Five-Year Review status recommendations as a better indicator of progress towards recovery (U.S. FWS 2012). The Five-Year Review documents are themselves informative and give an excellent evaluation of the five factors the U.S. ESA requires in consideration of listing and delisting decisions. However, the status recommendations only specify reviewers' opinions regarding uplisting or downlisting species. They are therefore not as useful as a metric describing progress made by species towards their recovery.

We would thus advise the U.S. FWS to reconsider their decision to phase out the BRSs, but rather reformulate them, keeping the following counsels in mind. (1) Any institution with either an interest in, or statutory/ regulatory responsibility for species at risk, be it sub-national, national or international, should establish a reporting procedure that: (a) makes explicit precisely what empirical data were used and who provided them; (b) provides a comprehensive listing of all documents reviewed as part of the analysis; and (c) distinguishes between trends in species abundance and distribution, versus trends in threat profiles (types of threats, severity, etc.). With respect to the latter, threat trends should be based on a standardized classification system, such as the IUCN Threats Classification Scheme (IUCN 2011). (2) Regulatory agencies with responsibility for protection and recovery of endangered species should establish publicly accessible data repositories where the abundance, range and threat data they collect can be deposited, archived, annotated and made publicly accessible, along with the associated metadata. The current cooperative initiative between the Center for Biological Diversity and the U.S. Fish and Wildlife Service - suitably expanded - might serve as a model for such an enterprise.

It is of the utmost importance for endangered species programs to evaluate and adaptively manage their conservation efforts by monitoring species' progress towards recovery (Lindenmayer et al. 2012). This process provides critical data that allows decision makers to take informed actions based on species' responses to management (Campbell et al. 2002) and may therefore better inform the allocation of limited financial and intellectual resources. The U.S. ESA is one of the most important pieces of environmental legislation in existence; as such, the organizations responsible for its implementation should strive to effectively communicate how well it is working.

1.6. Literature Cited

Abbitt, R. J. F., and J. M. Scott. 2001. Examining differences between recovered and declining endangered species. Conservation Biology 15(5):1274-1284.

Boersma P., P. Kareiva, W. F. Fagan, J. A. Clark, and J. M. Hoekstra. 2001. How good are endangered species recovery plans? Bioscience 51(8):643-649.

Bolten, A. B., L. B. Crowder, M. G. Dodd, S. L. MacPherson, J. A. Musick, B. A. Schroeder, B. E. Witherington, K. J. Long, and M. L. Snover. 2011. Quantifying multiple threats to endangered species: an example from loggerhead sea turtles. Frontiers in Ecology and the Environment 9(5):295-301.

Campbell, S., J. Clark, L. Crampton, A. Guerry, L. Hatch, P. Hosseini, J. Lawler, and R. O'Connor. 2002. An assessment of monitoring efforts in endangered species recovery plans. Ecological Applications 12(3):674-681.

Endangered Species Act (U.S. ESA). 1973. Public Law No. 93–205, 87. US statutes at large 884 (Dec.23, 1973). Available http://www.fws.gov/ENDANGERED/esa-library/pdf/ESAall.pdf. Accessed 2014 June 25.

European Union (EU) Environment Commission. 2014. What is biodiversity? Available: http://ec.europa.eu/environment/nature/biodiversity/intro/index_en.htm. Accessed 2014 May 9.

Fish and Wildlife Service (U.S. FWS). 1990 - 2012. Report to Congress on the recovery of threatened and endangered species: fiscal years 1990, 1992, 1994, 1996, 1997–1998, 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007-2008, 2009-2010. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.fws.gov/endangered/esa-library/index.html#recovery. Accessed 2014 May 09.

Fish and Wildlife Service (U.S. FWS). 2012. Report to Congress on the recovery of threatened and endangered species: fiscal years 2009-2010. Washington, (DC): U.S.

Fish and Wildlife Service. Available: http://www.fws.gov/endangered/esa-library/pdf/Recovery_Report_2010.pdf. Accessed 2014 July 01.

Fish and Wildlife Service (U.S. FWS). 2014a. Endangered species glossary. Available: http://www.fws.gov/Midwest/Endangered/glossary/index.html. Accessed 2014 May 09.

Fish and Wildlife Service (U.S. FWS). 2014b. Delisting report. Available: http://www.fws.gov/ecos/ajax/tess_public/DelistingReport.do. Accessed 2014 June 17.

Gerber, L., D. DeMaster, and P. Kareiva. 1999. Gray whales and the value of monitoring data in implementing the US Endangered Species Act. Conservation Biology 113(5):1215-1219.

Gibbs, K. E., and D. J. Currie. 2012. Protecting endangered species: Do the main legislative tools work? Plos One 7(5):e35730.

González-Suárez, M., P. M. Lucas, and E. Revilla. 2012. Biases in comparative analyses of extinction risk: mind the gap. Journal of Animal Ecology 81(6):1211-1222.

Gosnell, H. 2001. Section 7 of the endangered species act and the art of compromise: The evolution of a reasonable and prudent alternative for the Animas-La Plata Project. Natural Resources Journal 41(3):561-626.

Hatch, L., M. Uriarte, D. Fink, L. Aldrich-Wolfe, R. Allen, C. Webb, K. Zamudio, and A. Power. 2002. Jurisdiction over endangered species' habitat: The impacts of people and property on recovery planning. Ecological Applications 12(3):690-700.

Hayward, M. W. 2009. The need to rationalize and prioritize threatening processes used to determine threat status in the IUCN Red List. Conservation Biology 23(6):1568-1576.

International Union for the Conservation of Nature (IUCN). 2001. The IUCN Red List of threatened species: 2001 categories & criteria (version 3.1). Available: http://www.iucnredlist.org/static/categories_criteria_3_1. Accessed 2014 June 30.

International Union for the Conservation of Nature (IUCN). 2011. IUCN-CMP unified classification of direct threats. Available: http://www.iucnredlist.org/documents/June_2012_Guidance_Threats_Classification_Scheme.pdf. Accessed 2014 June 05.

International Union for the Conservation of Nature (IUCN). 2013. The IUCN Red List of threatened species. Version 2013.1. Available: http://www.iucnredlist.org. Accessed 2014 May 09.

Kerkvliet, J., and C. Langpap. 2007. Learning from endangered and threatened species recovery programs: A case study using U.S. Endangered Species Act recovery scores. Ecological Economics 63:499-510.

Lindenmayer, D. B., P. Gibbons, M. Bourke, M. Burgman, C. R. Dickman, S. Ferrier, J. Fitzsimons, D. Freudenberger, S. Garnett, C. Groves, R. Hobbs, R. Kingsford, C. Krebs, S. Legge, A. Lowe, R. Mclean, J. Montabault, H. Possingham, J. Radford, D. Robinson, L. Smallbone, D. Thomas, T. Varcoe, M. Vardon, G. Wardle, J. Woinarski, and A. Zerger. 2012. Improving biodiversity monitoring. Austral Ecology 37(3):285-294.

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, J. Grime, A. Hector, D. Hooper, M. Huston, D. Raffaelli, B. Schmid, D. Tilman, and D. Wardle. 2001. Ecology - Biodiversity and ecosystem functioning: Current knowledge and future challenges. Science 294(5543):804-808.

Mace, G., and R. Lande. 1991. Assessing extinction threats - Toward a re-evaluation of IUCN threatened species categories. Conservation Biology 5(2):148-157.

Male, T. D., and M. J. Bean. 2005. Measuring progress in US endangered species conservation. Ecology Letters 8(9):986-992.

Nakagawa, S., and R. P. Freckleton. 2008. Missing inaction: the dangers of ignoring missing data. Trends in Ecology & Evolution 23(11):592-596.

National Marine Fisheries Service (NMFS). 1991 - 2013. Report to Congress on the recovery of threatened and endangered species: fiscal years 1989-1991,1992-1994,1994-1996, 1996-1998,1998–2000,2000–2002,2002–2004,2004–2006,2006-2008,2008-2010, 2010-2012. Washington, (DC): Fish and Wildlife Service. Available: http://www.nmfs.noaa.gov/pr/laws/esa/biennial.htm. Accessed 2014 May 09

National Marine Fisheries Service (NMFS). 2014. NOAA fisheries: endangered and threatened marine species. Available: http://www.nmfs.noaa.gov/pr/species/esa/. Accessed 2014 May 9.

NatureServe. 2013. NatureServe conservation status. Available: http://explorer.natureserve.org/ranking.htm. Accessed 2014 May 30.

Pimm, S., G. Russell, J. Gittleman, and T. Brooks. 1995. The future of biodiversity. Science 269(5222):347-350.

Pullin, A. S., and T. M. Knight. 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conservation Biology 15(1):50-54.

Raudenbush, S., and X. Liu. 2000. Statistical power and optimal design for multisite randomized trials. Psychological Methods 5(2):199-213.

Schwartz, M. W. 2008. The performance of the Endangered Species Act. Annual Review of Ecology, Evolution, and Systematics 39:279-299.

Soulé, M.E. 1986. Conservation biology and the "real world". In Soulé, M.E. (ed.) Conservation Biology: The Science of Scarcity and Diversity. Sinauer Associates, Sunderland, M.A., 1-12.

Suckling K., N. Greenwald, and T. Curry. 2012. On time, On target. How the Endangered Species Act is saving America’s wildlife. Available: http://www.esasuccess.org/report_2012.html. Accessed 2014 May 9.

Taylor, M., K. Suckling, and J. Rachlinski. 2005. The effectiveness of the endangered species act: A quantitative analysis. Bioscience 55(4):360-367.

Wilcove, D., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. Bioscience 48(8):607-615.

1.7. Tables and Figures

Table 1.1. Spearman rank correlations between Biennial Recovery Index (BRI), Expert long-term (1970-2010) (ExOP Long) and Expert short-term (1990-2010) (ExOP Short) ratings of species recovery (n = 29 species; $p < 10^{-4}$ for all correlations).

Spearman Rank Correlations (ρ)	BRI	ExOP Long
ExOP Long	0.60	
ExOP Short	0.61	0.79

Table 1.2. Pearson correlations (r) or Spearman's rank correlations (ρ) of species' Biennial Recovery Index (BRI), Recovery Slope, NatureServe, IUCN Red List, Expert long-term (1970-2010) (ExOP Long) and Expert short-term (1990-2010) (ExOP Short) assessments of species recovery. Sample sizes are presented below correlations in parentheses (* p < 0.05; ** p < 0.01; *** p < 0.001).

	Recovery Slope	**BRI**	**IUCN**	**Nature Serve**	**ExOP Long**	**Correlation Metric**
BRI	0.30 *** (145)					r
IUCN	0.11 (69)	0.38 ** (69)				r
NatureServe	0.13 (83)	0.62 *** (83)	0.53 *** (39)			r
ExOP Long	0.51 ** (36)	0.70 *** (36)	-0.11 (28)	0.38 (24)		ρ
ExOP Short	0.53 ** (29)	0.71 *** (29)	-0.12 (23)	0.47 * (23)	0.86 *** (29)	ρ

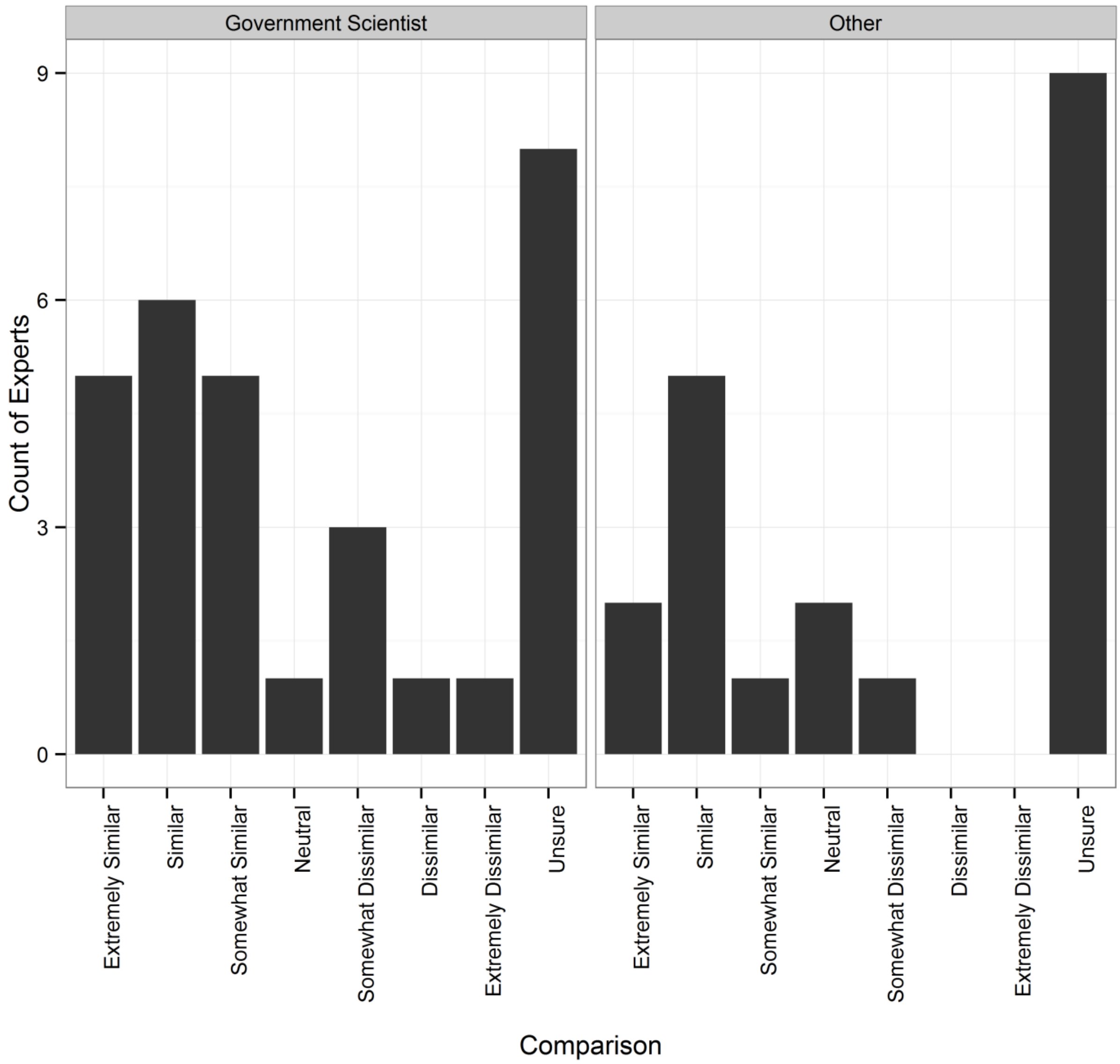

Figure 1.1. Experts' comparisons of personal opinions of species recovery trend to their set of Biennial Recovery Statuses (BRSs), grouped by respondent employment area ("Other" = academia, private sector, non-governmental organization and unspecified; N = 50).

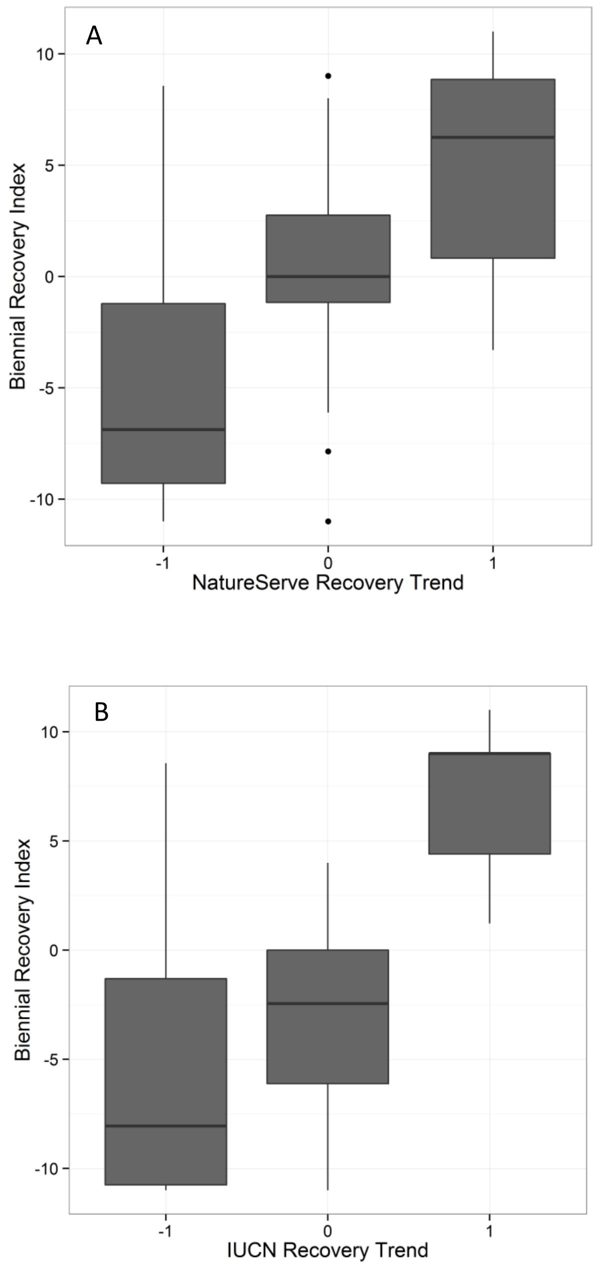

Figure 1.2. Box-plots illustrating the relationship between Biennial Recovery Index (BRI) and NatureServe (A) and IUCN Red List (B) assessments of species recovery trend (A: n = 106, ANOVA $r^2 = 0.37$; B: n = 64, ANOVA $r^2 = 0.49$. Both results are highly significant ($p < 10^{-10}$)).

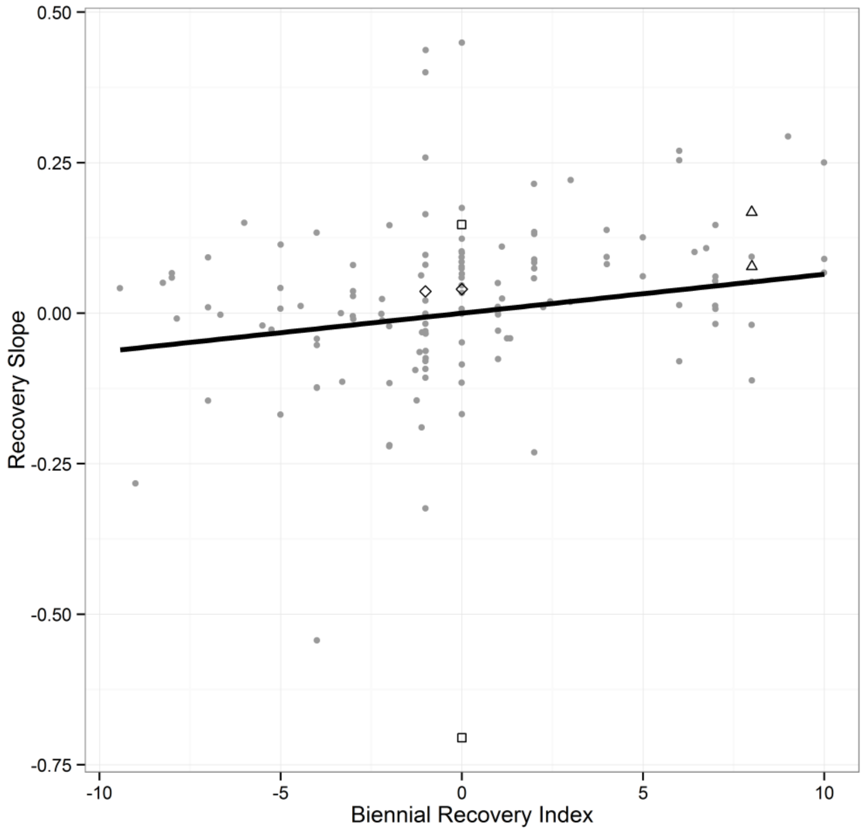

Figure 1.3. Linear regression of matching Biennial Recovery Index (BRI) to Recovery Slope (RS) scores, weighted by the inverse standard error of the RS. Both scores are calculated for overlapping time intervals in each species' dataset(s) ($n = 139$; $r^2 = 0.134$; $p < 10^{-6}$). To illustrate the variability in RS scores describing the same species, the points of the maximum (□), the minimum (◊), and the median (Δ) intra-specific variation in RS are presented.

CHAPTER TWO:

CORRELATES OF SPECIES RECOVERY UNDER THE U.S. ENDANGERED SPECIES ACT

2.1. ABSTRACT

This study aims to establish whether there are detectable associations between recovery trends of species listed under the U.S. Endangered Species Act (U.S. ESA) and either the threats to which they are exposed or the general tools and targeted actions that have been implemented to support their recovery. We characterized species recovery trends with respect to the recovery statuses published in the U.S. ESA biennial reports to Congress, as well as to estimates of changes in abundance or range size based on data extracted from peer-reviewed literature and government reports. We found that detected associations between species recovery and conservation provisions of the U.S. ESA differ depending on which metric is used to characterize recovery. Nevertheless, changes in species abundance or range size, and biennial recovery status trends were both positively related to mean annual funding and a bibliographic index of the amount of published information on the species. Species abundance and range trends were also moderately related to threats and recovery actions, although they varied considerably by taxonomic group. Our results show that conclusions about inter-specific variation in recovery and its relationship with hypothesized drivers depend critically upon the metric employed to estimate species recovery trends. Improved monitoring data evaluating species recovery and responses to their threats and recovery actions is needed to ensure that studies such as ours can provide useful insight and direction for species conservation.

2.2. Introduction

In response to the threat of global biodiversity loss, jurisdictions the world over have implemented legislation and policy instruments aimed at recovering endangered and threatened species in attempt to coordinate and manage efforts to combat extinction. Due to the urgency of the looming extinction crisis (Myers et al. 2000) and the limited resources available to counter it, a critical issue is determining which activities are endangering species and which elements of existing statutory, regulatory and policy instruments are most effective in bringing about recovery.

The United States Endangered Species Act (U.S. ESA 1973) is one of the oldest existing statutory instruments to protect species at risk of extinction (Boersma et al. 2001, Schwartz 2008). The recovery of endangered and threatened species, defined as "*the process by which the decline of an endangered or threatened species is arrested or reversed, or threats to its survival neutralized so that its long-term survival in nature can be ensured*" (U.S. FWS 2014a) is often cited as the ultimate purpose of the U.S. ESA (Clark 1996, Schwartz 2008, U.S. FWS 2013).

Other statutes protecting species at risk of extinction also consider recovery a key element of success. For example, the Canadian Species at Risk Act (SARA 2002) aims to *"provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity"*. Similarly, Australia's Environment Protection and Biodiversity Conservation Act (EPBC 1999) recognizes that in order to achieve its objectives the Act must include provisions to *"prevent the extinction, and promote the recovery, of threatened species".*

If species recovery is an explicit objective of these statutes (as well as their associated regulations and policies), an obvious metric for judging success is the extent to which they have in fact contributed to recovery. Any such assessment requires that the extent of species recovery first be determined. Only then can we begin to determine which activities or circumstances are associated with species declines, and which conservation actions are associated with their recovery.

2.2.1. Past attempts to determine correlates of recovery under the U.S. ESA

Previous attempts at assessing determinants of recovery for species listed under the U.S. ESA have used the Biennial Recovery Statuses (BRSs) as a proxy measure of recovery. These qualitative statuses (increasing/ stable/ decreasing) are published in the biennial *Reports to Congress on the Status of Endangered and Threatened Species* by the U.S. Fish and Wildlife Service (U.S. FWS) and National Marine Fisheries Service (NMFS) (U.S. FWS 1990-2012, NMFS 1991-2013). BRSs provide a qualitative index of species recovery trends over a two year period, and, when integrated over a longer period, in principle provide a description of a species' overall recovery trajectory. BRSs are available every two years for the period 1990-2010, but their publication has since been discontinued; in the view of the U.S. FWS, the BRSs may not reflect progress towards recovery, and there is concern that they have been misunderstood or misused (U.S. FWS 2012), albeit in unspecified ways.

Abbitt and Scott (2001) conducted one of the earliest attempts to relate species recovery trends to specific threats and recovery actions taken under the U.S. ESA. In their study, recovering species were identified as those delisted and downgraded to a lower threat level, or those proposed for such action, while declining species were identified according to their 1999 BRS. They found recovering and declining species to be associated with different sets of threats, suggesting that threats facing recovering species are perhaps easier to mitigate. Recovering species were also more likely to have more completed recovery objectives (as specified in the corresponding Recovery Plan).

Subsequent studies have related species recovery, again defined by BRSs, to the tools broadly related to U.S. ESA listing. Taylor et al. (2005) found that recovering species had been listed longer, were more likely to have had critical habitat designated, and were more likely to have had dedicated Recovery Plans (as opposed to multi-species or ecosystem plans) compared to species that were not recovering. Male and Bean (2005) also found species' BRSs to improve over time and to differ among taxonomic groups, with birds and mammals having the fewest species in decline. They also found greater U.S. FWS and NMFS funding to be correlated with improving recovery status. Kerkvliet and Langpap (2007) showed that recovering species were more likely than declining species to have approved Recovery Plans and, on average, a greater number of achieved recovery objectives. In contrast to Taylor et al. (2005), they found no detectable effect of critical habitat once species' funding was considered. Most recently, Gibbs and Currie (2012) found that species recovery was positively related to the number of years listed under the U.S. ESA, time since publication of their first Recovery Plan, and the magnitude of combined federal and state-level funding. None of these variables had much predictive value, however. Combined they explained less than 13 % of the variation in recovery trends among species.

Other studies have also examined the frequency with which various nominal threats (e.g. habitat destruction, overexploitation) are attributed to species declines, across or within taxonomic groups (Wilcove et al. 1998, Czech et al. 2000, Lawler et al. 2002). However, threats that are most pervasive may not necessarily be the most important for distinguishing improving vs. declining recovery trends.

In principle, quantitative data on population or range trends would be preferable to BRSs. However, population estimates, as well as information on species' threats and actions taken to promote their recovery, are dispersed throughout government reports, academic publications, and online databases – when they are published at all. Unlike other areas of research, there have been few successful attempts to systematically gather information from diverse sources and build a repository of the causes, treatments, and outcomes for endangered species and their conservation (Pullin & Knight 2001, Pullin & Knight 2009).

Although several researchers have conducted detailed evaluations of the threats and recovery actions for individual species listed under the U.S. ESA (e.g. Bolten et al. 2011, Darst et al. 2013), the sheer number of listed species combined with existing (and likely future) resource constraints means that such detailed analyses will be available for only a fraction of listed species. As an alternative approach, analyses conducted at a broad scale across multiple species may be useful in characterizing empirical associations between, on the one hand, species recovery trends, and threats and conservation actions on the other.

2.2.2. Study objective

Here we evaluate the extent to which recovery trends of species listed under the U.S. ESA are related to: A) the set of activities that put them at risk; or B) the general tools and targeted actions intended to promote their recovery. With opinion divided on the suitability of the BRSs as a metric of recovery, we also used trends in species' quantitative abundance or range size data as an alternative metric. Using both metrics, we re-evaluated the models developed by Gibbs and Currie (2012) to explore associations between species recovery and the tools related to U.S. ESA listing, which allowed us to determine whether results were consistent across measures of recovery. We also examined associations between species' abundance and range trends and their threat and recovery action profiles.

2.3. Methods

For inclusion in our study, we considered species, subspecies and distinct population segments (hereafter referred to as "species") listed under the U.S. ESA before 1981. We excluded island endemic species, species that are believed to have gone extinct before listing and species that have been subsequently delisted due to errors in their original listing decision (U.S. FWS 2014b).

2.3.1. The index of biennial recovery statuses (BRI) and trends in species abundance and range data (Recovery Slope)

We developed an index of recovery, the Biennial Recovery Index (BRI), using species' BRSs published in the biennial reports to Congress. Following methodology from Male & Bean (2005) and Gibbs and Currie (2012), we assigned a value of -1, 0 or 1 to each status of 'Decreasing', 'Stable' or 'Increasing', respectively. These values were then summed over time to create a scalar index of recovery. Statuses of 'Uncertain', 'In Captivity', 'Presumed Extinct', and 'Presumed Extirpated' were not scored in the index. BRSs from reports published between 1990 and 2010 were considered in the evaluation (U.S. FWS 1990-2012, NMFS 1991-2013); thus, the possible range of species' BRI scores is -11 (declining in all reports) to +11 (increasing in all reports). To account for unknown or missing statuses in the datasets, final BRI scores were adjusted by dividing by the proportion of known statuses, such that all scores are based on the same time frame (Gibbs and Currie 2012). This adjustment assumes that the probability of increasing, stable or decreasing status is the same among missing statuses as among known statuses.

We searched for quantitative estimates of changes in species' abundance or range size as an alternative to the BRI (see Appendix B for metadata). Abundance and range size data were obtained from the Center for Biological Diversity (Tucson, AZ), who are currently developing a database of species recovery narratives containing local and population-wide estimates of changes in species' population size and occupied range across time (Suckling et al. 2012). They obtained these data from consultations with species biologists, reviews of U.S. FWS and NMFS documents, relevant grey literature obtained from U.S. FWS and NMFS personnel, consulting agencies, and from the published academic literature.

Additional estimates of abundance and range were obtained through literature reviews conducted by a group of undergraduate biology students from the University of Ottawa. Eighteen participants were divided into two groups to search for abundance or range estimates for 54 species for which range and population data were still incomplete or lacking. The first group searched U.S. FWS Recovery Reports and Five Year Reviews, as well as literature cited in their associated bibliographies. The second group searched grey and published academic literature found through online searches using ProQuest's databases (See Appendix for C for search instructions and search key-words). All extracted data were referenced to a specific document. Within both groups, each species was randomly and anonymously assigned to at least two students to review independently. Students were provided with a database and associated set of metadata (Appendix D), the latter providing explicit instructions on how to codify retrieved abundance and range information and how to enter these data into their copy of the database. All student copies of the database were returned to the database manager who then compared the independent reviews of the same documents to check for discrepancies. If the independent extractions returned identical data, they were assumed to accurately reflect the content of the corresponding report. Discrepancies were resolved by referring directly to the document in question. When documents retrieved through online searches were reviewed by only one student, the database manager completed the second review.

Using the abundance and range estimates obtained from the various literature sources, a measure of recovery was calculated by fitting the model *log* (*Estimate + 0.5* * [*Minimum Estimate*]) ~ *Time* for each species' dataset(s) ("*Minimum Estimate*" is the smallest observed estimate of abundance or range size). The regression slope was used as a quantitative estimate of species recovery trend, termed Recovery Slope (RS). Searches often turned up multiple datasets for a particular species, representing different locations or populations, different measures of abundance or geographical distribution, or different sampling/ enumeration techniques (Appendix B). In such cases, a separate RS was estimated for each dataset.

Abundance and range datasets were examined to assess monotonicity of temporal trends. Of 205 datasets retrieved for 127 species (see Appendix G for characterization of species' abundance and range data), 63 had sufficient sample size (number of observations) to include a $Time^2$ term in the model fitting exercise and still have some confidence in estimated model parameters. Of these, eight displayed clear non-monotonic trends. In these eight cases, regression estimates of time trends were based on the most recent subset of the data for which the time trend was considered approximately linear (see example in Appendix H).

2.3.2. U.S. ESA TOOLS MODELS

We tested for associations between Recovery Slope (RS) and U.S. ESA tools, based on data obtained from Gibbs and Currie (2012). These data included: species' mean annual funding (based on all federal and state funding) calculated from annual expenditure reports to Congress from 1989 – 2004; a peer-reviewed information metric defined as the number of studies found from a July 2007 Web of Science search of each species' scientific name; whether (Yes or No) critical habitat had been designated by 2013; taxonomic designation (birds, fishes, herptiles (amphibians and reptiles), invertebrates, mammals, and plants); number of years elapsed since U.S. ESA listing to 2013; the number of years elapsed since the current Recovery Plan was published to 2013; and the number of years elapsed since the original Recovery Plan was first published to 2013. Both mean annual funding and the information metric were natural-log transformed. For full variable descriptions, see Appendix I.

Two different RS estimates were related to the U.S. ESA tools. RS_1 is based on abundance or range data collected from 1989 to 2010, corresponding to the set of years for which BRSs are available. For the same set of species, RS_2 is based on abundance and range data collected since the year of listing under the U.S. ESA up until 2013. For comparison, we also fit models using BRI as the dependent variable. Models of all possible linear combinations of the U.S. ESA tools variables were fit and assessed on the basis of Akaike's Information Criterion (AICc) scores.

To evaluate potential biases associated with attributes of the time series, we examined whether model fit (estimated by R^2) depended on the length (number of observations) of RS datasets included in our U.S. ESA tools models. We found that inclusion of datasets with fewer than seven observations resulted in a marked declined in model fit. Therefore, only datasets with seven or more observations were included in the analysis (see supporting material in Appendix J), resulting in U.S. ESA tools models being fit to 101 abundance and range datasets for 71 species.

2.3.3. Threats and recovery actions models

Information on threats and recovery actions was obtained through reviews of species' U.S. FWS and NMFS documents (Recovery Plans, Recovery Plan Action Statuses, Five Year

Reviews, Federal Register Listing Decisions, and/or Post-Delisting Monitoring Reports), again conducted with assistance from a group of forty-four undergraduate biology students from the University of Ottawa, following the same procedure as described above. See Appendix K for database variables and associated metadata.

Threats were categorized according to the International Union for the Conservation of Nature (IUCN) Threats Classification Scheme, Version 3.1 (IUCN 2011, Salafsky et al. 2008). Each of the 11 tier-1 threat categories (*Residential & Commercial Development, Agriculture & Aquaculture, Energy Production & Mining, Transportation & Service Corridors, Biological Resource Use, Human Intrusions & Disturbance, Natural Systems Modifications, Invasive & Other Problematic Species, Genes & Diseases, Pollution, Geological Events, and Climate Change and Severe Weather*) were coded as follows: 1 = reviewed documents state explicitly that the species has been exposed to the threat; 0 = reviewed documents state explicitly that the species has not been exposed to the threat or that the threat is insignificant, or there is no explicit mention of the threat whatsoever. Thus, for a particular species, if a threat is not mentioned, the threat is considered effectively absent (see Appendix K for full descriptions). Threat profiles occasionally varied among documents for a given species: in the case of conflict, the characterization from the most recently published document was used.

Recovery actions were also classified according to a system based on the IUCN Conservation Actions Classification Scheme (IUCN 2013, Salafsky et al. 2008). Two general classes of recovery actions were distinguished: those involving threat reduction (broadly construed), and those involving population augmentation. Thirteen binary threat reduction variables were scored (1 = reviewed documents state explicitly that the action has been taken; 0 = reviewed documents state that the action has explicitly not been taken or there was no explicit mention of the action being taken) relating to habitat modification, pollutant emissions and releases, invasive or problematic species, and commercial or recreational exploitation. Seven binary population augmentation variables (e.g. reintroduction, captive breeding) were also coded by reviewers (1 = reviewed documents state explicitly that the action has been taken; 0 = reviewed documents state that the action has explicitly not been taken or there was no explicit mention of the action being taken; see Appendix K for full description of variables and associated metadata). Conflicts in the characterization of species' recovery actions profiles were resolved following the same procedure as described above.

Any timing and duration attributes of threats and recovery actions were not distinguished because reviewed documents often simply did not provide sufficiently unambiguous information on these attributes. For the same reason, we did not attempt to distinguish between major or minor threats. While this simplification increases the reliability of data extraction, it reduces the likelihood of detecting associations with recovery status, particularly for recovery actions: for example, actions that were initiated some time ago are more likely to have had appreciable effects on recovery than those implemented only recently, all else being equal.

We fit models relating RS_2 to species' threats and recovery actions, excluding datasets with fewer than seven observations. As a result of the longer time frame, more datasets were included compared to our U.S. ESA tools models: 135 abundance and range datasets pertaining to 87 species. Models were fit separately for birds, fishes, mammals and plants, as threats and recovery actions profiles differ substantially by taxonomic group (Appendix L). Due to insufficient sample size, models could not be fit for herptiles and invertebrates.

For each taxon, threats and recovery actions variables for which there were at least seven occurrences of both binary responses within the taxon were considered for model inclusion. All such variables were then ranked according to the strength of their bivariate association with RS_2, defined by the reduction in AICc relative to the null model. The six variables with the strongest bivariate associations were then ranked by their pairwise Spearman's rank correlations to each other. Subsets of the six threats and recovery actions variables were extracted that showed (a) comparatively large bivariate associations with RS_2; and (b) comparatively low within-set correlations. Linear models consisting of these variable subsets were then fit and evaluated on the basis of AICc. Models were further constrained by the condition that $N/p \geq 5$, where N is the total sample size and p is the number of fitted parameters (Bentler & Chou 1987), so as to have some confidence in the robustness of the resulting parameter estimates.

2.3.4. Intra-specific variation in Recovery Slope

To estimate the relative size of the within vs. among species variation in RS, we calculated the Intra-class Correlation Coefficient (ICC) for the 23 species with multiple datasets. Because of potential concerns about biases resulting from variation in parameter estimates among multiple datasets for the same species, we repeated our analyses treating species rather than datasets as the unit of observation. For each of the species with multiple datasets, mean RS_1 and RS_2 were calculated by averaging constituent dataset RSs, weighted by the inverse of their standard error. Comparison of models between the two approaches allowed us to assess the extent to which effect sizes of candidate predictors were influenced by the level of analysis.

2.4. RESULTS

For species with multiple datasets, intra-class correlation is large (Raudenbush & Liu 2000) (ICC = 0.20; 95 % CI = [-0.04, 0.48]), with about 45 % of the total variance attributable to within species (i.e. among datasets) variation in RS_2 (similar results for RS_1 were obtained). Intra-class correlations also vary among different taxonomic groups (Table 2.1). These results suggest there is relatively high degree of within-species correlation in RS estimates.

2.4.1. U.S. ESA TOOLS MODELS

Most of the 101 abundance and range datasets (N = 71 species) (Table 2.2) showed an increasing trend since 1989 (median RS_1 = 0.01 $Year^{-1}$, 95 % CI = [-0.01 – 0.04]), whereas most recovery trends estimated using BRI were declining overall (median BRI = -1.10, 95 % CI = [-2.46 – 0.26]). A paired Student's t-test conducted using standardized BRI and species-level RS_1 values (calculated as the difference from sample means in standard deviation units) found a statistically significant difference (paired t = 2.38, df = 71, p = 0.02); indicating species' RS_1 recovery estimates are on average more positive than BRI.

Of 127 candidate RS_1 U.S. ESA tools models, 18 models yielded Δ AICs < 4 (Appendix M), with the overall best model showing a positive association between RS_1 and mean annual funding and a negative association with years since listing (Figure 2.1). Additional predictor variables increased explained variation by ≤ 2 %. As there was no overwhelming support for any one model based on Δ AIC, estimated coefficients were based on model averaging (Figure 2.2) revealing overall moderate model fit (mean pseudo R^2 = 0.20, SD = 0.01).

Models for RS_2 resulted in qualitatively similar results (Appendix N), as did those for mean RS_1 and RS_2, weighted inversely by the associated standard errors (i.e. models estimated at the species rather than dataset level; Appendix O).

Of 127 candidate models using BRI as the response variable, 15 yielded Δ AICs < 4 (Appendix P), with the overall best model indicating positive associations with peer-reviewed scientific information and years since original Recovery Plan publication, and a negative association with Critical Habitat designation (Figure 2.3). Additional predictor variables increased explained variation by ≤ 1 %. Since there was no overwhelming support for any one model based on Δ AIC, estimated coefficients were based on model averaging (Figure 2.4) resulting in overall moderate model fit (mean pseudo $R^2 = 0.24$, SD = 0.03).

Mean annual funding and peer-reviewed scientific information metrics are strongly correlated ($r^2 = 0.60$, $p < 10^{-15}$). As a result, the relative importances of these variables differ greatly in averaged models for BRI and RS. For both recovery metrics, when either mean annual funding or peer-reviewed scientific information metrics was excluded from the set of evaluated models, the other variable showed the strongest association with the recovery metric.

2.4.2. Threats and recovery actions models

The candidate threat and recovery action variables that could be investigated varied substantially among taxonomic groups owing to taxonomic differences in the prevalence of different threats and recovery actions. As a consequence, the best models (Table 2.3), model averaged coefficients and the relative importance of different predictor variables also varied among taxonomic groups (Figure 2.5).

For birds, 10 of 16 candidate models had Δ AICs < 4, with the best overall model showing a negative association between RS_2 and Natural Systems Modifications and positive association with Energy Production and Mining (Table 2.3), with the latter having higher importance (Figure 2.5). For fishes, 8 of 12 candidate models had Δ AICs < 4; however, none of the models were any more informative than the null model. For mammals, 6 of 20 candidate models had Δ AICs < 4, with the best overall model showing a negative association between RS_2 and Natural Systems Modifications and positive association with Species Reintroduction (Table 2.3), with the latter having higher importance (Figure 2.5). Lastly, for plants, 3 of 8 candidate models had Δ AICs < 4, with the best overall model showing a positive association between RS_2 and Species Reintroduction (Table 2.3), which was also shown to have the highest importance of all candidate predictors (Figure 2.5).

See Appendix Q for the results of all threats and recovery actions models tested for each taxonomic group. Models fitted at the species-level (using mean RS_2 weighted inversely by standard error) produced qualitatively similar results for model averaged estimates and their relative importances (Appendix R).

2.5. DISCUSSION

The predictive science of species recovery calls for the identification of generic recovery correlates across many species at risk of extinction (Hutchings et al. 2012). Our study found evidence that the majority of species' abundance or range data show recovering trends, although the aggregate recovery and threat index data prepared by the US Fish and Wildlife Service is less sanguine. We also found strong positive associations between species recovery and two tools related to U.S. ESA listing: mean annual funding and the amount of peer-reviewed scientific information. However, detected associations with other elements of the U.S ESA differed depending on which recovery metric was employed. Species' threats and recovery actions are also moderately related to their abundance and range trends; profiles of which vary considerably by taxonomic group.

2.5.1. U.S. ESA TOOLS MODELS

Our results show that conclusions about inter-specific variation in recovery under the U.S. ESA, as well as detected associations with its possible determinants, depend upon the metric employed to estimate species recovery trends. This should give researchers pause when assessing the evidentiary support for claims that the U.S ESA is or is not effective. For example, if one uses delisting from the U.S. ESA as the metric of recovery, a threshold delisting rate could be established below which one might conclude that the U.S. ESA is indeed ineffective (e.g. Pombo 2004). By contrast, if one uses temporal trends in abundance or range, a different picture emerges (e.g. Suckling et al. 2012). So given a set of candidate metrics, researchers are obliged to consider which one(s) are most appropriate, given the question(s) of interest, and be explicit about their rationale for metric choice. And if, as Hutchings et al. (2012) point out, an important element of an endangered species research program is the identification of correlates of species recovery, and if (as we have shown here) the choice of metric determines the set of detected correlates and the inferences drawn therefrom, clear rationales for metric choice, and explicit consideration of the advantages and shortcomings of all metrics, becomes particularly important.

As originally designed, the BRS incorporates two important dimensions of recovery: trends in species' population numbers and threats (U.S. FWS 2012). In principle, these should be negatively correlated: as the number, magnitude or extent of threats decline, population numbers should increase. But this will occur only if threats have been accurately characterized in the first instance – that is, if the factors that were considered to be drivers of population decline or range contraction are indeed the current limiting factors (Darst 2013).

The integration of threat and population trends in the BRI is one obvious explanation for the discrepancy between results based on the two metrics: clearly, RS is concerned only with trends in range or abundance. But more importantly, including both threat and population trend information in a composite score precludes the possibility of testing hypotheses (or examining associations) concerning, for example, the effectiveness of different threat mitigation approaches on species recovery. Using the approach adopted here and by others (e.g. Male and Bean 2005, Gibbs and Currie 2012), these sorts of hypotheses would only be testable if, for a sample of species, independent evaluations of threat trends and population trends were available. Thus, here we did not fit threats and recovery actions models to BRI simply because BRI takes into consideration changes in perceived threats or their management in status designations (U.S. FWS 2012). There is then by definition an association between predictor and response variables in any such models. Given these issues, we believe that the U.S. FWS should seriously consider revising its evaluation system such that trends in both threats and population numbers are scored independently, using independent data sources.

Notwithstanding their differences, we did find qualitatively similar positive associations of mean annual funding, and the bibliographic index of the amount of published information on the species to recovery for both metrics. The positive association found between funding and recovery is consistent with previous research (Male & Bean 2005, Kerkvliet & Langpap 2007, Gibbs & Currie 2012). Since funding appears to be a key tool for promoting recovery, we would expect the U.S. FWS and NMFS to be concerned about the efficiency and equality with which it is distributed. However, Schwartz (2008) found a 1,000-fold difference in federal and state spending between the 10^{th} and 90^{th} percentile species in funding rank for the year 2004. If financial resources are limited, yet recovery depends on the resources invested in recovery, the allocation of resources among species will be a key factor in determining whether species recover. Regarding the positive association with peer-reviewed scientific information, greater knowledge of species' biology and their threats has been suggested in past studies as one way to improve U.S. FWS and NMFS Recovery Plans (Clark et al. 2002). It is possible that this result reflects such a relationship, where greater information available for a species allows more informed management decisions to be taken. Given that the information metric and mean annual funding are strongly correlated, it is possible that some of the funding goes towards research which provides more information on species; making their effects on recovery trend hard to distinguish. Taken together, these results suggest that the successful recovery of species will require considerable investment into determining what actions or circumstances are causing species declines, and how to mitigate or compensate for them. Without such investment, conservation actions are less likely to be effective. This finding supports the call made by Scott and Goble (2005) for the establishment of a national database of actions taken under the U.S. ESA for each species, which would be a cost-effective tool for species recovery and would result in better informed policymakers and researchers.

Detected associations with other elements of the U.S ESA are as follows. Our results show a negative association between time since U.S. ESA listing and species recovery, as defined by trends in their abundance or range data. This result contradicts several previous studies (Male and Bean 2005, Taylor et al. 2005, Gibbs and Currie 2012), and is possibly due to our consideration of species limited to pre-1981 listing. Relative to species listed later in the 1970's it is possible that species listed earliest under the U.S. ESA have faced a greater challenge to increase in abundance or range since listing. This may not be reflected in BRI for the same set of species due to its inclusion of threat considerations in recovery status.

We found a positive relationship between years since original Recovery Plan publication and BRI, as did Gibbs and Currie (2012). Recovery Plans are central to the recovery planning process and must describe site-specific management actions the authors consider necessary for species to achieve recovery, define objective criteria against which species recovery will be measured, and estimate time and costs necessary to complete recommended actions (Hoekstra et al. 2002). Both the completion of recovery actions and the effects thereof require time, which may be responsible for the positive association found.

Critical habitat designation was negatively associated with BRI and weakly positively associated to RS, which is consistent with past research using the BRSs that did not find strong positive effects of critical habitat on species recovery (Male & Bean 2005, Kerkvliet & Langpap 2007, Gibbs & Currie 2012). Do these results mean that critical habitat does not positively influence recovery? Not necessarily - critical habitat designation will have a positive effect on species recovery only if (a) critical habitat designation actually results in its protection; and (b) the loss or degradation of critical habitat is a major cause of the species' decline or lack of recovery in the first instance. For species for which critical habitat is not currently the major problem, its protection is unlikely to have a detectable effect before its other major causes of impairment (e.g. exploitation, invasive species, etc.) are addressed.

2.5.2. THREATS AND RECOVERY ACTIONS MODELS

Our decision to exclude threat and recovery action variables for which there was insufficient representation of each binary response resulted in the elimination of variables that were very common within taxonomic groups. This could have eliminated threats or recovery actions that were most related to species recovery trends, with remaining variables exhibiting comparably weaker effects. Had sample sizes of species within taxonomic groups been larger we would likely not have had to eliminate so many variables from consideration. Overall, most threats included in models show a negative association with species recovery trends, while most recovery actions show a positive association. There are instances where threats are associated with a positive recovery trend, which could indicate that negative impacts of the threat have been successfully mitigated for the species reviewed, such that they can exhibit greater increases in abundance or range size. Likewise, several recovery actions are associated with negative recovery tends. This does not imply that actions are responsible for species declines or are completely ineffective; but could indicate that, over all species to which they are applied, they are insufficient to compensate for the activities or circumstances causing species declines. As well, given the amount of measurement error and uncertainty in all such data, even relationships that are causally strong will be statistically weak. This means that the probability of detecting even moderately strong relationships will be small. Consequently, this scale of analysis is useful only for identifying associations which can subsequently be investigated at finer resolutions, where uncertainty and measurement error is, presumably, smaller.

Threat reduction actions appear less able to distinguish between species recovery trends than population augmentation actions and threats. We tested whether an interaction existed between threat categories with targeted threat reduction actions (e.g. the Pollution threat category, with targeted recovery actions of Elimination or Reduction of Point Source and Non-Point Source Pollution) which could be hiding their effects. We did not find strong evidence of interactions in our data (Appendix S). Given our study’s small sample size, the large variation in species’ threats and recovery action profiles, and coarseness of the threat and recovery action categories, it is not surprising we found little evidence of strong interactions.

2.2.3. Important Caveats to Take Into Consideration

When interpreting our results, there are some important caveats to consider associated with the data we have used:

1. A recovery metric is only as good as the data upon which it is based (Male et al. 2006). Measures of species recovery (even those that truly reflect trends) almost certainly have considerable uncertainty for many species. Thus, the extent to which the factors identified as being related to recovery (or lack thereof) depends wholly on the extent to which the recovery metrics used capture species' trends.

2. The set of species included in our study is not a random sample. We searched for abundance or range data for species listed pre-1981 under the U.S. ESA as a means of restricting our search effort, and because if the U.S. ESA is in fact capable of promoting species recovery, its effects should on average be most pronounced for species that have been listed the longest. The resulting set of species is biased by our requirement for sufficient quantitative data describing changes in abundance or range through time, which are rare for endangered species (Gerber et al. 1999).

3. Since the species examined in our study are all listed pre-1981, their threat profiles are almost certainly coloured by the environmental issues deemed most important of the 1960's and 1970's; for example, the effects of pesticides on birds of prey and the exploitation of marine mammals. As well, early-listed species were often charismatic species with greater political influence (Ferraro et al. 2007). The amount of protection they are afforded by their listing (e.g. funding, number of recovery actions taken) may, therefore, be atypical of U.S. ESA listed species in general.

4. Finally, the attributions of species' threats and recovery actions are based on publications by species experts employed by the U.S. FWS and NMFS. However, as has been noted in past studies (Wilcove et al. 1998, Lawler et al. 2002), their attribution of threats may not always be based on experimental evidence or even quantitative data, which often do not exist (Darst et al. 2013).

To date, the quantification and prioritization of threats and recovery actions has received inadequate attention in most species' U.S. FWS and NMFS Recovery Plans (Clark et al. 2002). Continued investigation of the correlates of successful species recovery can help to identify actions with the greatest impact. With the growing list of species in need of attention, results from studies such as ours may become increasingly important for guiding conservation actions. Improved monitoring data evaluating species' recovery trends and responses to their threats and conservation measures is needed to ensure that such studies can provide useful insight and direction.

2.6. LITERATURE CITED

Abbitt, R. J. F., and J. M. Scott. 2001. Examining differences between recovered and declining endangered species. Conservation Biology: 15(5):1274-1284.

Bentler, P., and C. Chou. 1987. Practical issues in structural modeling. Sociological Methods & Research 16(1):78-117.

Boersma P., P. Kareiva, W. F. Fagan, J. A. Clark, and J. M. Hoekstra. 2001. How good are endangered species recovery plans? Bioscience 51(8):643-649.

Bolten, A. B., L. B. Crowder, M. G. Dodd, S. L. MacPherson, J. A. Musick, B. A. Schroeder, B. E. Witherington, K. J. Long, and M. L. Snover. 2011. Quantifying multiple threats to endangered species: an example from loggerhead sea turtles. Frontiers in Ecology and the Environment 9(5):295-301.

Clark, J. R. 1996. Overview of the legislative mandates and the agencies responsible for implementation of southern sea otter protection under the Endangered Species Act. Endangered Species UPDATE 13(12):28-30.

Clark, J., J. Hoekstra, P. Boersma, and P. Kareiva. 2002. Improving U.S. Endangered Species Act recovery plans: Key findings and recommendations of the SCB recovery plan project. Conservation Biology 16(6):1510-1519.

Czech, B., P. Krausman, and P. Devers. 2000. Economic associations among causes of species endangerment in the United States. Bioscience 50(7):593-601.

Darst, C., P. Murphy, N. Strout, S. Campbell, K. Field, L. Allison, and R. Averill-Murray. 2013. A strategy for prioritizing threats and recovery actions for at-risk species. Environmental Management 51(3):786-800.

Endangered Species Act (U.S. ESA). 1973. Public Law No. 93–205, 87. US Statutes at large 884 (Dec.23, 1973). Available http://www.fws.gov/ENDANGERED/esa-library/pdf/ESAall.pdf. Accessed 2014 June 25.

Environment Protection and Biodiversity Conservation Act (EPBC), 1999. Australian

Government, Office of Legislative Drafting and Publishing (OLDP), Canberra. Available: http://www.comlaw.gov.au/details/c2013c00301. Accessed 2014 June 25.

Ferraro, P. J., C. McIntosh, and M. Ospina. 2007. The effectiveness of the US Endangered Species Act: An econometric analysis using matching methods. Journal of Environmental Economics and Management 54(3):245-261.

Fish and Wildlife Service (U.S. FWS). 1990 - 2012. Report to Congress on the recovery of threatened and endangered species: fiscal years 1990, 1992, 1994, 1996, 1997–1998, 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007-2008, 2009-2010. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.fws.gov/endangered/esa-library/index.html#recovery. Accessed 2014 May 09.

Fish and Wildlife Service (U.S. FWS). 2012. Report to Congress on the recovery of endangered and threatened species. Fiscal Years 2009-2010. Available: http://www.fws.gov/endangered/esa-library/pdf/Recovery_Report_2010.pdf. Accessed 2014 July 18.

Fish and Wildlife Service (U.S. FWS). 2013. ESA Basic. 40 Years of conserving endangered species. Available: http://www.fws.gov/endangered/esa-library/pdf/ESA_basics.pdf. Accessed 2014 June 25.

Fish and Wildlife Service (U.S. FWS). 2014a. Endangered species glossary. Available: http://www.fws.gov/Midwest/Endangered/glossary/index.html. Accessed 2014 May 09.

Fish and Wildlife Service (U.S. FWS). 2014b. Delisting report. Available: http://www.fws. gov/ecos/ajax/tess_public/DelistingReport.do. Accessed 2014 June 17.

Gerber, L., D. DeMaster, and P. Kareiva. 1999. Gray whales and the value of monitoring data in implementing the US Endangered Species Act. Conservation Biology 13(5):1215-1219.

Gibbs, K. E., and D. J. Currie. 2012. Protecting endangered species: Do the main legislative tools work? Plos One 7(5):e35730.

Hoekstra, J., J. Clark, W. Fagan, and P. Boersma. 2002. A comprehensive review of Endangered Species Act recovery plans. Ecological Applications 12(3):630-640.

Hutchings, J. A., S. H. M. Butchart, B. Collen, M. K. Schwartz, and R. S. Waples. 2012. Red flags: correlates of impaired species recovery. Trends in Ecology & Evolution 27(10):542-546.

International Union for the Conservation of Nature (IUCN). 2011. IUCN-CMP unified classification of direct threats. Available: http://www.iucnredlist.org/documents/June_2012_Guidance_Threats_Classification_Scheme.pdf. Accessed 2014 June 05.

International Union for the Conservation of Nature (IUCN). 2013. Conservation actions classification scheme (Version 2.0). Available: http://www.iucnredlist.org/technical-documents/classification-schemes/conservation-actions-classification-scheme-ver2. Accessed 2014 June 05.

Kerkvliet, J., and C. Langpap. 2007. Learning from endangered and threatened species recovery programs: A case study using U.S. Endangered Species Act recovery scores. Ecological Economics 63:499-510.

Lawler, J. J., S. P. Campbell, A. D. Guerry, M. B. Kolozsvary, and R. J. O'Connor. 2002. The scope and treatment of threats in endangered species recovery plans. Ecological Applications 12(3):663-667.

Male, T. D., and M. J. Bean. 2005. Measuring progress in US endangered species conservation. Ecology Letters 8(9):986-992.

Male T. D., Walsh S., Bean M. J. 2006. A recovery index: developing a new metric to track endangered species recovery progress. Endangered Species Update 23:62–68

Myers, N., R. Mittermeier, C. Mittermeier, G. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403(6772):853-858.

National Marine Fisheries Service (NMFS). 1991 - 2013. Report to congress on the recovery of threatened and endangered species: fiscal years 1989-1991, 1992-1994, 1994-1996, 1996-1998, 1998–2000, 2000–2002, 2002–2004, 2004–2006, 2006-2008, 2008-2010, 2010-2012. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.nmfs.noaa.gov/pr/laws/esa/biennial.htm. Accessed 2014 May 09.

Pombo, R.W. 2004. Committee on Resources Report – The ESA at 30: A mandate for modernization. Available: http://www.citizenreviewonline.org/april2004/esa.htm. Accessed 2014 August 24.

Pullin, A. S., and T. M. Knight. 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conservation Biology 15(1):50-54.

Pullin, A. S., and T. M. Knight. 2009. Doing more good than harm - Building an evidence-base for conservation and environmental management. Biological Conservation 142:931-934.

Raudenbush, S., and X. Liu. 2000. Statistical power and optimal design for multisite randomized trials. Psychological methods 5(2):199-213.

Salafsky, N., D. Salzer, A. J. Stattersfield, C. Hilton-Taylor, R. Neugarten, S. H. M. Butchart, B. Collen, N. Cox, L. L. Master, S. O' Connor, and D. Wilkie. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conservation Biology 22(4):897-911.

Species at Risk Act (SARA). 2002. Bill C-5, An act respecting the protection of wildlife species at risk in Canada. Available: http://laws-lois.justice.gc.ca/PDF/S-15.3.pdf. Accessed 2014 June 25.

Schwartz, M. W. 2008. The performance of the Endangered Species Act. Annual Review of Ecology, Evolution, and Systematics 39:279-299.

Scott, J., and D. Goble. 2005. A database for the ESA. Bioscience 55(4):299-299.Suckling K., N. Greenwald, and T. Curry. 2012. On Time, On Target. How the Endangered Species Act Is Saving America's Wildlife. Available: http://www.esasuccess.org/report_2012.html. Accessed 2014 May 9.

Suckling K., N. Greenwald, and T. Curry. 2012. On time, on target. How the Endangered Species Act is saving America's wildlife. Available: http://www.esasuccess.org/report_2012.html. Accessed 2014 May 9.

Taylor, M., K. Suckling, and J. Rachlinski. 2005. The effectiveness of the endangered species act: A quantitative analysis. Bioscience 55(4):360-367.

Wilcove, D., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. Bioscience 48(8):607-615.

2.7. Tables and Figures

Table 2.1. Intra-class correlation coefficients (ICC), associated lower and upper 95 % confidence intervals, the proportion of the total variance (Vt) in RS_2 due to intraspecific variation (Vw - among datasets) for each taxonomic group, based on N = 23 species with multiple datasets of ≥ 7 observations.

Taxonomic Group	ICC	V_w/V_t	Number of Species	Number of Datasets
Birds	0.18 [-0.60, 0.96]	57 %	3	7
Fishes	-0.17 [-0.21, 0.51]	98 %	3	17
Herptiles	0.73 [0.23, 0.95]	19 %	6	15
Invertebrates	0.26 [-0.45, 0.96]	57 %	3	8
Mammals	-0.83 [-0.98, 0.16]	94 %	4	8
Plants	-0.05 [-0.26, 0.73]	83 %	4	16

Table 2.2. Breakdown of taxonomic groups included in U.S. ESA general tools and threats and recovery actions (TRAs) models, according to dataset and species counts.

	Dataset Count		Species Count	
	U.S. ESA Tools	**TRAs**	**U.S. ESA Tools**	**TRAs**
Birds	17	26	16	22
Fishes	26	26	12	12
Herptiles	7	-	5	-
Invertebrates	10	-	7	-
Mammals	21	28	19	24
Plants	20	26	12	14

Table 2.3. Best overall threats and recovery actions model coefficients (+ SE) and pseudo-R^2 by taxonomic group, relating to RS_2 calculated at the individual dataset level.

Taxon	Threats and Recovery Actions Variables			Pseudo-R^2
	Energy Production & Mining	Natural Systems Modifications	Species Reintroduction	
Birds	0.07 (0.04)	-0.10 (0.04)	-	0.37
Fishes	-	-	-	0.00
Mammals	-	-0.05 (0.02)	0.06 (0.02)	0.30
Plants	-	-	0.14 (0.05)	0.26

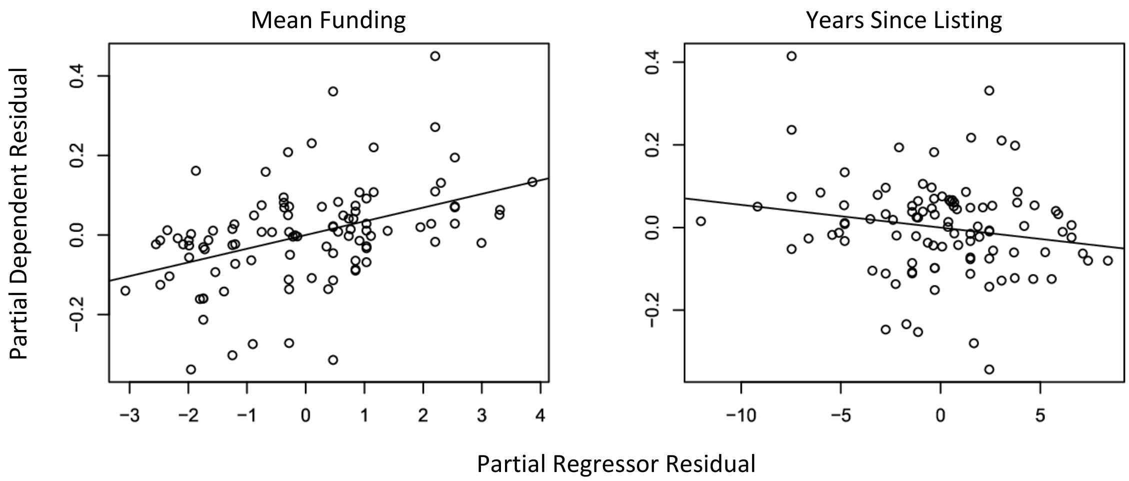

Figure 2.1. Partial plots of variables retained in the best overall U.S. ESA tools model for RS_1, calculated at the individual dataset level, relating to Mean Funding and Years Since Listing (N = 101). Solid lines show fitted slopes.

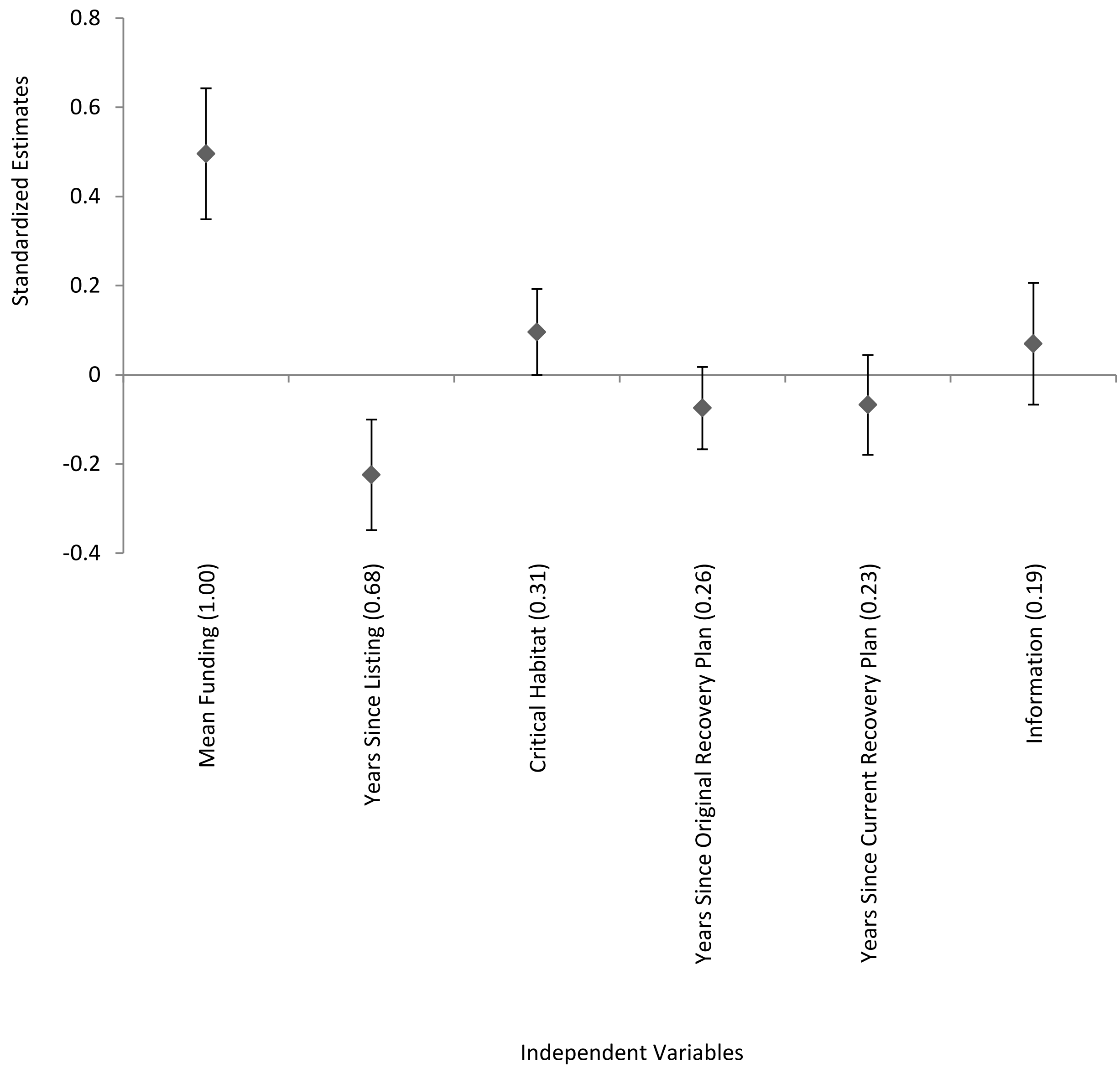

Figure 2.2. Standardized model average coefficients (+ SE) over all U.S. ESA tools models with Δ AIC < 4 for RS_1 calculated at the individual dataset level (N = 101). Variables are listed according to relative importance, which is presented in parentheses. Mean Funding and Information variables were found to be strongly collinear ($r^2 = 0.60$, $p < 10^{-15}$).

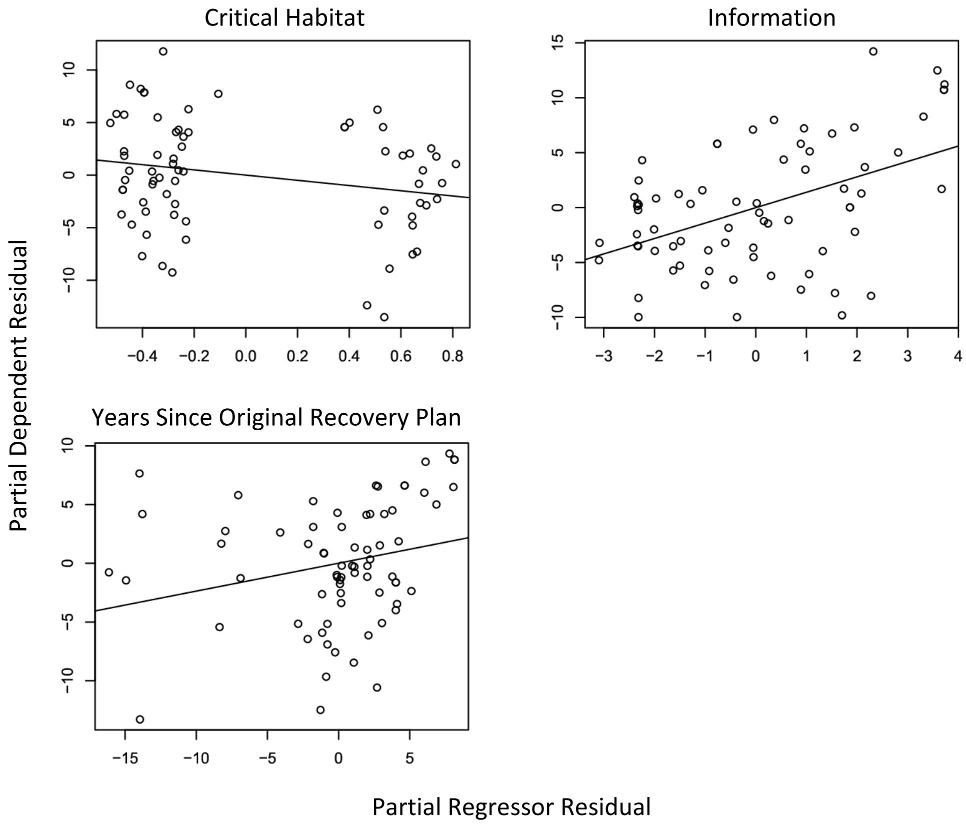

Figure 2.3. Partial plots of variables retained in the best overall U.S. ESA tools model for BRI, relating to Critical Habitat, Information and Years Since Original Recovery Plan (N = 71). Solid lines show fitted slopes.

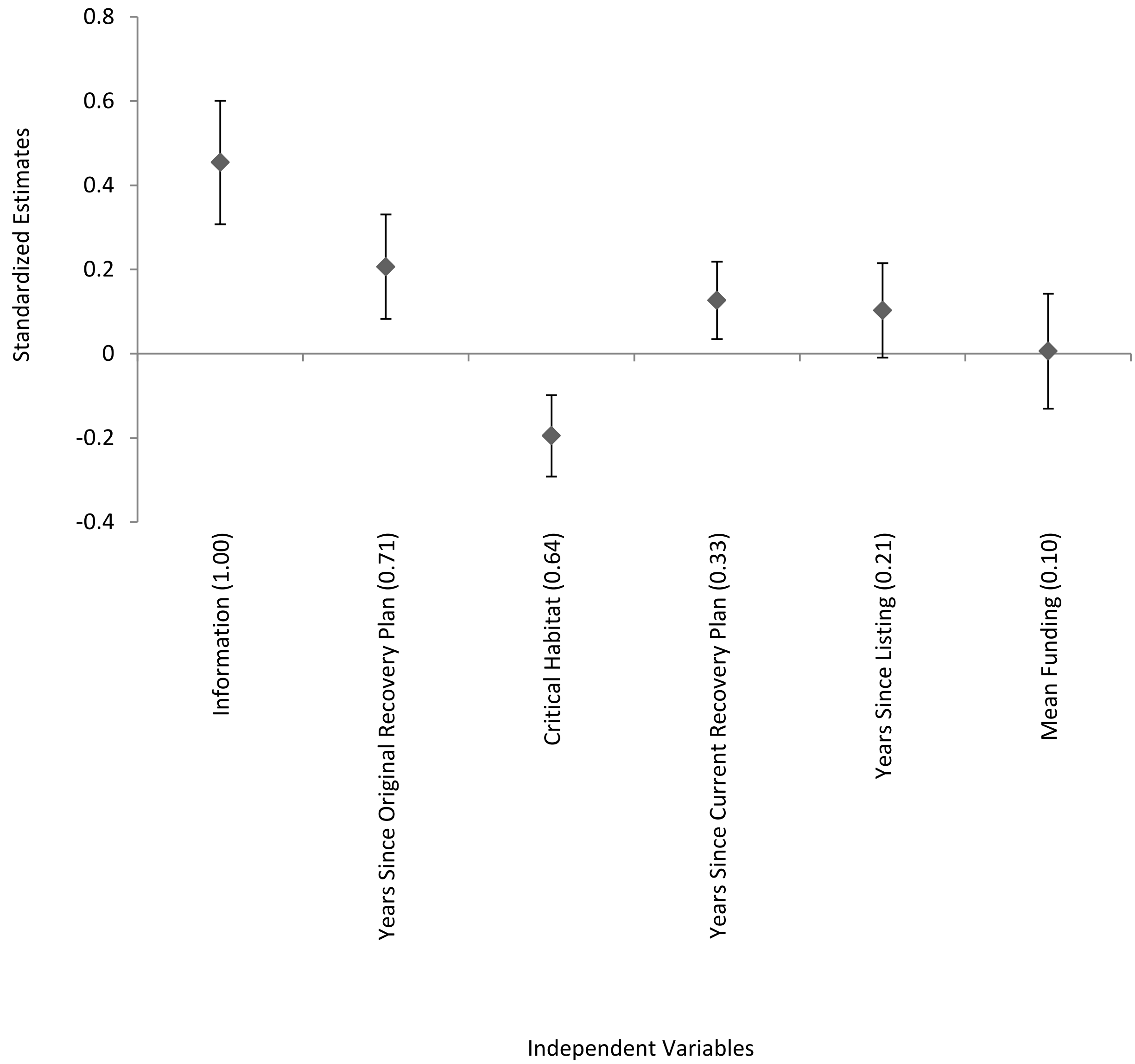

Figure 2.4. Standardized model average coefficients (+ SE) over all U.S. ESA tools models with Δ AIC < 4 for BRI (N = 71). Variables are listed according to relative importance, which is presented in parentheses. Mean Funding and Information variables were found to be strongly collinear ($r^2 = 0.60$, $p < 10^{-15}$).

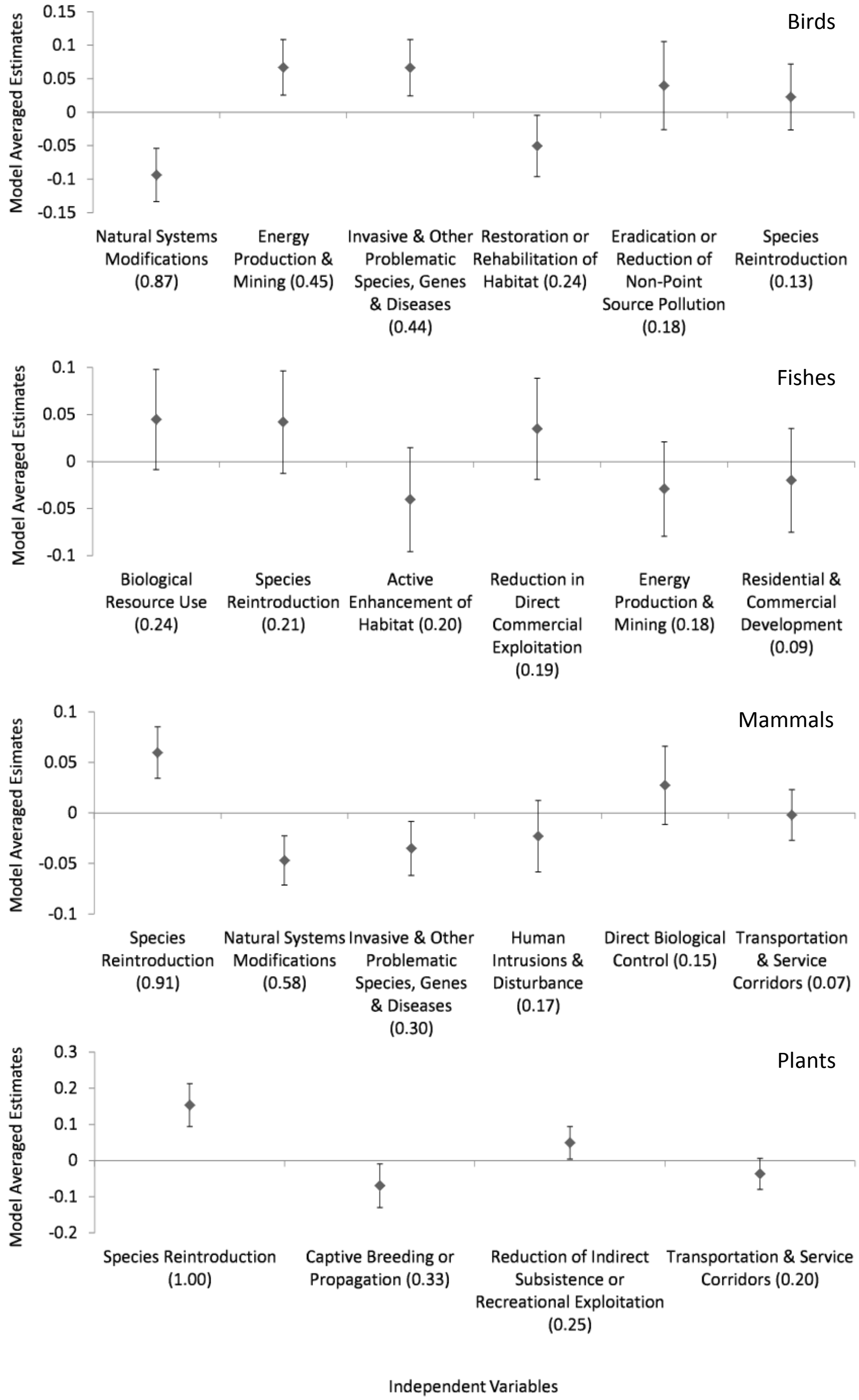

Figure 2.5. Model averaged coefficients (+ SE) based on threats and recovery actions models fitted for RS_2, calculated at the individual dataset level. Variables are listed according to relative importance, which is presented in parentheses. Mean pseudo-R^2 of averaged models with Δ AIC < 4 for Birds = 0.34 (SD = 0.07; N = 26), Fishes = 0.05 (SD = 0.02; N = 26), Mammals = 0.25 (SD = 0.06; N = 28) and Plants = 0.30 (SD = 0.02; N = 26).

GENERAL CONCLUSION

The aim of this thesis was to evaluate the recovery trends of species listed pre-1981 under the U.S. Endangered Species Act (U.S. ESA 1973). We examined the degree to which species recovery trends, as defined by their Biennial Recovery Statuses (BRSs) published in the U.S. ESA biennial reports to Congress (U.S. FWS 1990-2012, NMFS 1991-2013), reflect the trends described by their quantitative abundance or range data, as well as other qualitative indices of recovery. Using BRSs and trends in species' abundance and range data we then attempted to determine what factors (threats, recovery actions or legislated tools) were able to distinguish improving vs. declining recovery trends of listed species.

In Chapter One, we determined that the species experts who responded to our survey generally think well of the BRSs, which are moderately correlated to their own opinions of species recovery. The BRSs are also moderately correlated to two qualitative recovery metrics produced by the NatureServe and the IUCN. In contrast, the relationship between species' BRSs and trends derived by their abundance and range data is weak. However, given the differences in scale and the various degrees of uncertainty within our metrics, we would not expect to find strong relationships between them all.

We have two major concerns with the BRSs, the first of which is that we do not know what information they are based on. The only way to know, explicitly, what information went into the BRS assessments is for all data sources to be meticulously recorded and, in keeping with the current U.S. open access policy (Noorden 2013), to have this information publicly available. Our second concern with the BRSs is their combination of changes to species' population size and associated threats in their determination of recovery trend. The fact that some activity or circumstance is thought to be threatening a species does not guarantee that it in fact is. Ultimately, the only evidence that a threat exists is its impact on species population dynamics. The solution to this problem would be for the U.S. FWS and NMFS to devise two separate indices of recovery, which would evaluate species recovery trends according to threat level and population separately.

In Chapter Two, we found both the BRSs and trends in species' abundance or range data to be moderately related to the general tools related to U.S. ESA listing - the most important being mean annual funding or scientific peer-reviewed information. Threats and recovery actions were also moderately related to species' abundance and range trends; although they varied considerably by taxonomic group. Most threats showed a negative association with species recovery trends, while most recovery actions showed a positive association.

Our results showed that associations between species recovery and the U.S. ESA tools greatly differ according to the metric used to define recovery. Therefore, researchers who wish to use any of the existing metrics of recovery to explore patterns or test hypotheses concerning factors contributing to, or impeding species recovery, must be aware that their results may well depend on which metric they use. Thus, they are advised to use multiple metrics whenever possible, and focus on robust patterns that result.

The only way we can possibly evaluate how effective our legislative and policy instruments are at achieving their intended purpose of protecting and recovering species at risk of extinction is to systematically record their responses to perceived threats and conservation tools. We hope that our analyses have succeeded in highlighting the importance of monitoring species recovery trends, and demonstrating the potential of these data for evaluating their causes of endangerment, as well as directing and managing conservation actions.

There are many possible avenues of further investigation which extend from this research. For example, regarding the correlations between our quantitative recovery metric and our series of qualitative recovery measures, it would be informative to determine how strong their correlations could *possibly* be. To accomplish this, series of species abundance data in which researchers have high confidence of their accuracy would need to be obtained and their derived trends compared to the other metrics. This could be done using the North American Breeding Bird Survey data for instance, which has been used by many researchers. Alternatively, abundance data could be obtained only for species which have small ranges and are frequently monitored, so that confidence in their abundance estimates is high. The strength of the correlations obtained could then be compared to those found in our study.

The results of our analyses examining associations between recovery and ESA tools apply across a broad assemblage of species. It would also be of interest to determine how the strength of associations between the variables examined change as species included in the analysis are refined. For example, if only the species for which habitat loss has been identified as the limiting factor for their recovery are included in the analysis, then how would the effect of Critical Habitat designation on recovery change as a result?

The results from our analyses examining associations between species recovery and threats and recovery actions are plagued by small sample sizes. With a larger set of species, it would be of interest to determine whether variables we could not test in our analyses due to lack of variation species' threats and recovery actions profiles are in fact more important that those we were able to examine. With a larger sample size of species, we would also be able to separate our analyses according to factors other than taxonomic group. For example, species could be grouped by U.S. FWS region or by ecosystem type. Results may then indicate which threats or recovery actions have been adequately addressed by U.S. FWS and NMFS field offices or which require their further attention.

Finally, further dissection of the positive association between species recovery and mean funding levels which were found by ours and several other studies (e.g. Male and Bean 2005, Gibbs and Currie 2012) is required to determine how greater funding can promote recovery. Money alone does not recover species, but rather how it is used. A suite of actions are funded through federal and state agencies aimed at recovering listed species including (but not limited to) captive breeding programs, land purchases, environmental restoration, species research, and public education and outreach. Determining which of the funded actions are responsible for increased species recovery remains a research priority.

LITERATURE CITED

Endangered Species Act (U.S. ESA). 1973. Public Law No. 93–205, 87. US statutes at large 884 (Dec.23, 1973). Available http://www.fws.gov/ENDANGERED/esa-library/pdf/ESAall.pdf. Accessed 2014 June 25.

Fish and Wildlife Service (U.S. FWS). 1990 - 2012. Report to Congress on the recovery of threatened and endangered species: fiscal years 1990, 1992, 1994, 1996, 1997–1998, 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007-2008, 2009-2010. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.fws.gov/endangered/esa-library/index.html#recovery. Accessed 2014 May 09.

Gibbs, K. E., and D. J. Currie. 2012. Protecting endangered species: Do the main legislative tools work? Plos One 7(5):e35730.

Male, T. D., and M. J. Bean. 2005. Measuring progress in US endangered species conservation. Ecology Letters 8(9):986-992.

National Marine Fisheries Service (NMFS). 1991 - 2013. Report to Congress on the recovery of threatened and endangered species: fiscal years 1989-1991, 1992-1994, 1994-1996, 1996-1998, 1998–2000, 2000–2002, 2002–2004, 2004–2006, 2006-2008, 2008-2010, 2010-2012. Washington, (DC): U.S. Fish and Wildlife Service. Available: http://www.nmfs.noaa.gov/pr/laws/esa/biennial.htm. Accessed 2014 May 09.

Noorden, R.V. 2013. White House announces new US open-access policy. Available: http://blogs.nature.com/news/2013/02/us-white-house-announces-open-access-policy.html. Accessed 2014 August 03.

APPENDIX A - ONLINE QUESTIONNAIRE TO SPECIES EXPERTS

Measuring the Success of the United States Endangered Species Act

Online Survey Consent Form

Invitation to Participate: You are invited to participate in the above mentioned research study conducted by Shahira Khair, David Currie and Scott Findlay of the University of Ottawa, and Noah Greenwald of the Center for Biological Diversity.

Purpose of the Study: This survey is part of an MSc thesis whose goal is to address the question: among species listed under the United States Endangered Species Act (US ESA), what distinguishes species that are recovering from those that are not? We are contacting experts on individual species listed under the Act to help resolve three subsidiary questions. First, among the many threats to individual listed species, can specific ones be identified as most important? Which recovery actions have proven to be most effective? Finally, do listing statuses provide accurate assessments of species recovery?

Participation: Your participation will consist of completing the following survey, which should take approximately 15 to 20 minutes to complete. In this survey, we ask respondents to identify the species with which they are most knowledgeable, and assist us by:

1. Providing their expert opinion for a series of questions about species recovery status and threats;

2. Referencing or attaching any reports, publications or datasets with associated metadata that they produced, are aware of, or possess, which contain information on population surveys documenting abundance trends and/or range trends for the species they have chosen to review. If respondents are sending raw data in the form of a spreadsheet or other database, please provide any metadata and let us know if there are restrictions on its use. Any publication from this survey will properly attribute the source of all data used.

Risks: Your participation in this study will entail that you provide information which could, in some instances, result in social repercussions such as being negatively judged by employers. The researchers will make every effort to minimize these risks, by ensuring that all information shared will remain strictly confidential, and that all results will be published in aggregate format.

Benefits: Your participation in this study will contribute to an evaluation of the success of the U.S. Endangered Species Act at promoting species recovery, and will help suggest key actions to advance species recovery.

Confidentiality and Anonymity: The information you share will remain strictly confidential. Contact information is being requested from survey respondents but is not required to participate. Contact information provided will be used to ensure that survey results represent the opinions of experts in the field, and will allow researchers to contact respondents if any follow-up questions arise. All personal information will be kept confidential and survey data will be stored in a format that cannot be linked to individual respondents. Identities of participants will not be revealed in any resulting publications. Submissions from anonymous respondents are still appreciated. Survey responses will be used only for the purposes of this research.

Conservation of Data: The data collected from the electronic survey will be kept in a secure manner. Data files will be encrypted and password protected, and will only be accessible to researchers at the University of Ottawa and the Center for Biological Diversity. Data will be archived at the University of Ottawa for a minimum of 5 years.

Voluntary Participation: You are under no obligation to participate and if you choose to participate, you may withdraw from the study at any time and/or refuse to answer any questions, without suffering any negative consequences. If you choose to withdraw, all data submitted before the time of withdrawal will still be available for use by researchers.

If you have any questions about the study, you may contact researchers at the coordinates listed below:

Principal Contacts:

Shahira Khair

M.Sc. Candidate
Department of Biology
University of Ottawa

Noah Greenwald

Endangered Species Director
Center for Biological Diversity

If you have any questions regarding the ethical conduct of this study, you may contact:

The Protocol Officer for Ethics in Research

University of Ottawa
Tabaret Hall Room 154
550 Cumberland Street
Ottawa, ON K1N 6N5

Acceptance: I wish to participate in the above research study, and hereby give my direct consent.

○ I Agree

○ I Do Not Agree

Measuring the Success of the United States Endangered Species Act

Section A – Respondent Information

If you are willing to provide contact information, in case we have further questions, we would be grateful. It will help us to ensure that the survey results represent the opinions of experts in the field. All personal information will be kept confidential and survey data will be stored in a format that cannot be linked to individual respondents. If you prefer to remain anonymous, we would still appreciate your opinions. Simply bypass this section by clicking the "Next" button at the bottom of the page.

Contact information form

Name:	
Affiliated institution(s):	
Email address:	
Telephone number:	

Highest level of education

○ Doctorate

○ Masters

○ Bachelors

○ College

○ Secondary School

Current employment area
Select all that apply:

☐ Academia

☐ Government

☐ Industry or Private Sector

☐ Other, please specify... ______________________

Region where you are currently employed
Select one of the following:

○ Afghanistan

... 188 additional choices hidden ...

○ Zimbabwe

If United States selected above, select one of the following areas:

- ○ U.S. North-East
- ○ U.S. South-East
- ○ U.S. Mid-West
- ○ U.S. South-West
- ○ U.S. West
- ○ Not Applicable

Section B - Species Selection

Identify the species for which you are most familiar and comfortable assessing in this survey.
Select one of the following species listed under the ESA pre-1981:

** DPS = Distinct Population Segment*

- ○ " Other Species "
- ○ Alabama Cavefish (Speoplatyrhinus poulsoni)

  ... 212 additional choices hidden ...

- ○ Yuma Clapper Rail (Rallus longirostris yumanensis)

If "Other Species" selected above, indicate the name of the species you intend to review below.

Rate your level of knowledge with respect to the conservation and recovery status of your chosen species.

- ○ **Extremely Knowledgeable -** I personally study and/or manage the conservation of this particular species. I generate primary data on the conservation of this species.
- ○ **Quite Knowledgeable -** This species falls within my professional responsibility. I am in a position to evaluate the primary studies on the conservation of this species, and I interact with persons who carry out that work.
- ○ **Knowledgeable -** I have reasonably detailed knowledge of the conservation and recovery of this species. I am very familiar with the publicly available information on the conservation and recovery of this species, but I do not bring independent information to the assessment of species status.
- ○ **Aware -** I am aware in a general sense of the conservation and recovery of this species, but I do not have detailed knowledge of the subject.
- ○ **Unknowledgeable -** I know comparatively little about the conservation and recovery of this species, and am not familiar with the publicly available information.

Section C – Assessment of Threats and Recovery Actions

This section of the survey is designed to obtain information on the threats faced by species as well as any recovery actions that have been taken to address them.

For the species that you have chosen to review, you will be asked to identify direct threats (proximate human activities or natural processes that have immediate impacts on species status) which you consider to be explicitly responsible for species loss. You should consider threats that have, in your opinion, been the most responsible in either contributing to species decline and/or impeding recovery.

Respondents will also be asked to identify any recovery actions (acts that prevent further loss of a species, and remove or reduce threats) that have been taken for their chosen species, and assess their effectiveness, amount of effort expended, and scale of application.

Respondents are encouraged to expand upon the nature of selected direct threats and recovery actions in the open comment sections.

Question 1: In your estimation, what are the most important direct threats to your species?

The set of direct threats below are taken from the IUCN Threats Classification System (Version 3.1).
See link HERE for definitions of threat categories.

We are looking for your opinion on what direct threats have played the most influential role in determining species survival.

Select from the list below the direct threats which, in your opinion, are responsible for causing or contributing to your species' risk of extinction. Do not select all possible threats affecting your reviewed species - only those you deem the most important in either contributing to its decline and/ or impeding its recovery.

- ☐ 1. Residential and/or commercial development
- ☐ 2. Agriculture and/or aquaculture
- ☐ 3. Energy production and/or mining
- ☐ 4. Transportation and/or service corridors
- ☐ 5. Biological resource use
- ☐ 6. Human intrusions and/or disturbance
- ☐ 7. Natural system modifications
- ☐ 8. Invasive and/or other problematic species, genes and/or diseases
- ☐ 9. Pollution
- ☐ 10. Geological events
- ☐ 11. Climate change and/or severe weather
- ☐ None of the above
- ☐ Unsure

Open Comments

Matrix 1: In your estimation, what are the most important direct threats to your species?

Please respond to the following questions for the set of threats selected in Question 1.

See link HERE for definitions of direct threat categories from the IUCN Threats Classification System (Version 3.1).

*** A very important threat is one which, in your view, is absolutely critical to reduce/mitigate if species decline is to be halted or recovery is to be achieved. A very unimportant threat is one whose successful mitigation, in isolation, would only marginally mitigate species decline, or have only slightly increased the chances of successful recovery.*

IUCN Direct Threats	Temporal Characteristics	Spatial Characteristics	Population Characteristics	** Threat Importance	Recovery Actions	Recovery Action Effectiveness
	Are threats **Past, Current,** or **Future** hazards? Choose one or more options for each threat.	Do threats occur throughout the entire species range (**Complete**) or only in part of the species range (**Partial**)? Choose one of the options below for each threat.	Do threats affect all individuals of a species (**Complete**) or only specific members (**Partial**)? Choose one of the options below for each threat.	How important are threats to species survival? Provide a rating of importance for each threat.	Have recovery actions been taken to address threats? Choose one of the options below for each threat.	How effective have the recovery actions been to mitigate threats? Provide a rating of action effect for each threat indicated as having been addressed by a recovery action.
Row repeats for each threat (1–11)	○ Past ○ Present ○ Future ○ Unsure	○ Complete ○ Partial ○ Unsure	○ Complete ○ Partial ○ Unsure	○ Extremely Important ○ Very Important ○ Moderately Important ○ Slightly Important ○ Not at all Important ○ Unsure	○ Yes ○ No ○ Unsure	○ Completely Effective ○ Very Effective ○ Moderately Effective ○ Slightly Effective ○ Not At All Effective ○ Unsure ○ Not Applicable

Open Comments

Question 2: Have recovery actions been taken in response to direct threats facing species?

Our interest lies in determining whether some types of recovery actions have proven to be more effective at reducing direct threats to species survival or recovery.

Please indicate the recovery actions that have been employed for your species.

Threat Category: Habitat Modification

Recovery Actions	Employed	Not Employed	Unsure
1. Elimination/ prevention of source of habitat modification	○	○	○
2. Protection of remaining habitat	○	○	○
3. Restoration and/ or rehabilitation (intention to return habitat to "original" state)	○	○	○
4. Active enhancement (intention to return habitat to state deemed better than the "original")	○	○	○

Threat Category: Pollution

Recovery Actions	Employed	Not Employed	Unsure
5. Elimination/ reduction of point-source pollution	○	○	○
6. Elimination/ reduction of non-point source pollution	○	○	○
7. Elimination/ reduction of pollution effects through habitat preservation and/ or maintenance operations (e.g. creation of buffer zones, tailings inoculations)	○	○	○

Threat Category: Invasive or Problematic Species

Recovery Actions	Employed	Not Employed	Unsure
8. Direct biological control (e.g. cull, introduction of parasites/ disease targeted towards invasive/ problematic species)	○	○	○
9. Indirect control (modification of food source or habitat of invasive/ problematic species)	○	○	○
10. Vector reduction (restriction in pathways of movement/ transmission of invasive/ problematic species)	○	○	○

Threat Category: Over exploitation

Recovery Actions	Employed	Not Employed	Unsure
11. Reduction in direct commercial exploitation	○	○	○
12. Reduction in direct subsistence or recreational exploitation	○	○	○
13. Reduction in indirect commercial exploitation (e.g. by catch)	○	○	○
14. Reduction in indirect subsistence or recreational exploitation	○	○	○

Open Comments

Matrix 2: Have recovery actions been taken in response to direct threats facing species?

For recovery actions indicated as having been employed for your species in the preceding question, please evaluate their overall impact on direct threat levels, and provide details as to the geographic scope of their application and effort expended.

	Effectiveness For each recovery action, rate how effectively it has mitigated direct threats to species survival.	Geographic Scope For each recovery action, rate the geographic scale at which it was implemented. Rate level 1 - 5, where 1 = Very limited area; 5 = Over entire species range.	Effort Expended For each recovery action, indicate the level of effort (time, money and/or energy) allocated to its implementation. Rate level 1 - 5, where 1 = Negligible effort; 5 = Very large effort.
Row repeats for each recovery action (1-14)	○ Completely Effective ○ Very Effective ○ Moderately Effective ○ Slightly Effective ○ Not At All Effective ○ Unsure	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Unsure	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Unsure

Open Comments

Question 3: Have population augmentation initiatives been taken in response to species decline?

Please indicate whether or not the following categories of population augmentation initiatives have been undertaken for your species?

	Employed	Not Employed	Unsure
1. <u>Species Introduction</u> - Releasing species into areas where they have never existed before (old habitat gone/degraded, but new habitat is considered suitable).	○	○	○
2. <u>Species Relocation</u> - Relocating species to areas where they once existed, but no longer are found.	○	○	○
3. <u>Species Re-introduction</u> - Releasing captive species to areas where they once existed.	○	○	○
4. <u>Species Translocation</u> - Moving species between occupied areas as a means to increase genetic variability, local population viability.	○	○	○
5. <u>Captive Breeding</u>	○	○	○
6. <u>Fish Hatcheries</u>	○	○	○
7. <u>Gene or Seed Banks</u>	○	○	○

Open Comments

Matrix 3: Have population augmentation initiatives been taken in response to species decline?

For population augmentation initiatives indicated as having been employed for your species in the preceding question, please evaluate their overall impact on direct threat levels, and provide details as to the geographic scope of their application and effort expended.

	Effectiveness For each population augmentation initiative, rate how effectively it has mitigated direct threats to species survival.	Geographic Scope For each population augmentation initiative, rate the geographic scale at which it was implemented. Rate level 1 - 5, where 1 = Very limited area; 5 = Over entire species range.	Effort Expended For each population augmentation initiative, indicate the level of effort (time, money and/or energy) allocated to its implementation. Rate level 1 - 5, where 1 = Negligible effort; 5 = Very large effort.
Row repeats for each population augmentation initiative (1-7)	○ Completely Effective ○ Very Effective ○ Moderately Effective ○ Slightly Effective ○ Not At All Effective ○ Unsure	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Unsure	○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Unsure

Open Comments

<u>Section D – How reliable are the status assessments produced by the US Fish and Wildlife Service in their biennial Report to Congress on the Recovery of Threatened and Endangered Species?</u>

Status trends for species listed under the US ESA are produced by the US FWS and reported in their Biennial Reports to Congress. Although the status trends are provided by US FWS field staff with very intimate knowledge on each particular species, each of the reported trends is a combined measure of "population numbers and threats, and is determined on an annual basis relative to the previous reporting year's outcome. It is not a long-term trend, and thus does not necessarily reflect progress towards recovery" (US FWS 2012)[1].

Despite the caution put forth by the US FWS, biennial status trends have been used in the published literature as a measure of species recovery; in part because they are the only data available for many species. The question remains, however, how useful are the data for describing recovery success?

We extracted recovery data from the years 1990-2010 from the Biennial Reports to Congress for each listed species, and constructed a composite recovery score (see Gibbs and Currie (2012) for methodology[2]). Scores vary from +11 (improving status in every report) to -11 (declining status in every report). Please download the resulting score for your reviewed species by clicking <u>HERE.</u>

Did you review the recovery score data from the Biennial Reports to Congress for your species?

○ Yes

○ No

Have you ever contributed recovery status information to the US FWS for your chosen species?

○ Yes

○ No

○ Unsure

Based on your own understanding of your reviewed species' recovery (for the purposes of this assessment, defined as <u>changes in both population and threat level</u>), please rate how you would characterize the trajectory of recovery success for the following time period:

	Declining sharply	Declining	Declining slightly	Stable	Improving slightly	Improving	Improving sharply	Unsure	Not Applicable
1970-1980	○	○	○	○	○	○	○	○	○

[1] http://www.fws.gov/endangered/esa-library/pdf/Recovery_Report_2010.pdf

[2] Gibbs KE, Currie DJ (2012) Protecting Endangered Species: Do the Main Legislative Tools Work? PLoS ONE 7(5): e35730. doi:10.1371/journal.pone.0035730

If you would prefer to break your responses into finer time periods, please do so here. Otherwise, skip this part of the question.

	Declining sharply	Declining	Declining slightly	Stable	Improving slightly	Improving	Improving sharply	Unsure	Not Applicable
1970-1980	○	○	○	○	○	○	○	○	○
1980-1990	○	○	○	○	○	○	○	○	○
1990-2000	○	○	○	○	○	○	○	○	○
2000-2010	○	○	○	○	○	○	○	○	○

Would your evaluation(s) made in the preceding question have been considerably different had your assessment of species recovery been based only upon consideration of changes in population?

○ Yes

○ No

○ Unsure

○ Not Applicable

If you answered "Yes" to the above question, would your evaluation have resulted in a more "Improving" or "Declining" trajectory?

○ Improving

○ Declining

○ Unsure

○ Not Applicable

Based on the information contained in the dataset, please give your opinion on how closely the reported US FWS recovery trend for your species compares to your personal views about the recovery trend.

Extremely Dissimilar	Dissimilar	Somewhat Dissimilar	Neutral	Somewhat Similar	Similar	Extremely Similar	Unsure	Not Applicable
○	○	○	○	○	○	○	○	○

Open Comments

Thank You!

You have successfully completed the survey! Thank you for taking the time to review the threats, recovery actions, and status trajectory associated with your chosen species.

If you are willing to further assist our efforts in documenting species recovery, please reference or attach below, any reports/ publications/ datasets (with associated metadata) that you have produced, are aware of, or possess, which contain information on population surveys documenting abundance trends and/or range trends for the species you have chosen to review.

Please reference below any documents you are willing to share.

APPENDIX B – QUANTITATIVE ABUNDANCE AND RANGE DATABASE METADATA

Key Master: Unique species identifier

Taxon: Taxonomic grouping

NameCommon: Common species name

NameScientific: Scientific species name

DataType: Measurement type: Abundance (Adults, Breeding Pairs, Catch Per Unit Effort, Clumps, Individuals, Nesting Females, Nesting Pairs, Nests, Pairs, Spawning Fish), Locations (number of), Populations, Range

PopData: Does row contain abundance or population estimate? 1 = Yes, 0 = No

RangeData: Does row contain location or range estimate? 1 = Yes, 0 = No

Time: Year of estimate

Location: Area to which estimate applies

PopEstimate: Abundance/Population estimate value (if NA, then "999")

PopUnits: Unit of measure for PopEstimate (if NA, then "999")

PopEstMethod: Method of PopEstimate collection (if NA, then "999")

PopPrecision: Precision of PopEstimate value (if NA, then "999")

RangeSizeEstimate: Range/Location estimate value (if NA, then "999")

RangeSizeUnits: Unit of measure for RangeSizeEstimate (if NA, then "999")

RangeSizePrecision: Precision of RanegSizeEstimate value (if NA, then "999")

DataSource: Reference to estimate source if different than Primary Source

PrimarySource: Reference to source material in which estimate was found

PrimarySourceType: Source type (Academic Journal, Book, Conference Proceedings, Dissertations and Theses, Federal Register, Memo (GOV), Online Database (Academic/GOV/NGO), Online Presentation (GOV), Private Communication, Private Database (GOV), Report (Academic, Contractor, GOV,NGO), Website (GOV, News Agency, NGO)

Notes: Additional comments

APPENDIX C – LITERATURE REVIEW INSTRUCTIONS AND SEARCH KEY WORDS

FWS Publication Reviews

Each student will be assigned a set of 10 species to review. Every species is being reviewed twice in order to obtain a measure of inter-relater reliability. Keep the identities of the species you are reviewing to yourselves, so as to remove bias in your responses.

Perform the following instructions for each of the species you have been assigned.

Literature Search Instructions

1. Navigate to the US Fish and Wildlife Service ECOS database (http://ecos.fws.gov) and enter the name of your assigned species into the search field. Select the appropriate species entry from the drop down menu.
2. On the species page that appears, scroll down until you reach the "Recovery" heading. Two documents may be listed here: i) the Species' Recovery Plan and ii) the Species' Five Year Review. Download the most recent versions of these two documents and enter their details into your Bibliographic Database. (Limit reviewed Recovery Plans to those written since 1990).
3. After entering the details of the Recovery Plan and/or Five Year Review into your Bibliographic Database, review both documents for cited literature that describes trends in species population size and spatial distribution. Search for trend key words (for e.g. *'increasing', 'decreasing', 'stable', 'trend', 'population', 'range', 'area of occupancy', 'extent of occurrence'*), as well as tables and figures illustrating changes in population and range.
4. Acquire the cited literature describing species population and range trends to add to your Bibliographic Database. Use the University of Ottawa's journal subscriptions to retrieve academic publications, and use Google to search for cited grey literature (e.g. government reports). Limit time spent searching on Google to a maximum 5 minutes per document. Upon accessing a document, scan its abstract or executive summary to determine its eligibility for inclusion in the Bibliographic Database (see section below on Inclusion Criteria).

Inclusion Criteria

Upon recovering publications, read through the abstracts or executive summary, and determine whether the following criteria are satisfied:

i. The abstract or summary specifically refers to the assigned species.
ii. The abstract or summary refers to a study that was conducted in the United States.
iii. Information in the abstract or summary suggests that the paper includes quantitative and/or descriptive estimates of species population (size, density, reproductive output, etc.) OR the abstract or summary includes quantitative and/or descriptive measures of area occupied by species (range, distribution, etc.).

If the publication in question satisfies all three of these criteria, then add it to your Bibliographic Database. If the document was found using the University of Ottawa's library search tools, add it first to your Refworks account and download the bibliographic details using the instructions below.

Refworks Instructions

1. Access Refworks via the following link: (uottawa.ca.libguides.com/refworks_en). After creating your own account you will be able to add all documents accessed through the library's resources to your References list by selecting the Refworks export citation link.
2. When your list of references in Refworks is complete, you can export citation information to an Excel spreadsheet using the following directions.
    i. In Refworks, under the "References" tab, select "Export" from the drop down menu that appears.
    ii. In the "Export References" Popup box and under the "References to Include" heading, select the folder that contains your references to export. Within "Export Format" select "Tab Delimited". Click the "Export" button (Ensure that popup blockers are turned off).
    iii. A window will open containing your reference data in text. Right click within the window and select "Save As". Save the file in .txt format in a location where you can find it easily.
    iv. Open the saved document in Microsoft Excel. In the "Text Import Wizard" that appears, unsure that "Delimited" is selected under "Original data type". Click "Next". Under "Delimiters" ensure "Tab" is selected. Click "Next". Under "Column Data Format" ensure "General" is selected. Click "Finish".
    v. A spreadsheet with all document citation information will appear. You can now copy and paste cells from this spreadsheet to easily populate your Bibliographic Database.

Bibliographic Database Population Instructions

Using publications retrieved from your literature searches, populate your Bibliographic Database. Refer to the document entitled Bibliographic Database Metadata for variable definitions.

Recovery Database Population Instructions

Once your set of publications is compiled you're ready to being mining the literature for data. Read through your documents for data on population and range size, making sure to examine all tables, figures, and supplemental information. Using retrieved data, populate your Recovery Database. Refer to the document entitled Recovery Database Metadata for variable definitions.

Primary and Secondary Publication Reviews

Each student will be assigned a set of 12 species to review. Every species is being reviewed twice in order to obtain a measure of inter-relater reliability. Keep the identities of the species you are reviewing to yourselves, so as to remove bias in your responses.

Perform the following instructions for each of the species you have been assigned.

Literature Search Instructions

5. Navigate to the US Fish and Wildlife Service ECOS database (http://ecos.fws.gov) and enter the name of your assigned species into the search field. Select the appropriate species entry from the drop down menu.
6. Scroll down the species page until you reach the "Other Resources" heading. Under this is a link to "NatureServe Explorer Species Reports". Click this link to access the NatureServe Explorer site, be sure to click OK to the prompt that appears. On the NatureServe Explorer webpage expand the "References" tab. Use the University of Ottawa's journal subscriptions to retrieve listed academic publications, and use Google to search for listed grey literature (e.g. government reports, student theses, etc.). Limit time spent searching on Google to a maximum 5 minutes per document. Upon accessing a document, scan its abstract or executive summary to determine its eligibility for inclusion in the Bibliographic Database (see section below on Inclusion Criteria).
7. Using the University of Ottawa's subscription to the *ProQuest* database, perform a literary search for primary publications and grey literature using the Keyword Search Directions below. In some cases a citation for a piece of grey literature will be stored in the *ProQuest* database without a complete document attached. In these cases perform a quick Google search to see if the document is available elsewhere online. Upon accessing a document, scan its abstract or executive summary to determine its eligibility for inclusion in the Bibliographic Database (see section below on Inclusion Criteria).

Keyword Search Directions

Using the advanced search options in *ProQuest*, perform an initial search for documents containing your species' name.

i. "Common Name" **OR** "*Scientific Name*" (* make certain to use quotations around your species name)

If your search returns a manageable number of results (i.e. less than 50) proceed to directions on Inclusion Criteria below.

If the search returns too many results (i.e. greater than 50), perform a refined search using the following key terms, in sequence.

ii. "Common Name" **OR** "*Scientific Name*" **AND** conservation
iii. "Common Name" **OR** "*Scientific Name*" **AND** recovery

iv. "Common Name" **OR** "*Scientific Name*" **AND** distribution
v. "Common Name" **OR** "*Scientific Name*" **AND** abundance
vi. "Common Name" **OR** "Scientific Name" **AND** density
vii. "Common Name" **OR** "*Scientific Name*" **AND** range
viii. "Common Name" **OR** "*Scientific Name*" **AND** area of occupancy
ix. "Common Name" **OR** "*Scientific Name*" **AND** population **AND** size **OR** distribution

* If the number returned results is too high, or if there are many non-useful sources returned, you can limit the "Source Type" of returned results through the advanced search options. The most relevant sources are (in alphabetical order) Conference Papers & Proceedings, Dissertations & Theses, Government & Official Publications, Reports, and Scholarly Journals.

Inclusion Criteria

Upon recovering publications, read through the abstracts or executive summary, and determine whether the following criteria are satisfied:

iv. The abstract or summary specifically refers to the assigned species.
v. The abstract or summary refers to a study that was conducted in the United States.
vi. Information in the abstract or summary suggests that the paper includes quantitative and/or descriptive estimates of species population (size, density, reproductive output, etc.) OR the abstract or summary includes quantitative and/or descriptive measures of area occupied by species (range, distribution, etc.).

If the publication in question satisfies all three of these criteria, then add it to your Bibliographic Database. If the document was found using the University of Ottawa's library search tools, add it first to your Refworks account and download the bibliographic details using the instructions below.

Refworks Instructions

3. Access Refworks via the following link: (uottawa.ca.libguides.com/refworks_en). After creating your own account you will be able to add all documents accessed through the library's resources to your References list by export the citation to your Refworks account.
4. When your list of references in Refworks is complete, you can export their citation information to an Excel spreadsheet using the following directions.
    i. In Refworks, under the "References" tab, select "Export" from the drop down menu that appears.
    ii. In the "Export References" Popup box and under the "References to Include" heading, select the folder that contains your references to export. Within "Export Format" select "Tab Delimited". Click the "Export" button (Ensure that popup blockers are turned off).

iii. A window will open containing your reference data in text. Right click within the window and select "Save As". Save the file in .txt format in a location where you can find it easily.
iv. Open the saved document in Microsoft Excel. In the "Text Import Wizard" that appears, unsure that "Delimited" is selected under "Original data type". Click "Next". Under "Delimiters" ensure "Tab" is selected. Click "Next". Under "Column Data Format" ensure "General" is selected. Click "Finish".
v. A spreadsheet with all document citation information will appear. You can now copy and paste cells from this spreadsheet to easily populate your Bibliographic Database.

Bibliographic Database Population Instructions

Using publications retrieved from your literature searches, populate your Bibliographic Database. Refer to the document entitled Bibliographic Database Metadata for variable definitions.

For documents found using the University of Ottawa's library resources, populating your Bibliographic Database will best easiest if Refworks is used to manage your references. See below for instructions.

Recovery Database Population Instructions

Once your set of publications is compiled you're ready to being mining the literature for data. Read through your documents for data on population and range size, making sure to examine all tables, figures, and supplemental information. Using retrieved data, populate your Recovery Database. Refer to the document entitled Recovery Database Metadata for variable definitions.

APPENDIX D – QUANTITATIVE RECOVERY ESTIMATE AND BIBLIOGRAPHIC INFORMATION DATABASE METADATA

Recovery Estimate Database Metadata

Identifier Variables

KeyMaster: Species identifier number.

NameCommon: Common name of species.

NameScientific: Latin name of species.

PrimarySource: Citation of the document being mined for data. Enter Author(s)/ Organisation. (Year). Publication Title. (+ Journal Name, Volume, Issue, Start Page – *for white literature*) or (+ web link – *for grey literature*).

Spatial and Temporal Variables

MultiPopRange: In the associated document, is data presented on multiple species populations or ranges? If Yes, enter 1. If No, enter 0.

Time1 and **Time 2:** Time frame associated with your data. If range of years is given enter range extremes in Time1 and Time2 (e.g. 1991-1995: enter 1991 in Time1 and 1995 in Time2). If data is from a single year enter year in Time1 and 999 in Time2. If data is historical (i.e. prior time period with no specific date) enter 0 in Time1 and 999 in Time2. If no time frame for data is given, enter 999 in both Time1 and Time2.

Location: Spatial record associated with your data. If data applies to the entire range of the species, enter 1. If data applies to limited area of species range enter 0. If no location is given for data, enter 999.

LocationText: If data applies to a limited area of species' range (i.e. if '0' was entered under '**Location**' variable) enter the location to which the data applies as text, citing verbatim from the document. Enter 999 if Not Applicable.

Recovery Variables

PopPresent: Specify whether a population of the species is known to exist at the associated time and location. If Yes, enter 1. If No, enter 0. If Not Applicable, enter 999.

PopTrend: Specify the trend in change of population size at the associated time and location. If Increasing, enter 1. If Decreasing, enter -1. If stable, enter 0. If Not Applicable, enter 999.

PopEstimate: Specify the estimated population size of the species at the associated time and location. Population estimate will most often refer to either the number of individual species, or number of populations of species. Enter a numerical value, a range of numerical values (e.g. 100-200), a greater than or less than estimate >/< (e.g. >200). If Not Applicable, enter 999.

PopUnits: Specify the category associated with the entered PopEstimate value. If number of Individual species, enter 1. If number of Populations of species, enter 2. For Other units, enter a text description. If Not Applicable, enter 999.

PopEstMethod: Specify the method used to acquire population estimate. For Full Census, enter 1. For Random Sample, enter 2. For Mark-Recapture, enter 3. For Other methods, enter as text description. If Not Applicable, enter 999.

PopPrecision: Specify the precision of the PopEstimate value. Enter the confidence interval provided in document being reviewed. If Not Applicable, enter 999.

RangeSizeTrend: Specify the trend in change of range size at the associated time and location. If Increasing, enter 1. If Decreasing, enter -1. If stable, enter 0. If Not Applicable, enter 999.

RangeSizeEstimate: Specify the estimated range size of the species at the associated time and location. Enter numerical value. If not applicable, enter 999.

RangeSizeUnits: Specify units associated with the estimated range size. Enter text value. If not applicable, enter 999.

RangeSizePrecision: Specify the precision of the RangeSizeEstimate value. Enter the confidence interval provided in document being reviewed. If Not Applicable, enter 999.

DataSource: If the data input is cited in the PrimarySource as coming from another reference, input citation for said external reference.

Bibliographic Database Metadata

Identifier Variables

KeyMaster: Species identifier number.

NameCommon: Common name of species.

NameScientific: Latin name of species.

Reference Variables

ReferenceType: Classify the document as one of the following: if 'Journal Article' enter 1, if 'Dissertation/Thesis' enter 2, if 'Report' enter 3, and if 'Other', enter text description.

AuthorsPrimary: Enter the names of the report authors as Last Name, First Name (Full First Name or Initials).

TitlePrimary: Enter the title of the document.

PeriodicalFull: If the document was published in a periodical, enter the full name of the periodical.

PubYear: Enter the year in which the document was published.

Volume: If the document was published in a periodical or a series of publications, enter the volume number.

Issue: If the document was published in a periodical or a series of publications, enter the issue number.

StartPage: If the document was published in a periodical, enter the start page number.

Publisher: Enter the name of the publisher (if applicable).

PlaceofPublication: Enter the place of publication (if applicable).

Links: Enter the URL to access the document online.

Database: If document was retrieved from an online database, enter the database name.

Document Variables

DocFigures: Does the document contain figures illustrating data on species population and range? If Yes, enter 1; if No, enter 0. If Not Applicable, enter 999. If Unsure, enter 888.

DocRangeMaps: Does the document contain species range maps? If Yes, enter 1; if No, enter 0. If Not Applicable, enter 999. If Unsure, enter 888.

DocTables: Does the document contain tables with data on species population and range? If Yes, enter 1; if No, enter 0. If Not Applicable, enter 999. If Unsure, enter 888.

DocSuppLit: Does the document have associated supplemental material? If Yes, enter 1; if No, enter 0. If Not Applicable, enter 999. If Unsure, enter 888.

Contact Variables

Contact Name: Enter name of author listed for correspondence. If no such author is specifically listed, search Google for contact details of the first or second listed author. Enter 999 if Not Applicable.

Contact Affiliation: Enter affiliation for correspondence author. Enter 999 if Not Applicable.

Contact Email: Enter email of correspondence author. Enter 999 if Not Applicable.

APPENDIX E – RECOVERY METRIC CORRELATIONS WITH MEAN BRI AND RS

Table E.1. Pearson correlations (r) or Spearman's rank correlations (ρ) of species' mean Biennial Recovery Index (BRI), mean Recovery Slope weighted by inverse standard error, NatureServe, IUCN Red List, Expert long-term (1970-2010) (ExOP Long) and Expert short-term (1990-2010) (ExOP Short) assessments of species recovery. Sample sizes are presented below correlations in parentheses (* p < 0.05; ** p < 0.01; *** p < 0.001).

	Recovery Slope	BRI	IUCN	Nature Serve	ExOP Long	Correlation Metric
BRI	0.34 *** (92)					r
IUCN	0.33 (36)	0.37 * (36)				r
NatureServe	0.13 (55)	0.61 *** (55)	0.53 * (20)			r
ExOP Long	0.40 (18)	0.69 ** (18)	-0.16 (12)	0.32 (12)		ρ
ExOP Short	0.39 (15)	0.73 ** (15)	-0.17 (10)	0.56 (12)	0.81 *** (15)	ρ

APPENDIX F - CHARACTERIZATION OF RESPONSE TO EXPERT SURVEY

Table F.1. List of species reviewed in survey to experts for which BRI and Recovery Slope metrics were calculated, ordered by taxonomic group.

Taxonomic Group	Species Name
Birds	Attwater's Greater Prairie Chicken
	Bald Eagle (Continental U.S. DPS)
	California Condor
	Mississippi Sandhill Crane
	Red-Cockaded Woodpecker
Fishes	Colorado Pikeminnow
	Devil's Hole Pupfish
	Iowa Pliestocene Snail
Invertebrates	Palos Verdes blue
	Socorro Isopod
Mammals	Delmarva Peninsula Fox Squirrel
	Gray Wolf (Northern Rockies DPS)
	Humpback Whale
	Indiana Bat
	Key Deer
Plants	Furbish's Lousewort
	Mesa Verde Cactus
	Tennessee coneflower

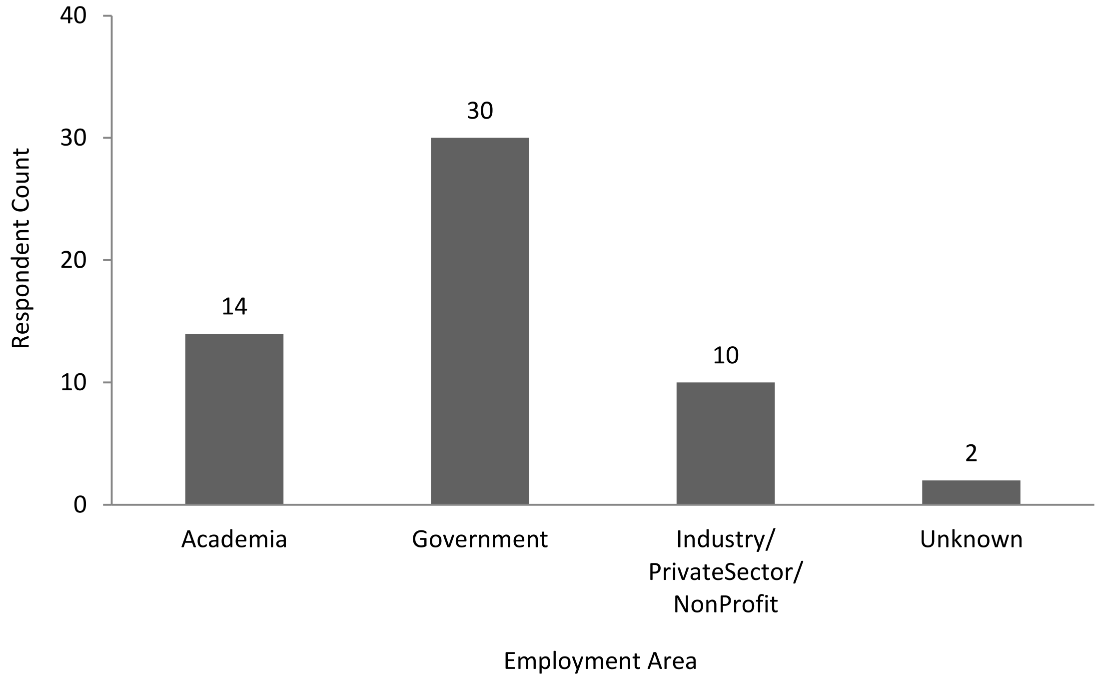

Figure F.1. Current employment sectors of respondents to the experts survey. Counts are presented above bars.

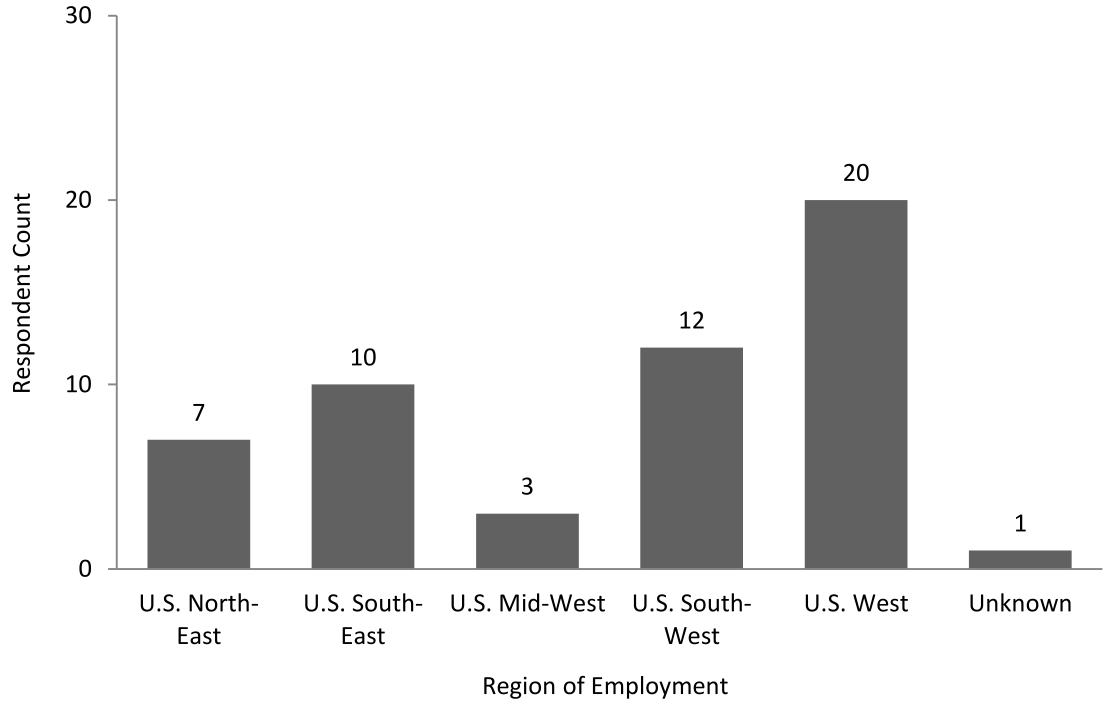

Figure F.2. The locations of employment of respondents to the experts survey. Counts are presented above bars.

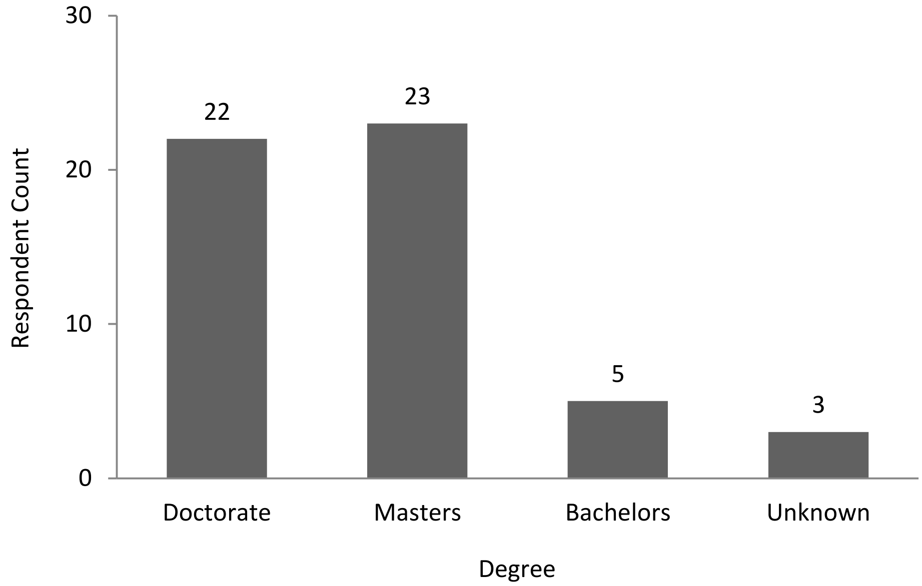

Figure F.3. Highest level of education obtained of respondents to the experts survey. Counts are presented above bars.

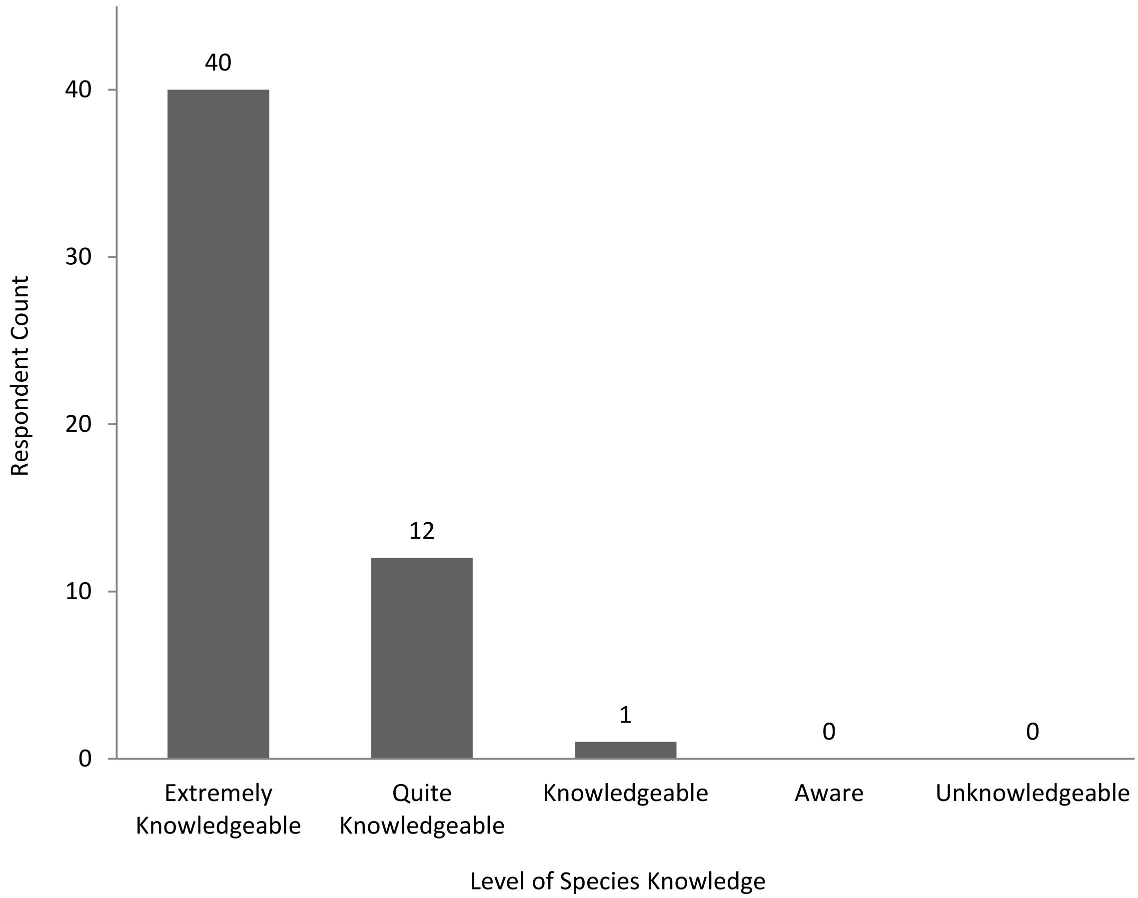

Figure F.4. Distribution of survey respondents' self-ratings of conservation-knowledge for their reviewed species. Counts are presented above bars. Extremely Knowledgeable = I personally study and/or manage the conservation of this particular species. I generate primary data on the conservation of this species; Quite Knowledgeable = This species falls within my professional responsibility. I am in a position to evaluate the primary studies on the conservation of this species, and I interact with persons who carry out that work; Knowledgeable = I have reasonably detailed knowledge of the conservation and recovery of this species. I am very familiar with the publically available information on the conservation and recovery of this species, but I do not bring independent information to the assessment of species status; Aware = I am aware in a general sense of the conservation and recovery of this species, but I do not have detailed knowledge of the subject; Unknowledgeable = I know comparatively little about the conservation and recovery of this species and am not familiar with the publically available information.

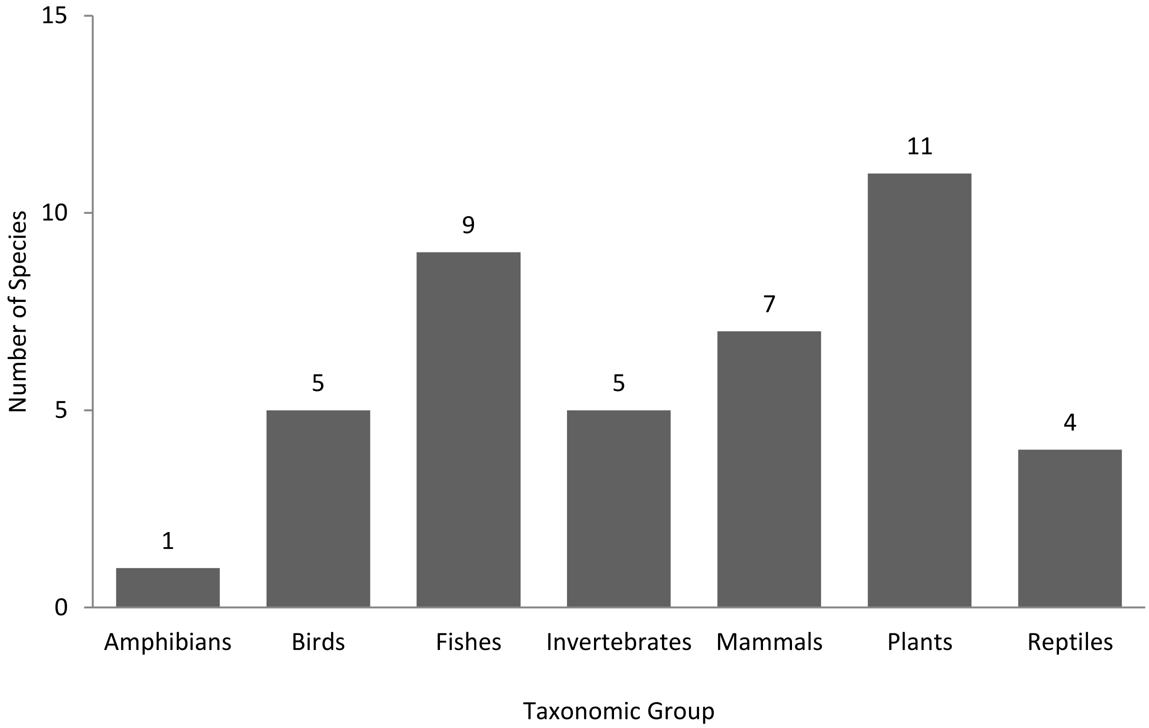

Figure F.5. Taxonomic distribution of species reviewed in experts survey. Counts are presented above bars.

Appendix G – Characterization of retrieved abundance and range estimates

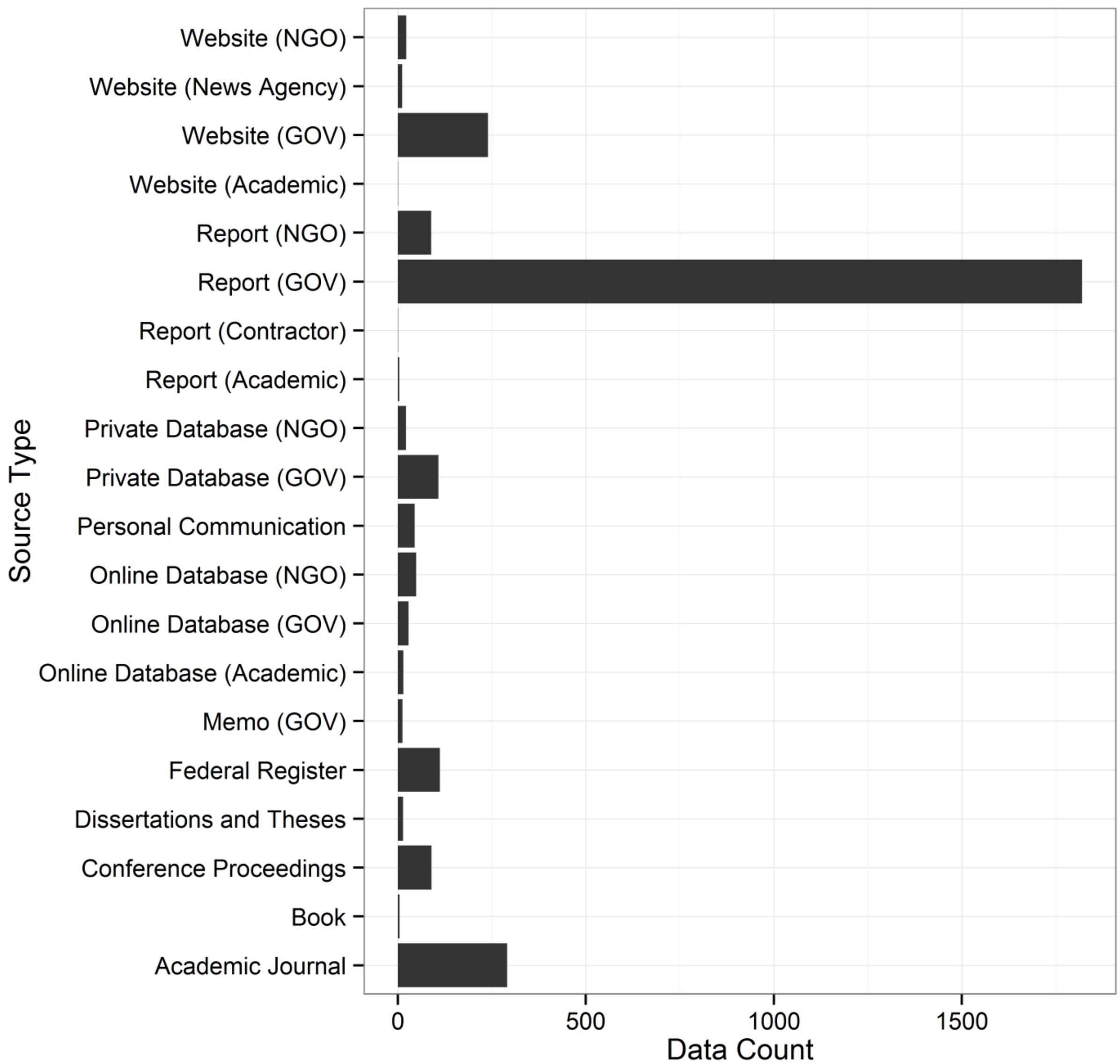

Figure G.1. Count of abundance and range data (N = 2,983) grouped according to publication source.

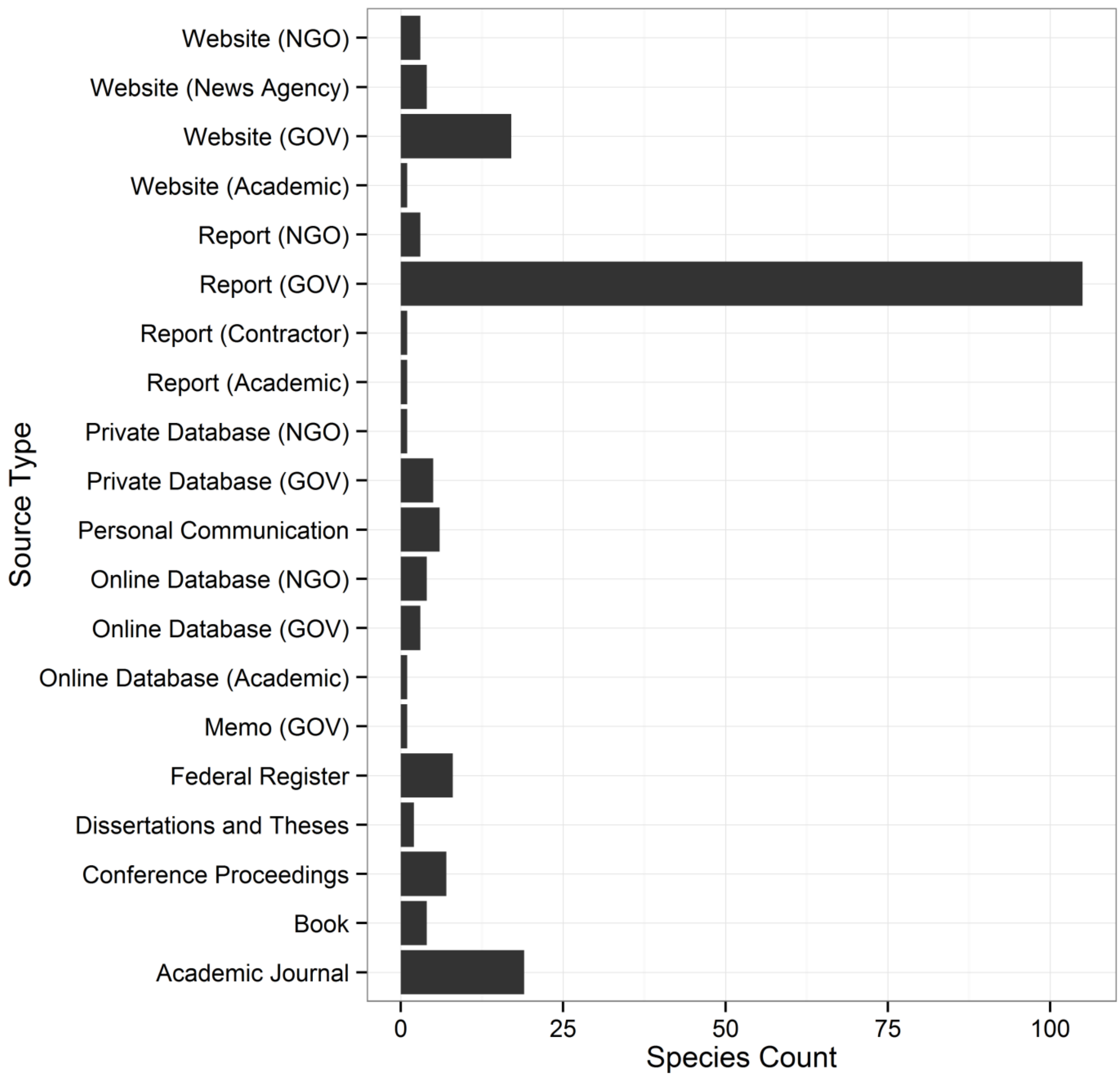

Figure G.2. Count of species for which abundance or range data were found in each publication source.

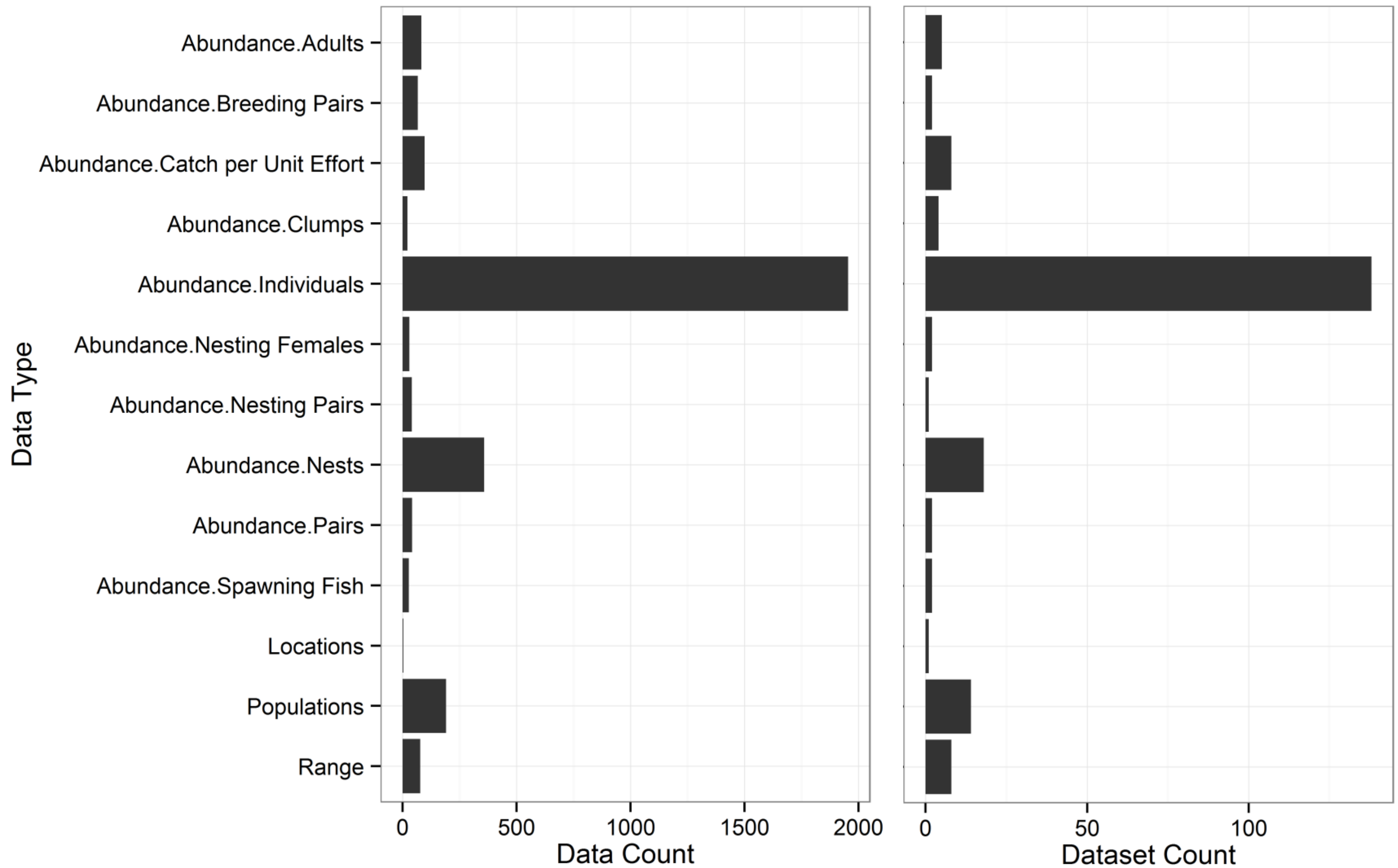

Figure G.3. Counts of abundance and range data (N = 2,983) (Panel A) and datasets (N = 205) (Panel B), grouped by measurement type.

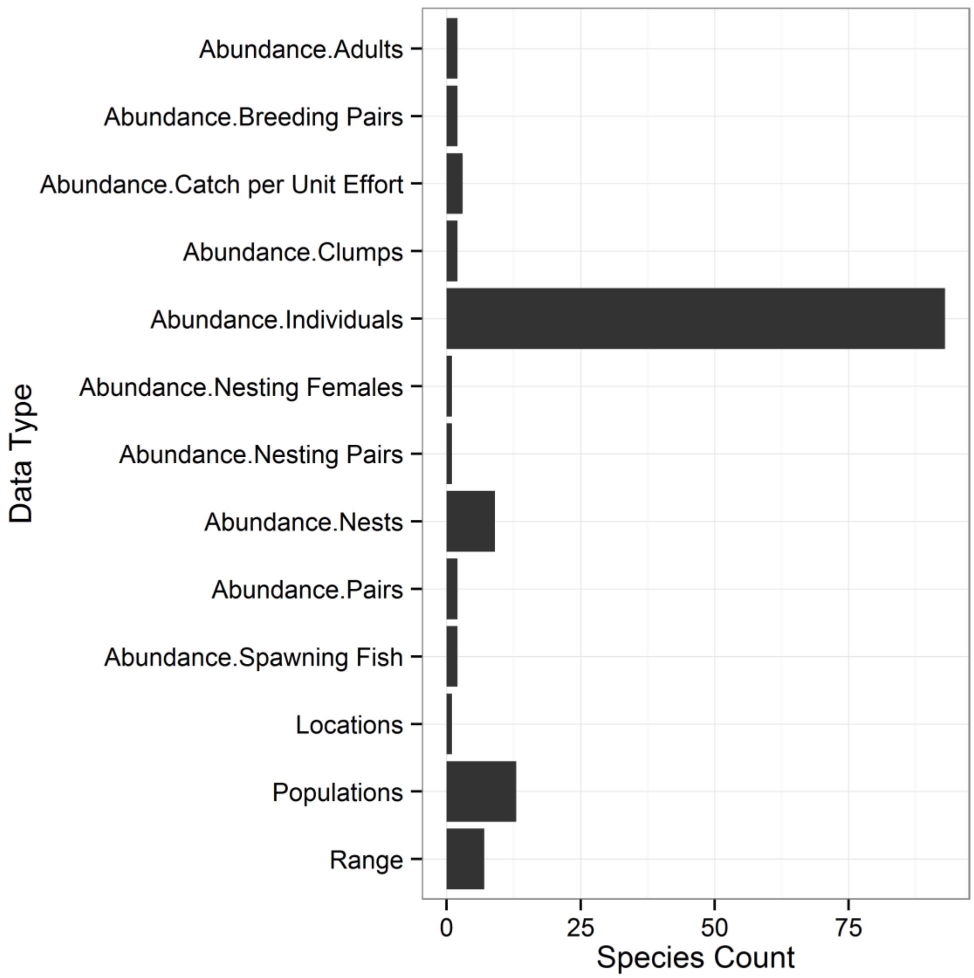

Figure G.4. Species counts, grouped according to dataset measurement type.

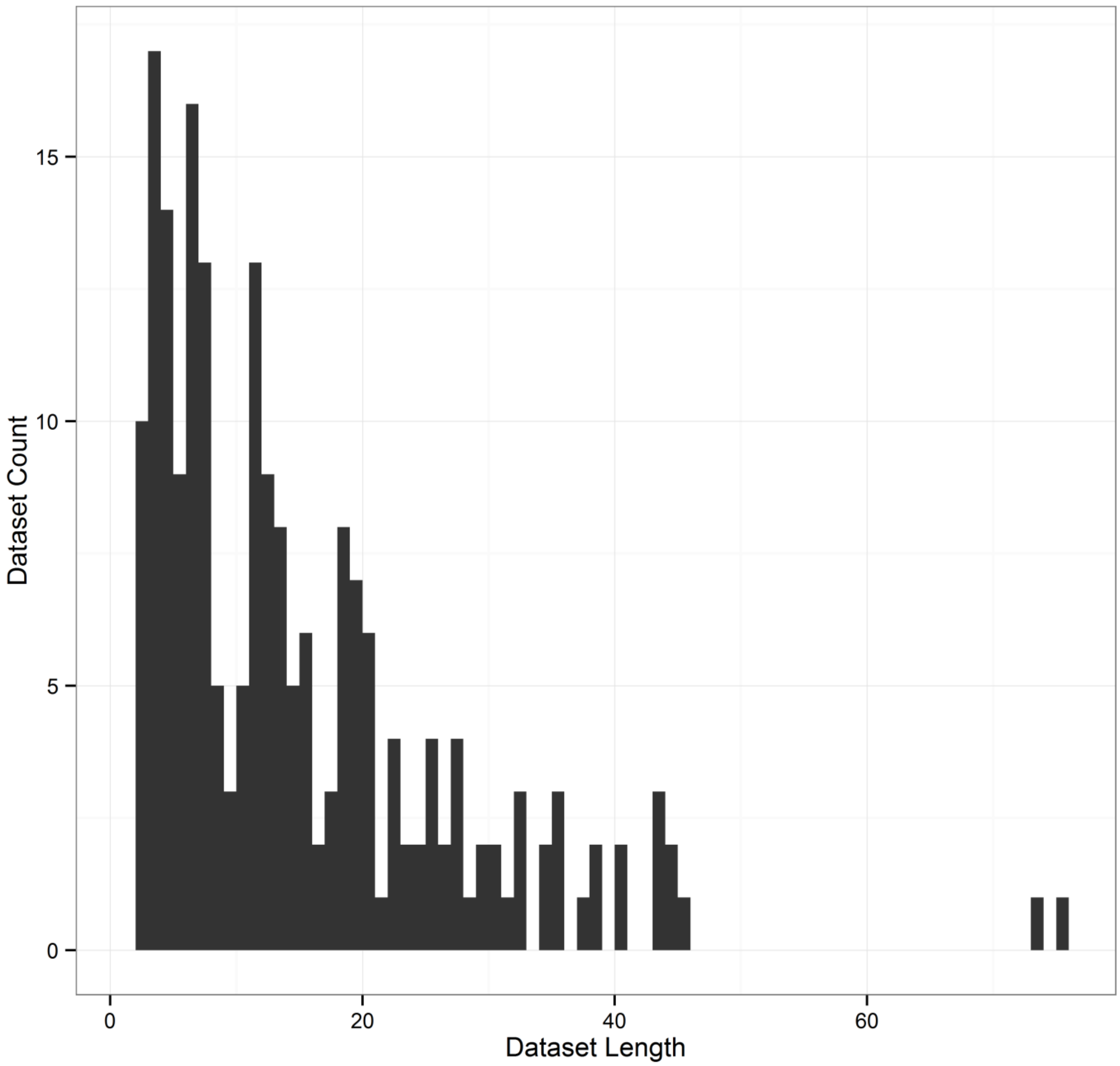

Figure G.5. Count of species' datasets (N = 205) ordered by length (number of individual years of observation).

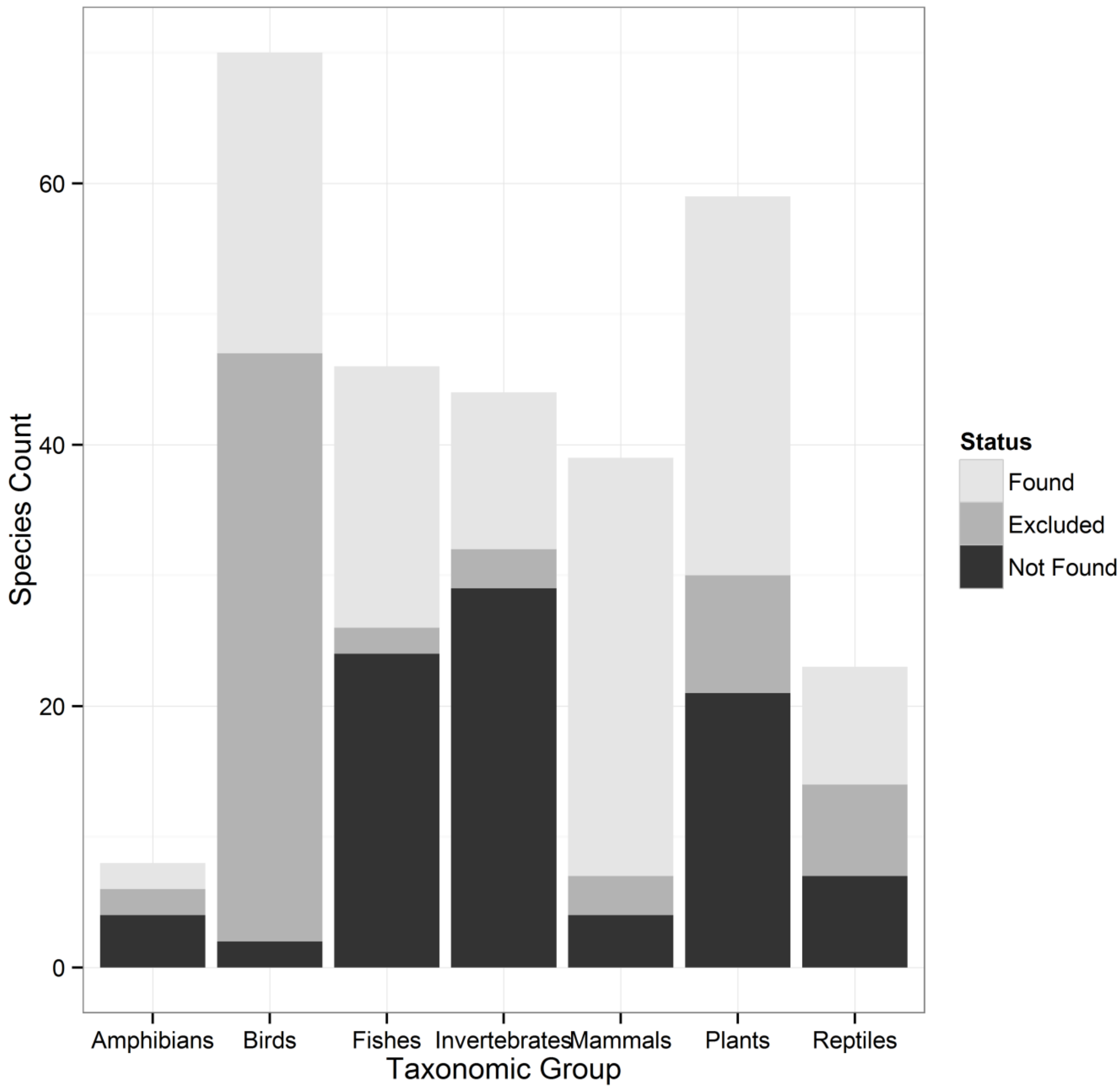

Figure G.7. Count of pre-1981 U.S. ESA-listed species ordered by taxonomic group. Number of species for which data was found = 127; number of species excluded from search = 72; number of species for which data was not found = 91.

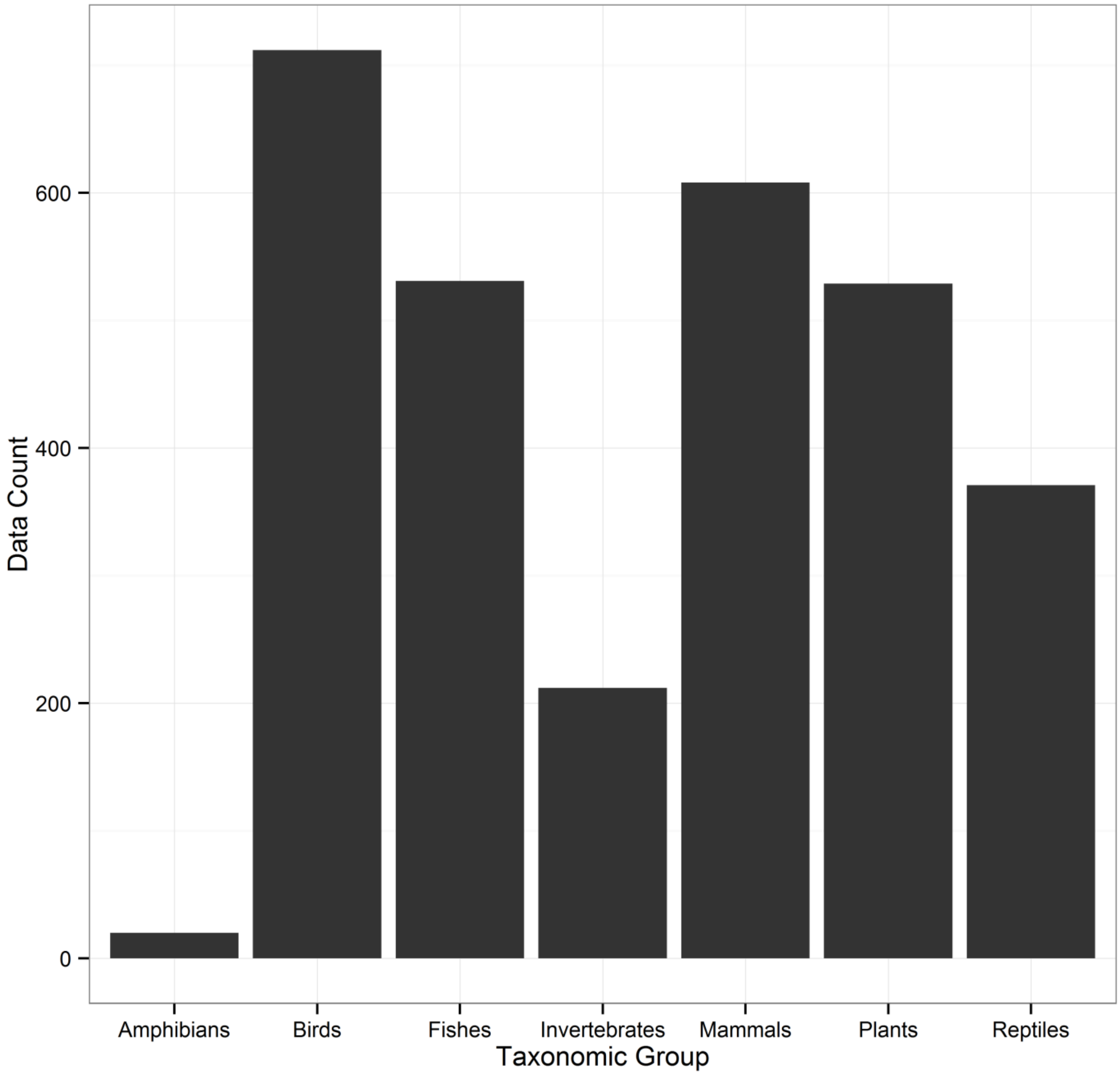

Figure G.8. Count of abundance and range data (N = 2,983) organized by taxonomic group of associated species.

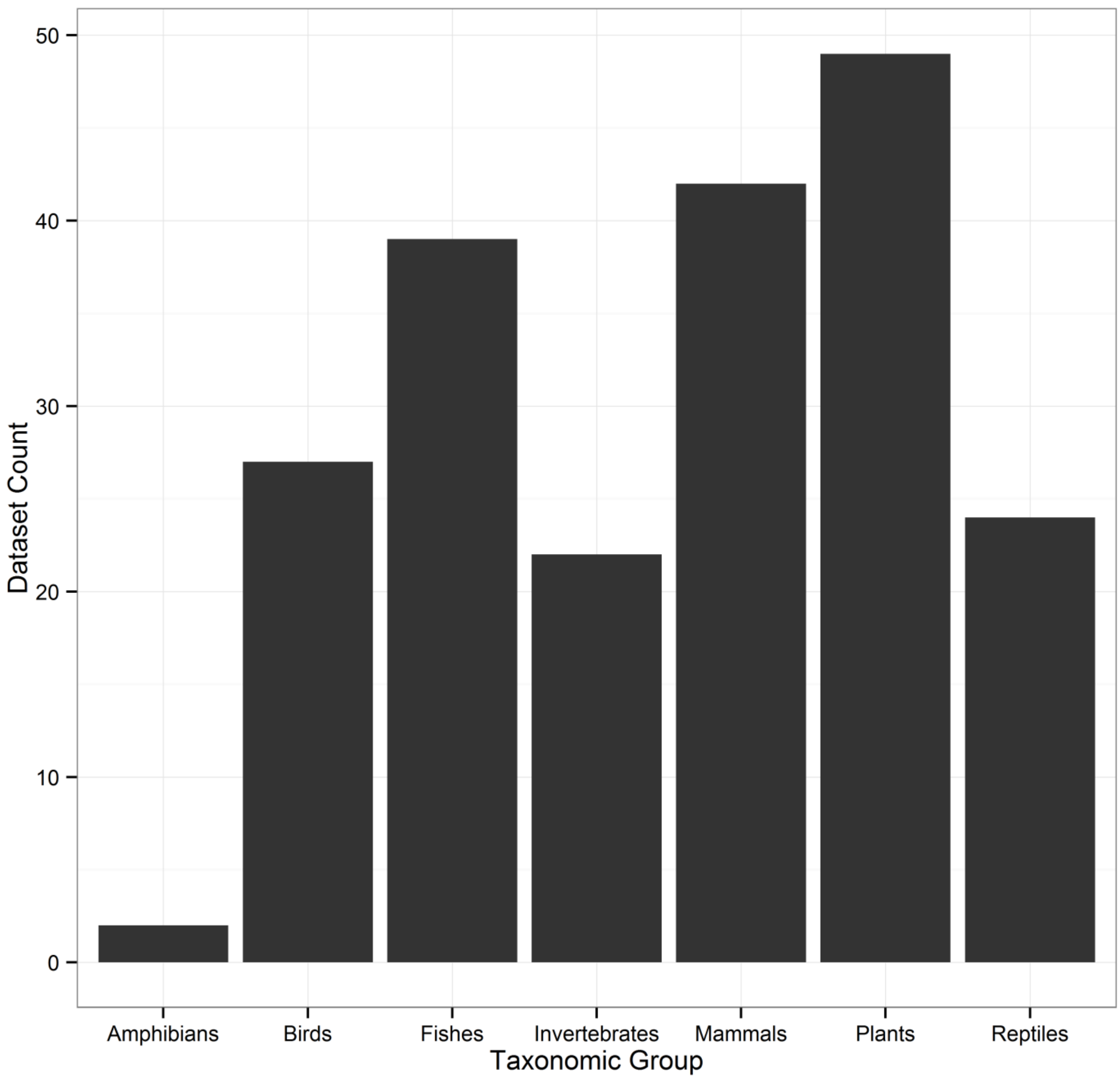

Figure G.9. Count of abundance and range datasets (N = 205) organized by taxonomic group of associated species.

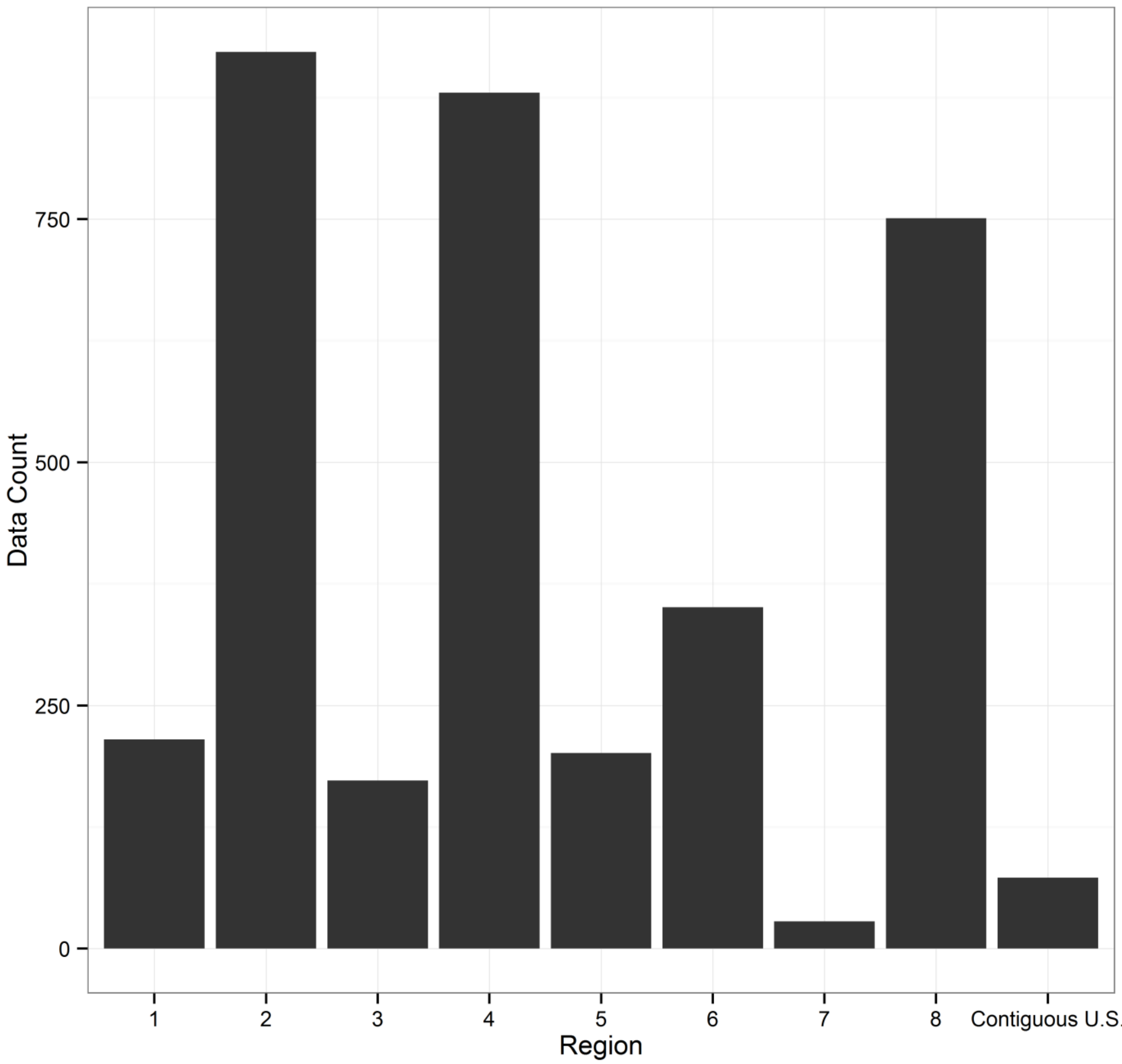

Figure G.10. Distribution of abundance and range data (N = 2,983) across U.S. FWS Regions or Contiguous U.S. (1 = Pacific Region; 2 = Southwest Region; 3 = Great Lakes-Big River Region; 4 = Southeast Region; 5 = Northeast Region; 6 = Mountain-Prairie Region; 7 = Alaska Region; 8 = California and Nevada Region).

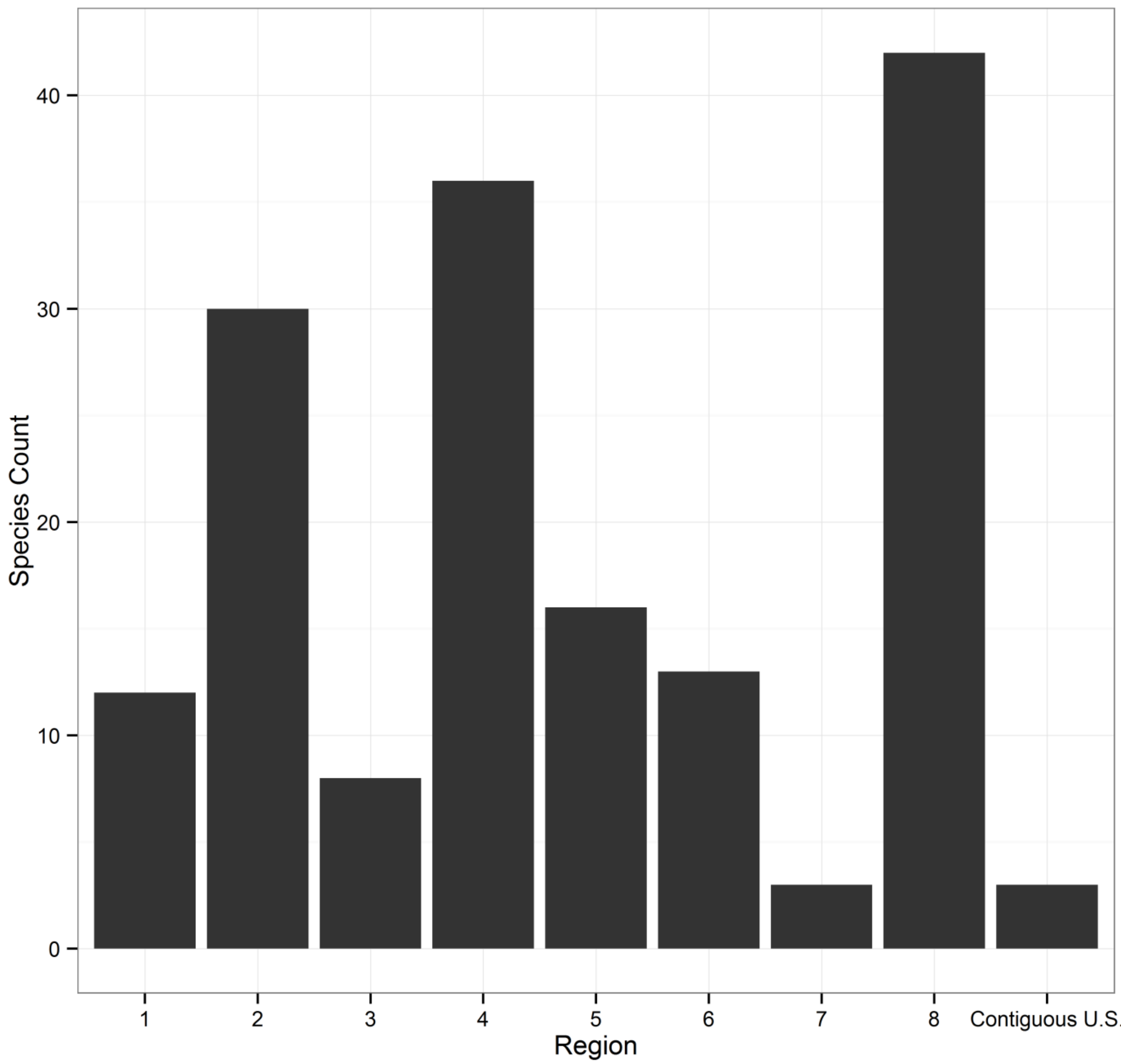

Figure G.11. Distribution species across U.S. FWS Regions or Contiguous U.S. 1 = Pacific Region; 2 = Southwest Region; 3 = Great Lakes-Big River Region; 4 = Southeast Region; 5 = Northeast Region; 6 = Mountain-Prairie Region; 7 = Alaska Region; 8 = California and Nevada Region.

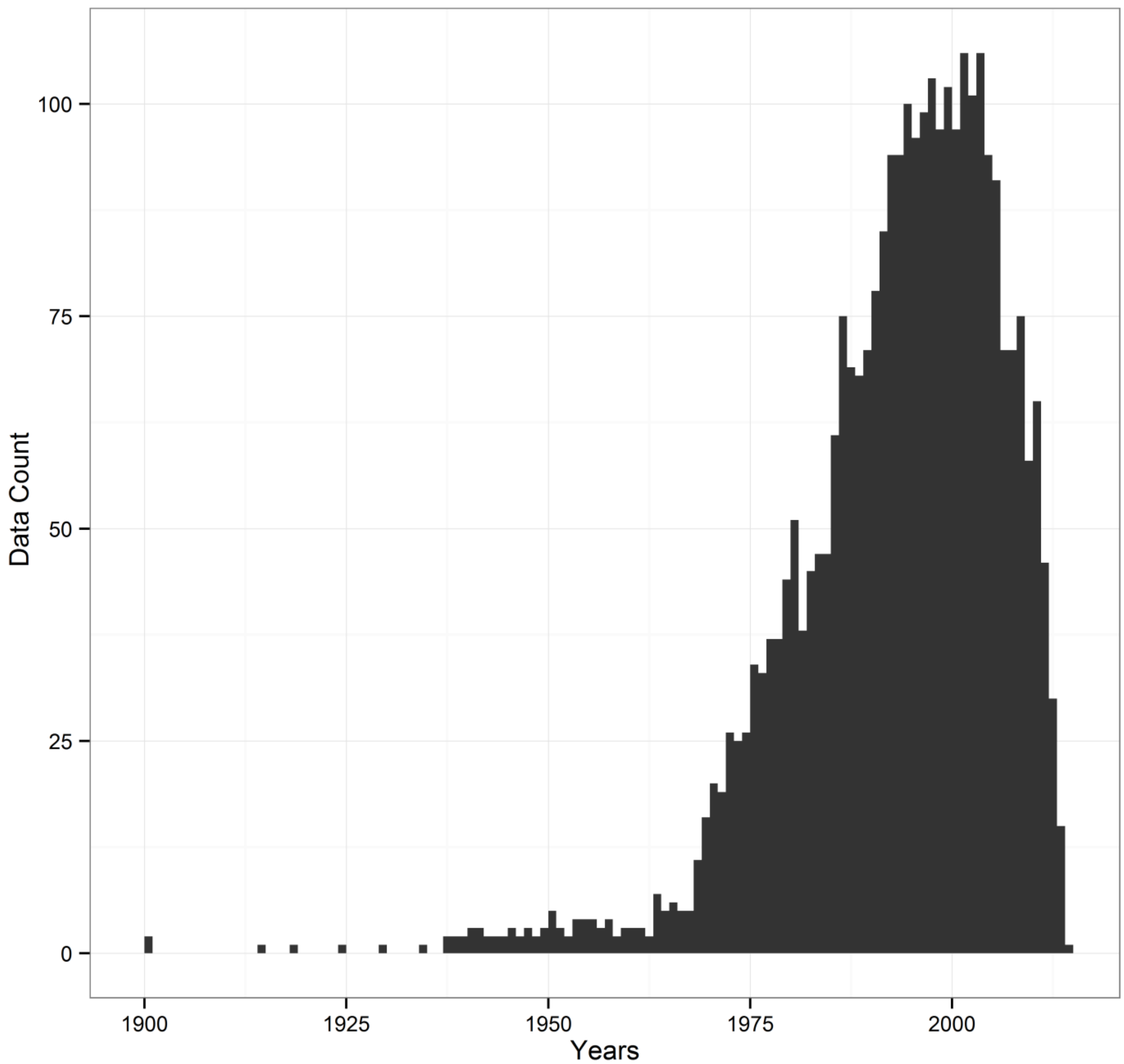

Figure G.12. Temporal distribution of count of abundance and range data (N = 2,983) from 1900 to 2014.

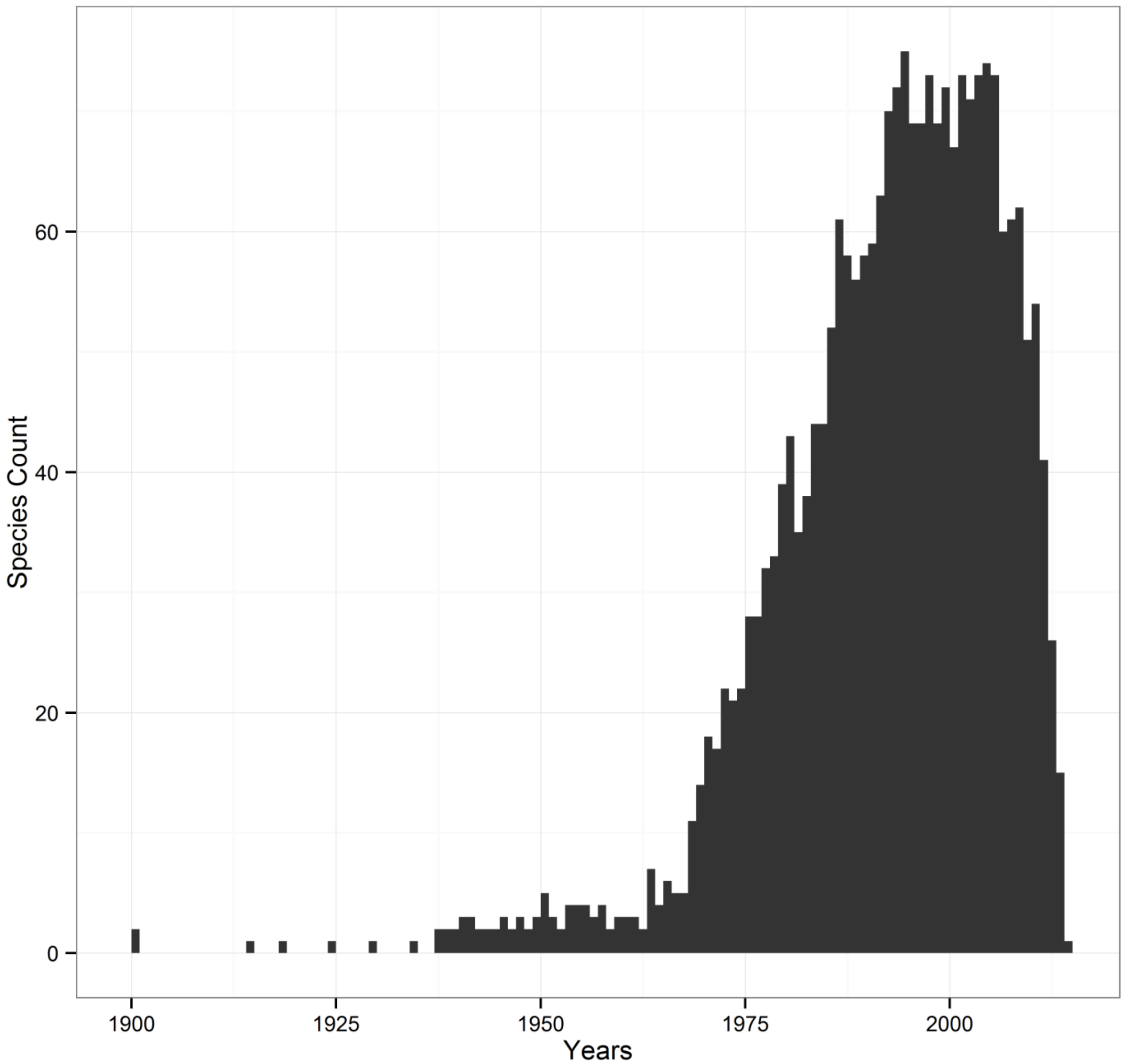

Figure G.13. Temporal distribution of count of species with data collected from 1900 to 2014.

APPENDIX H – EXAMPLE OF TREATMENT OF NON-MONOTONIC DATASETS

For abundance or range datasets with clear non-monotonic trends, regression estimates were based on the most recent subset of the data for which the time trend was considered approximately monotonic. Figure H.1 illustrates an example for Kemp Ridley's Sea Turtle nest counts from U.S. FWS managed beaches in the Gulf of Mexico. Yearly monitoring data from 1966 – 1999 show a clear quadratic trend. To calculate Recovery Slope, only estimates after the minimum value in the quadratic function were used - approximately the year 1984.

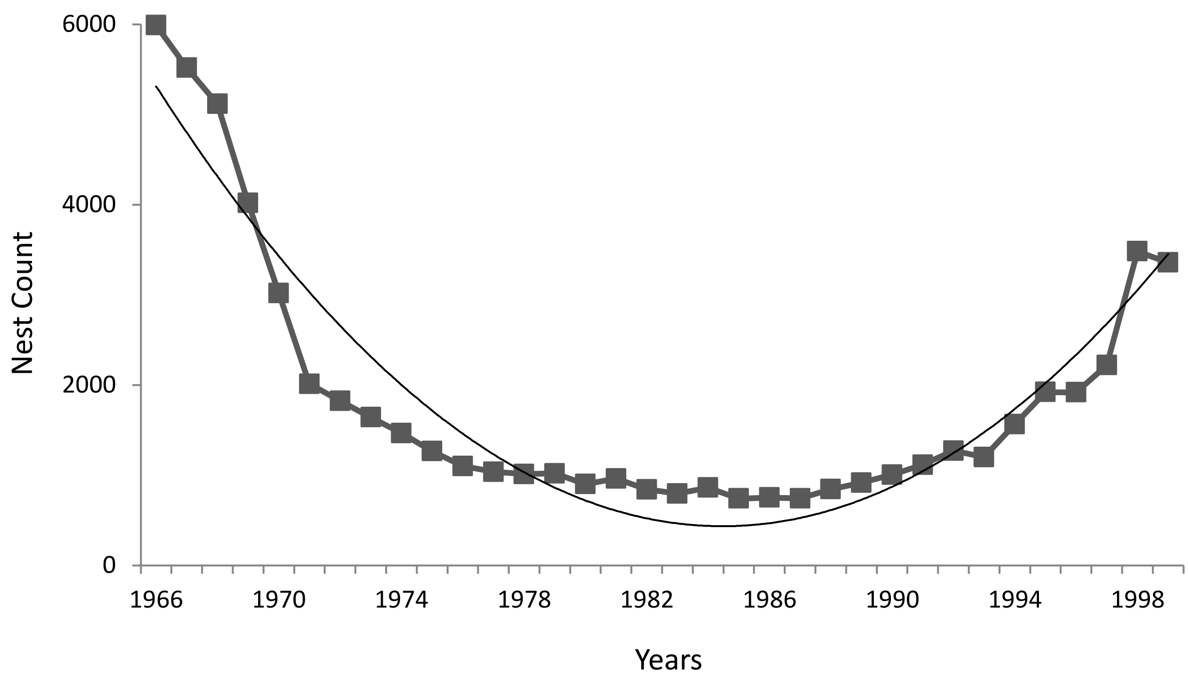

Figure H.1. Nest count estimates from U.S. FWS managed beaches in the Gulf of Mexico for Kemp Ridley's Sea Turtle (*Lepidochelys kempii*). A second order polynomial trend line is presented.

APPENDIX I – U.S. ESA TOOLS METADATA

Taxon: Categorical variable where 1 = birds, 2 = fish, 3 = herptiles, 4 =invertebrates, 5 = mammals, and 6= plants

Yearslisted: Number of years the species has been listed using 2004 as the base year.

CH: Categorical variable, where 1 = critical habitat has been designated, 0 = critical habitat has not been designated.

OriginalRPYear: Year in which the species first Recovery Plan was approved.

RecentRPYear: Year of most recent revision of species Recovery Plan.

Information: Natural log transformed number of studies found from a Web of Science search conducted in July 2007 of each species' scientific name.

MeanFund: Natural log transformed mean yearly funding including all reported federal and state funding.

APPENDIX J – SUPPORTING INFORMATION FOR INCLUDING ABUNDANCE AND RANGE DATASETS WITH ≥ 7 OBSERVATIONS IN U.S. ESA TOOLS AND THREATS AND RECOVERY ACTIONS MODELS

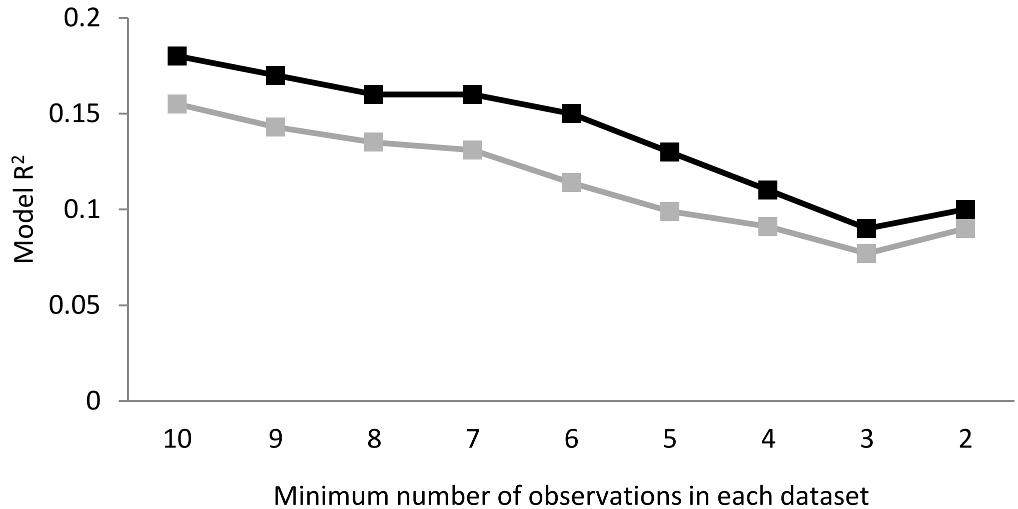

Figure J.1. Reduction in U.S. ESA tools model R^2 with inclusion of Recovery Slope (RS) measures calculated from datasets with fewer observations. Black line indicates RS calculated with data since 1989; light grey since U.S. ESA listing date. Model is RS ~ Mean Funding – Years Since U.S. ESA Listing.

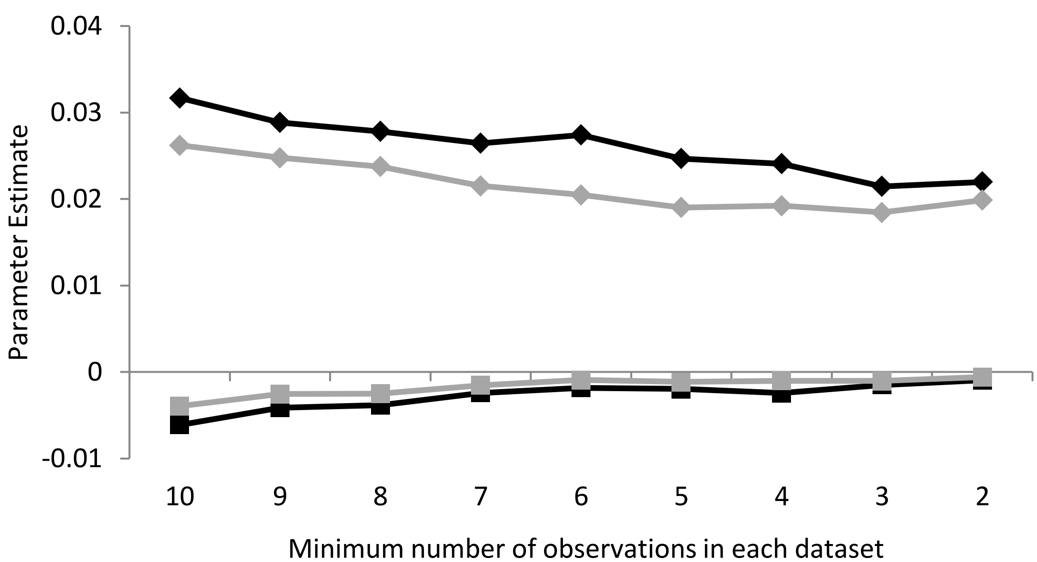

Figure J.2. Change in U.S. ESA tools model parameter estimates with inclusion of Recovery Slope (RS) measures calculated from datasets with fewer observations. Model is RS ~ Mean Funding – Years Since U.S. ESA Listing. Black lines indicate RS calculated with data since 1989; light grey since U.S. ESA listing date. Diamond shaped points represent Mean Funding estimates and square shaped points represent Years Since U.S. ESA Listing estimates.

Appendix K – Threats and recovery actions variables metadata

BIO3115.ESA.1

Hello BIO3115 students. Please read through the notes below before starting the data pulling exercise.

The following fields should be completed for each of the species for which you are assigned (e.g. all those on your spreadsheet). Some of the fields below have been filled in already. Variable names are indicated below in blue, next to their descriptions.

Species Recovery Plans, Plan Action Statuses, Five-Year Reviews, and Post-delisting Monitoring Plans will be used to mine data to complete your databases.

Both the US Fish and Wildlife Service and the National Marine Fisheries Service are mandated to create an Endangered Species Recovery Plan for each species listed under the US Endangered Species Act, which outlines the goals, tasks required, estimated costs and timeline to recovery.
Plan Action Statuses display the completion statuses of ongoing and planned recovery actions as proposed in the Recovery Plans.
Five-Year Reviews are periodic analyses of species' status conducted to ensure listing classifications are accurate. They take into consideration the five factors used to determine listing decisions: (1) habitat modification, destruction, or curtailment; (2) overutilization of the species for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or manmade threats to continued existence.
Section 4(g) of the Endangered Species Act requires the Fish and Wildlife Service to monitor, for a minimum of five years, any species that is delisted due to its recovery. The post-delisting monitoring focuses on reviewing and evaluating: (1) population characteristics (2) threats and (3) the implementation of legal and management commitments that are important in reducing threats or maintaining threats at sufficiently low levels.

To retrieve your documents, access the online shared drive HERE. Please download all of your documents to your own computers before continuing.

Before starting the data pulling, please go through each of your assigned documents to be sure you have the correct ones. If you are uncertain which of a species' documents correspond to those you were assigned to, please contact Shahira Khair for help.

Please do not pull your data with another volunteer – do your own independently. It is important from a statistical point of view that we have two volunteers pull the same data independently. In some cases you may have a few of the same species as another volunteer either in your group or in your class. Thank you for respecting the importance of keeping the data pulled independently.

Some advice to bear in mind when pulling data. Five Year Reviews are much shorter than Recovery Plans or Post Delisting Monitoring Plans, and can sometimes be read through quickly to find data. Unfortunately, none of the documents are consistent in structure or content across all species. For longer documents, before pulling data, scan the entire document to identify sections related to threats and recovery actions (for example, "Threats and Reasons for Listing", "Recovery Objectives and Criteria", "Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)"). Read through these sections to input related data. Following this, use key words searches of survey variables and their key words in their descriptions to complete your database. Example key words are indicated below in purple.

Plan Action Statuses are unique from the other document types, in that they are in table format, and correspond only to the Recovery Actions and Population Augmentation Variables. These should be read through thoroughly, paying special attention to only the "Action Status" column. Actions should only be noted as having been taken if their status is "Ongoing" or "Complete".

Some Five Year Review, Recovery Plan and Plan Action Status documents are compiled using an ecosystem approach, and thus contain information for multiple species. If reviewing one of these documents, please be careful to only include information pertaining to the assigned species.

Identifier Variables

ReviewerName: Name of reviewer associated with each entry (*already provided*).

KeyMaster: Unique identifier variable (*already provided*).

NameCommon: Common name(s) of species (*already provided*).

NameScientific: Scientific name(s) of species (*already provided*).

Taxon: Species taxonomic ranking (*already provided*).

Source: Enter type of document data is being pulled from. For a Species Recovery Plan, enter "1". For a Five Year Review, enter "2".

PubYear: Enter the year of publication of the document being reviewed

Threat Variables

Please read through all threat categories below before scoring.

Definition of threats from IUCN: "Direct threats are the proximate human activities or processes that have impacted, are impacting, or may impact the status of the taxon being assessed (e.g., unsustainable fishing or logging). Direct threats are synonymous with sources of stress and proximate pressures. Threats can be past (historical, unlikely to return or historical, likely to return), ongoing, and/or likely to occur in the future."

RCD (Residential and Commercial Development)
"Threats from human settlements or other non-agricultural land uses with a substantial footprint." For example: development of a housing community, military bases, shopping centres, train yards, landfills, ski hills, resorts, campgrounds.

Example Key Words: resident, settle, commerce| commercial, develop, urban, military, housing, construct

If it explicitly states residential and commercial development is a threat, enter "1".

If it explicitly states residential and commercial development is not a threat, enter "0". If it is unknown whether residential and commercial development is a threat or not, or there is no information on this threat, enter "999".

AG (Agriculture & Aquaculture)
"Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture (includes the impacts of any fencing around farmed areas)." For example: grazing, stands of timber planted outside of forested areas, crops.

Example Key Words: agri| agriculture, aqua| aquaculture, farm, ranch, develop, forestry, culture, crop

If it explicitly states agriculture is a threat, enter "1".

If it explicitly states agriculture is not a threat, enter "0". If it is unknown whether agriculture is a threat or not, or there is no information on this threat, enter "999".

EPM (Energy Production and Mining)
"Threats from production of non-biological resources." For example: Exploring for, developing, and producing: petroleum and other liquid hydrocarbons; minerals and rocks; renewable energy; oil spills that result at a drill site (note: oil spills that result from tankers or pipelines would go into Transportation and Service Corridors below).

Example Key Words: energy, mining, development, produce| production, carbon, drill, oil, mineral, rock, construct

If it explicitly states energy production and mining is a threat, enter "1".

If it explicitly states energy production and mining is not a threat, enter "0". If it is unknown whether energy production and mining is a threat or not, or there is no information on this threat, enter "999".

TSC (Transportation and Service Corridors)
"*Threats from long narrow transport corridors and the vehicles that use them, including associated wildlife mortality. This class includes transportation corridors outside of human settlements and industrial developments."* For example: highways, secondary roads, logging roads, bridges, road kill, electrical & phone wires, oil & gas pipelines, electrocution of wildlife, flight paths.

Example Key Words: transport, corridor, road, path, channel, highway, wire, pipe, power, line, construct

If it explicitly states transportation and service corridors is a threat, enter "1".

If it explicitly states transportation and service corridors is not a threat, enter "0". If it is unknown whether transportation and service corridors is a threat or not, or there is no information on this threat, enter "999".

BRU (Biological Resource Use)
"*Threats from consumptive use of "wild" biological resources including both deliberate and unintentional harvesting effects; also persecution or control of specific species*." *Note:*

Consumptive means either directly or indirectly removed or destroyed. For example: killing or trapping animals, butterfly collecting, harvesting plants, persecution.

Example Key Words: harvest, hunt, collect, remove| removal, kill, destroy| destruction, persecute| persecution, trap, control

If it explicitly states biological resource use is a threat, enter "1".

If it explicitly states biological resource use is not a threat, enter "0". If it is unknown whether biological resource use is a threat or not, or there is no information on this threat, enter "999".

HIM (Human Intrusions and Disturbance)
"*Threats from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources*." For example: off-road vehicles, snowmobiles, hikers, cross-country skiers, birdwatchers, pets brought into conflict, mine fields, tanks & other military vehicles, training exercises & ranges, defoliation, munitions testing, etc.

Example Key Words: intrude| intrusion, disturb, alter, destroy| destruction, disrupt, damage

If it explicitly states human intrusions and disturbance is a threat, enter "1".

If it explicitly states human intrusions and disturbance is not a threat, enter "0". If it is unknown whether human intrusions and disturbance is a threat or not, or there is no information on this threat, enter "999".

NSM (Natural Systems Modifications)
"*Threats from actions that convert or degrade habitat in service of "managing" natural or semi-natural systems, often to improve human welfare*." "*This category deals primarily with changes to natural processes such as fire, hydrology, and sedimentation, rather than land use."* For example: human activities that cause either too much or too little fire/water in a system; dams or other water management; tree thinning in parks, beach construction.

Example Key Words: modify| modification, manage, system, dam, hydro, construct

If it explicitly states natural systems modifications is a threat, enter "1".

If it explicitly states natural systems modifications is not a threat, enter "0". If it is unknown whether natural systems modifications is a threat or not, or there is no information on this threat, enter "999".

IOP (Invasive & Other Problematic Species, Genes & Diseases)
"Threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance."

Example Key Words: invasive| invasion, foreign, alien, native

If it explicitly states invasive and other problematic species, genes and diseases is a threat, enter "1".

If it explicitly states invasive and other problematic species, genes and diseases is not a threat, enter "0". If it is unknown whether invasive and other problematic species, genes and diseases is a threat or not, or there is no information on this threat, enter "999".

POL (Pollution)
"Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources." For example: Waste water effluent, oil spills, mining seepage, rubbish including rubbish that entangle wildlife, noise pollution.

Example Key Words: pollute| pollutant| pollution, contaminate| contamination, effluent, tailing, point, source, waste, runoff, emission, release

If it explicitly states pollution is a threat, enter "1".

If it explicitly states pollution is not a threat, enter "0". If it is unknown whether pollution is a threat or not, or there is no information on this threat, enter "999".

GE (Geological Events)
"Threats from catastrophic geological events." For example: volcanoes and earthquakes.

Example Key Words: geology| geological, disturb, natural, disaster, earthquake, volcano, meteor

If it explicitly states geological events is a threat, enter "1".

If it explicitly states geological events is not a threat, enter "0". If it is unknown whether geological events is a threat or not, or there is no information on this threat, enter "999".

CCSW (Climate Change and Severe Weather)
"*Threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation, or potentially can wipe out a vulnerable species or habitat*." For example: sea level rise, desertification, hurricanes, tornadoes, drought, and erosion of beaches during severe storms.

Example Key Words: climate, weather, global warm, extreme, severe, natural, disaster, flood, drought, fire, hurricane, tornado, erosion, sea level rise

If it explicitly states climate change and severe weather is a threat, enter "1".

If it explicitly states climate change and severe weather is not a threat, enter "0". If it is unknown whether climate change and severe weather is a threat or not, or there is no information on this threat, enter "999".

Recovery Action Variables

Threat Reduction Actions

Please read through all recovery action categories below before scoring.

Definition of Recovery actions from US FWS: Recovery actions refer to acts that prevent further loss of a species, and remove or reduce threats … and are considered necessary to recovery species and their habitats.

Habitat Modification

EPMHab (Elimination/ Prevention of Source of Habitat Modification)
Actions that eliminate or prevent direct or indirect sources of habitat alteration, which diminish the ability for habitat to enable species' survival or recovery (for example, restrictions placed on removal or alteration of habitat activities, such as logging, grass-burning hydro-dam building/operations).

Example Key Words: habitat, modify| modification, change, alter, prevent, eliminate| elimination

If it is explicitly stated that actions have been taken to eliminate or prevent a source of habitat modification, enter "1".

If it is explicitly stated that actions have not been taken to eliminate or prevent a source of habitat modification, enter "0".

If it is unknown whether or not actions have been taken to eliminate or prevent a source of habitat modification, or there is no information on this recovery action, enter "999" in this field.

PRHab (Protection of Remaining Habitat)
Actions to conserve and protect habitat essential to the continued survival or recovery of a species (for example, creation of wildlife reserves or protected areas that disallow multiple destructive activities).

Example Key Words: habitat, protect, conserve| conservation, preserve| preservation, reserve| reservation

If it is explicitly stated that actions have been taken to protect remaining areas of species' habitat, enter "1".

If it is explicitly stated that actions have not been taken to protect remaining areas of species' habitat, enter "0".

If it is unknown whether or not actions have been taken to protect remaining areas of species' habitat, or there is no information on this recovery action, enter "999" in this field.

RRHab (Restoration and/or Rehabilitation of Habitat)
Action to the effect of restoring degraded habitat to its 'original' state (for example, soil de-contamination, re-forestation, re-introduction of food sources).

Example Key Words: habitat, restore| restoration, rehab, repair, establish

If it is explicitly stated that actions have been taken to restore or rehabilitate areas of species' habitat, enter "1".

If it is explicitly stated that actions have not been taken to restore or rehabilitate areas of species' habitat, enter "0".

If it is unknown whether or not actions have been taken to restore or rehabilitate areas of species' habitat, or there is no information on this recovery action, enter "999" in this field.

ENHab (Active Enhancement of Habitat)
Actions to the effect of restoring degraded habitat to a state deemed to be better than its 'original' state (for example, stocking food sources in greater supply that naturally found, creation or conversion of more suitable habitat that naturally found).

Example Key Words: habitat, restore| restoration, enhance, improve, better

If it is explicitly stated that actions have been taken to actively enhance areas of species' habitat, enter "1".

If it is explicitly stated that actions have not been taken to actively enhance areas of species' habitat, enter "0".

If it is unknown whether or not actions have been taken to actively enhance areas of species' habitat, or there is no information on this recovery action, enter "999" in this field.

Pollution

ERPSPoll (Elimination or Reduction of Point Source Pollution)
Actions to stop or reduce the emissions or releases to air, land, or water of a single identifiable source of pollution (for example, placing restrictions on emissions and releases contents and/ or total amounts).

Example Key Words: pollute| pollutant| pollution, eliminate| elimination, reduce| reduction, stop, point, source, emission, release, contaminant, toxin, pollution

If it is explicitly stated that actions have been taken towards the elimination or reduction of point source pollution, enter "1".

If it is explicitly stated that actions have not been taken towards the elimination or reduction of point source pollution, enter "0".

If it is unknown whether or not actions have been taken towards the elimination or reduction of point source pollution, or there is no information on this recovery action, enter "999" in this field.

ERNonPSPoll (Elimination or Reduction of Non-Point Source Pollution)
Actions to stop or reduce the emissions or releases to air, land or water of many diffuse sources of pollution (for example, creation of buffer zones, retention ponds and/ or erosion control structures around habitat of interest, to control runoff).

Example Key Words: pollute| pollutant| pollution, eliminate| elimination, reduce| reduction, stop, point, source, emission, release, contaminant, toxin, buffer, diffuse

If it is explicitly stated that actions have been taken towards the elimination or reduction of non-point source pollution, enter "1".

If it is explicitly stated that actions have not been taken towards the elimination or reduction of non-point source pollution, enter "0".

If it is unknown whether or not actions have been taken towards the elimination or reduction of non-point source pollution, or there is no information on this recovery action, enter "999" in this field.

Invasive or Problematic Species

DBCtrl (Direct Biological Control)
Direct actions targeting biological control of invasive or problematic species (for example: culling species of interest, introduction of parasites or disease targeted to species of interest).

Example Key Words: direct, control, target, invasive| invasion, parasite, disease, kill, cull, remove| removal, destroy| destruction

If it is explicitly stated that direct biological control of invasive or problematic species has occurred, enter "1".

If it is explicitly stated that direct biological control of invasive or problematic species has not occurred, enter "0".

If it is unknown whether or not direct biological control of invasive or problematic species has occurred, or there is no information on this recovery action, enter "999" in this field.

InDBCtrl (Indirect Biological Control)
Indirect actions targeting biological control of invasive or problematic species (for example: modification of species of interest's habitat or food sources).

Example Key Words: indirect, control, target, invasive, parasite, disease, modify| modification, alter, change

If it is explicitly stated that indirect biological control of invasive or problematic species has occurred, enter "1".

If it is explicitly stated that indirect biological control of invasive or problematic species has not occurred, enter "0".

If it is unknown whether or not indirect biological control of invasive or problematic species has occurred, or there is no information on this recovery action, enter "999" in this field.

RVec (Vector Reduction)
Restriction of pathways of movement transmission of invasive or problematic species (for example: importation bans, mandatory cleansing/ disinfection procedures).

Example Key Words: vector, path, move| movement, transmission, invasive| invasion, problem| problematic, ban, clean, infect

If it is explicitly stated that actions have been taken to control invasive or problematic species transmission vectors, enter "1".

If it is explicitly stated that actions have not been taken to control invasive or problematic species transmission vectors, enter "0".

If it is unknown whether or not actions have been taken to control invasive or problematic species transmission vectors, or there is no information on this recovery action, enter "999" in this field.

Over-Exploitation

RDCommEx (Reduction of Direct Commercial Exploitation)
Actions reducing the harmful impact of direct exploitation of a species for commercial means (for example: imposing fishing catch limits or bans on commercial vessels).

Example Key Words: commerce| commercial, sell, trade, export, import, exploit, hunt, fish, gather, ban, reduce| reduction, restrict, limit, control

If it is explicitly stated that actions have been taken to reduce direct commercial exploitation, enter "1".

If it is explicitly stated that actions have not been taken to reduce direct commercial exploitation, enter "0".

If it is unknown whether or not actions have been taken to reduce direct commercial exploitation, or there is no information on this recovery action, enter "999" in this field.

RDSubEx (Reduction of Direct Subsistence/ Recreational Exploitation)
Actions reducing the harmful impact of direct exploitation of a species for subsistence or recreational means (for example: setting fishing catch, hunting and gathering limits or bans on individuals and poachers).

Example Key Words: recreation, subsistence, sport, game, exploit, hunt, fish, gather, ban, reduce| reduction, restrict, limit, control

If it is explicitly stated that actions have been taken to reduce direct subsistence and/or recreational exploitation, enter "1".

If it is explicitly stated that actions have not been taken to reduce direct subsistence and/or recreational exploitation, enter "0".

If it is unknown whether or not actions have been taken to reduce direct subsistence and/or recreational exploitation, or there is no information on this recovery action, enter "999" in this field.

RInDCommEx (Reduction of Indirect Commercial Exploitation)
Actions reducing the harmful impact of commercial exploitation done indirectly to species of interest (for example: setting by catch restrictions for commercial fishing vessels, imposing regulation through commercial incidental take permits).

Example Key Words: commerce| commercial, sell, trade, export, import, exploit, hunt, fish, gather, ban, reduce| reduction, restrict, limit, control, by catch, take

If it is explicitly stated that actions have been taken to reduce indirect commercial exploitation, enter "1".

If it is explicitly stated that actions have not been taken to reduce indirect commercial exploitation, enter "0".

If it is unknown whether or not actions have been taken to reduce indirect commercial exploitation, or there is no information on this recovery action, enter "999" in this field.

RInDSubEx (Reduction of Indirect Subsistence/ Recreational Exploitation)
Actions reducing the harmful impact of subsistence or recreational exploitation done indirectly to species of interest (for example: setting by catch restrictions from subsistence or recreational fishing, hunting and gathering, imposing regulation through personal incidental take permits).

Example Key Words: recreation, subsistence, sport, game, exploit, hunt, fish, gather, ban, reduce| reduction, restrict, limit, control, by catch, take

If it is explicitly stated that actions have been taken to reduce indirect subsistence or recreational exploitation, enter "1".

If it is explicitly stated that actions have not been taken to reduce indirect subsistence or recreational exploitation, enter "0".

If it is unknown whether or not actions have been taken to reduce indirect subsistence or recreational exploitation, or there is no information on this recovery action, enter "999" in this field.

Population Augmentation Actions

Please read through all population augmentation categories below before scoring.

Definition of Population Augmentation: Method of reducing species loss via augmenting declining or threatened populations with individuals from captive-bred, or stable, wild populations.

SpIN (Species Introduction)
Releasing species into areas where they have never before existed (old habitat being gone, or degraded, but new habitat is considered suitable).

Example Key Words: introduce, release, establish

If it is explicitly stated that species introductions have occurred, enter "1".

If it is explicitly stated that species introductions have not occurred, enter "0".

If it is unknown whether or not species introductions have occurred, or there is no information on this population augmentation action, enter "999" in this field.

SpREIN (Species Re-Introduction)
Releasing captive species into areas where they existed in the past.

Example Key Words: re-introduce| introduce, captive, release, re settle

If it is explicitly stated that species re-introductions have occurred, enter "1".

If it is explicitly stated that species re-introductions have not occurred, enter "0".

If it is unknown whether or not species re-introductions have occurred, or there is no information on this population augmentation action, enter “999” in this field.

SpRELOC (Species Relocation)
Relocating species to areas where they once existed, but no longer are found.

Example Key Words: relocate, move, resettle, transplant

If it is explicitly stated that species relocations have occurred, enter “1”.

If it is explicitly stated that species relocations have not occurred, enter “0”.

If it is unknown whether or not species relocations have occurred, or there is no information on this population augmentation action, enter “999” in this field.

SPTLOC (Species Translocation)
Moving species between occupied areas as a means to increase genetic variability, and local population viability.

Example Key Words: translocate, move, distribute| distribution

If it is explicitly stated that species translocations have occurred, enter “1”.

If it is explicitly stated that species translocations have not occurred, enter “0”.

If it is unknown whether or not species translocations have occurred, or there is no information on this population augmentation action, enter “999” in this field.

CAPB (Captive Breeding)
The process of breeding animals in human controlled environments with restrictive settings, in order to counter extinction rate (may include eventual goal of re-introduction).

Example Key Words: captive| captivity, breed| breeding

If it is explicitly stated that captive breeding programs have been employed, enter “1”.

If it is explicitly stated that captive breeding programs have not been employed, enter “0”.

If it is unknown whether or not captive breeding programs have been employed, or there is no information on this population augmentation action, enter “999” in this field.

FHATCH (Fish Hatcheries)
The process of artificially breeding, hatching and rearing larval and juvenile fish to supplement natural populations.

Example Key Words: fish, hatchery, artificial, breed| breeding, hatch| hatching, rear| rearing, supplement

If it is explicitly stated that fish hatcheries have been employed, enter “1”.

If it is explicitly stated that fish hatcheries have not been employed, enter “0”.

If it is unknown whether or not fish hatcheries have been employed, or there is no information on this population augmentation action, enter “999” in this field.

GSBANK (Gene or Seed Banks)
Types of bio-repositories which preserve genetic material. In plants, often accomplished through socking seeds; whereas in animals, freezing of sperm and eggs in zoological freezers is required.

Example Key Words: gene, seed, bank, repository, store| storage| storing

If it is explicitly stated that gene or seed banks have been employed, enter “1”.

If it is explicitly stated that gene or seed banks have not been employed, enter “0”.

If it is unknown whether or not gene or seed banks have been employed, or there is no information on this population augmentation action, enter “999” in this field.

APPENDIX L – THREAT AND RECOVERY ACTION PROFILES FOR BIRDS, FISHES, MAMMALS AND PLANTS TAXONOMIC GROUPS

Table L.1. The distribution of threats and recovery actions within the different taxonomic groups under examination. Grey colour indicates sufficient representation (≥ 7) of both binary responses to warrant consideration for model inclusion. Black and white colours indicate inadequate representation of absences ("0") and presences ("1") respectively.

		Birds	Fishes	Mammals	Plants
	Dataset Count	26	26	28	26
	Species Count	22	12	24	14
Threats	Residential & Commercial Development				
	Agriculture & Aquaculture				
	Energy Production & Mining				
	Transportation & Service Corridors				
	Biological Resource Use				
	Human Intrusions & Disturbance				
	Natural Systems Modifications				
	Invasive & Other Problematic Species, Genes & Diseases				
	Pollution				
	Geological Events				
	Climate Change & Severe Weather				
Threat Reduction Actions	Elimination or Prevention of Source of Habitat Modification				
	Protection of Remaining Habitat				
	Restoration or Rehabilitation of Habitat				
	Active Enhancement of Habitat				
	Elimination or Reduction of Point Source Pollution				
	Elimination or Reduction of Non-Point Source Pollution				
	Direct Biological Control				
	Indirect Biological Control				
	Vector Reduction				
	Reduction of Direct Commercial Exploitation				
	Reduction of Direct Subsistence or Recreational Exploitation				
	Reduction of Indirect Commercial Exploitation				
	Reduction of Indirect Subsistence or Recreational Exploitation				
Population Augmentation Actions	Species Introduction				
	Species Reintroduction				
	Species Relocation				
	Species Translocation				
	Captive Breeding or Propagation				
	Fish Hatcheries				
	Gene or Seed Banks				

APPENDIX M – TOP-RANKED U.S. ESA TOOLS MODELS PREDICTING RECOVERY SLOPE CALCULATED SINCE 1989

Table M.1. The top-ranked U.S. ESA tools models (Δ AIC < 4) predicting Recovery Slope calculated for years 1989 - 2010. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	65.32	-126.52	18.62	0.00
Mean Funding – Years Since Listing	0.20	76.78	-145.14	0.00	0.13
Mean Funding	0.18	75.07	-143.90	1.24	0.07
Critical Habitat + Mean Funding – Years Since Listing	0.21	77.22	-143.80	1.33	0.07
Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.21	77.16	-143.68	1.46	0.06
Mean Funding – Years Since Listing – Years Since Current Recovery Plan	0.21	76.98	-143.33	1.81	0.05
Information + Mean Funding – Years Since Listing	0.21	76.94	-143.26	1.88	0.05
Critical Habitat + Mean Funding	0.19	75.74	-143.05	2.08	0.05
Critical Habitat + Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.22	77.65	-142.40	2.74	0.03
Mean Funding – Years Since Original Recovery Plan	0.18	75.36	-142.30	2.83	0.03
Mean Funding – Years Since Current Recovery Plan	0.18	75.30	-142.19	2.94	0.03
Critical Habitat + Mean Funding – Years Since Listing – Years Since Current Recovery Plan	0.21	77.42	-141.95	3.18	0.03
Information + Mean Funding	0.18	75.13	-141.85	3.29	0.02
Critical Habitat + Information + Mean Funding – Years Since Listing	0.21	77.31	-141.74	3.40	0.02
Information + Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.21	77.30	-141.70	3.44	0.02
Information + Mean Funding – Years Since Listing – Years Since Current Recovery Plan	0.21	77.23	-141.56	3.57	0.02
Critical Habitat + Mean Funding – Years Since Original Recovery Plan	0.19	76.08	-141.53	3.61	0.02
Mean Funding – Years Since Listing – Years Since Current Recovery Plan – Years Since Original Recovery Plan	0.21	77.20	-141.50	3.63	0.02
Critical Habitat + Mean Funding – Years Since Current Recovery Plan	0.19	75.97	-141.30	3.84	0.02

Appendix N – Results from U.S. ESA tools models predicting Recovery Slope calculated since U.S. ESA listing date

Table N.1. The top-ranked U.S. ESA tools models (Δ AIC < 4) predicting Recovery Slope calculated since species' U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	67.64	-131.17	17.71	0.00
Mean Funding – Years Since Listing	0.20	78.65	-148.88	0.00	0.16
Mean Funding	0.17	77.10	-147.95	0.93	0.10
Critical Habitat + Mean Funding – Years Since Listing	0.20	78.94	-147.24	1.63	0.07
Information + Mean Funding – Years Since Listing	0.20	78.70	-146.77	2.10	0.06
Critical Habitat + Mean Funding	0.18	77.57	-146.72	2.16	0.05
Mean Funding – Years Since Listing – Years Since Current Recovery Plan	0.20	78.67	-146.71	2.17	0.05
Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.20	78.65	-146.67	2.21	0.05
Mean Funding – Years Since Current Recovery Plan	0.17	77.13	-145.85	3.03	0.04
Information + Mean Funding	0.17	77.11	-145.80	3.08	0.03
Mean Funding + Years Since Original Recovery Plan	0.17	77.10	-145.78	3.09	0.03
Critical Habitat + Mean Funding – Years Since Listing – Years Since Current Recovery Plan	0.20	78.96	-145.03	3.85	0.02
Critical Habitat + Information + Mean Funding – Years Since Listing	0.20	78.96	-145.03	3.85	0.02
Critical Habitat + Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.20	78.94	-144.99	3.89	0.02

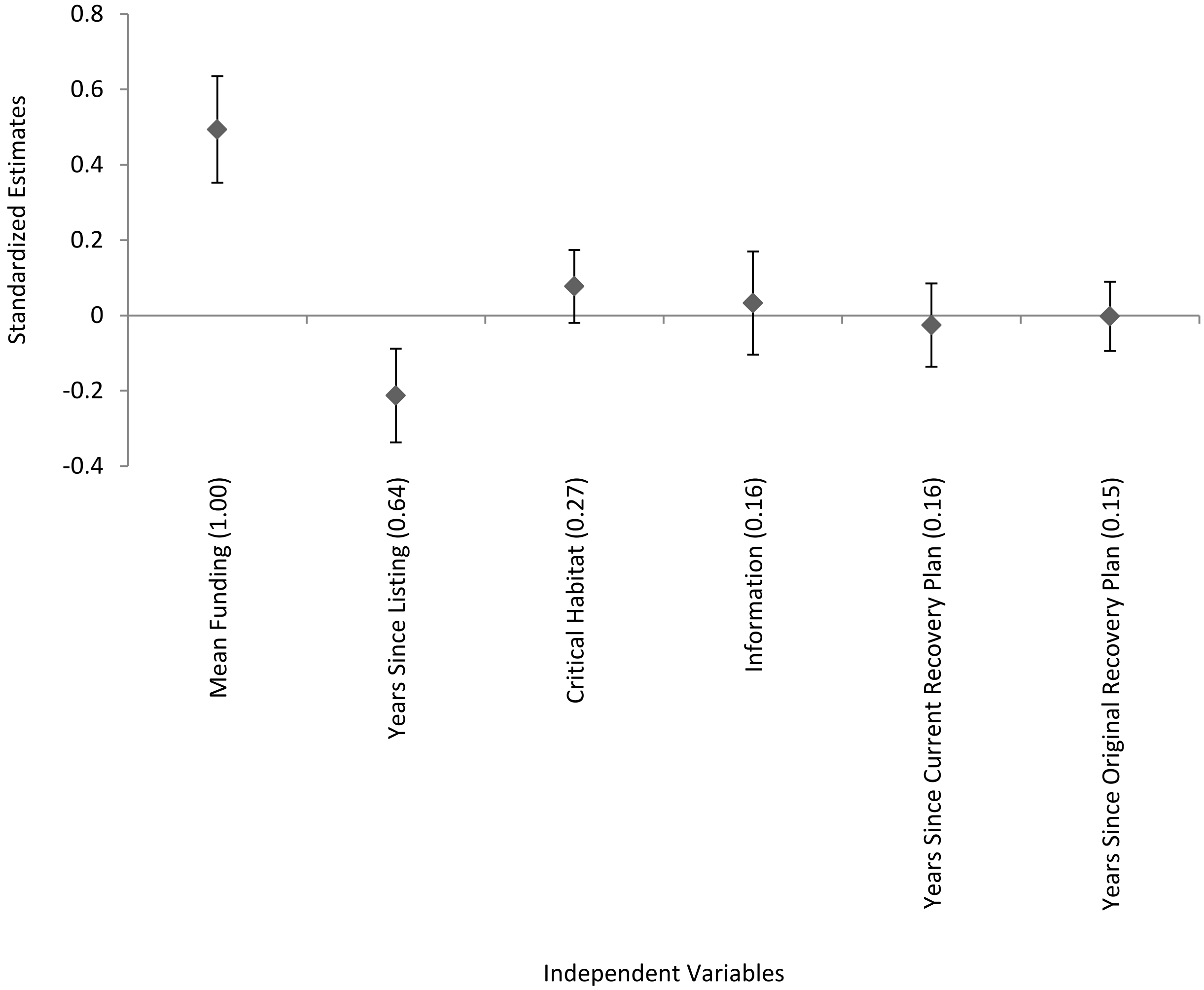

Figure N.1. Standardized model average coefficients (+ SE) over all U.S. ESA tools models with Δ AIC < 4 for RS_2 calculated at the individual dataset level (N = 101). Variables are listed according to relative importance, which is presented in parentheses.

Appendix O – Results from U.S. ESA tools models predicting mean Recovery Slope, inversely weighted by SE.

Table O.1. The top-ranked U.S. ESA tools models (Δ AIC < 4) predicting arithmetic mean Recovery Slope inversely weighted by SE, calculated for years 1989 - 2010. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	67.29	-130.41	15.25	0.00
Mean Funding – Years Since Listing	0.24	77.13	-145.66	0.00	0.08
Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.26	78.07	-145.22	0.44	0.07
Mean Funding	0.21	75.77	-145.19	0.47	0.07
Information + Mean Funding – Years Since Listing	0.26	77.88	-144.84	0.82	0.06
Mean Funding – Years Since Original Recovery Plan	0.23	76.62	-144.63	1.03	0.05
Information + Mean Funding	0.23	76.58	-144.55	1.11	0.05
Information + Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.28	78.74	-144.17	1.48	0.04
Critical Habitat + Mean Funding	0.22	76.24	-143.88	1.78	0.03
Critical Habitat + Mean Funding – Years Since Listing	0.25	77.39	-143.86	1.79	0.03
Information + Mean Funding – Years Since Original Recovery Plan	0.25	77.34	-143.76	1.89	0.03
Information	0.19	74.99	-143.62	2.04	0.03
Critical Habitat + Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.27	78.46	-143.61	2.05	0.03
Mean Funding – Years Since Listing + Years Since Current Recovery Plan – Years Since Original Recovery Plan	0.27	78.45	-143.58	2.07	0.03
Critical Habitat + Mean Funding – Years Since Original Recovery Plan	0.24	77.25	-143.58	2.08	0.03
Mean Funding – Years Since Listing + Years Since Current Recovery Plan	0.24	77.16	-143.40	2.26	0.03
Mean Funding + Years Since Current Recovery Plan + Years Since Original Recovery Plan	0.24	77.06	-143.20	2.46	0.02
Mean Funding + Years Since Current Recovery Plan	0.21	75.83	-143.06	2.60	0.02
Critical Habitat + Information + Mean Funding	0.24	76.87	-142.83	2.83	0.02
Critical Habitat + Information + Mean Funding – Years Since Listing	0.26	78.02	-142.74	2.92	0.02
Information + Mean Funding – Years Since Listing + Years Since Current Recovery Plan	0.26	77.89	-142.46	3.19	0.02

Information – Years Since Original Recovery Plan	0.21	75.50	-142.39	3.27	0.02
Information + Mean Funding + Years Since Current Recovery Plan	0.23	76.60	-142.27	3.38	0.02
Critical Habitat + Information + Mean Funding – Years Since Original Recovery Plan	0.26	77.78	-142.25	3.41	0.02
Critical Habitat + Mean Funding + Years Since Current Recovery Plan – Years Since Original Recovery Plan	0.26	77.77	-142.23	3.43	0.01
Information + Mean Funding – Years Since Listing + Years Since Current Recovery Plan – Years Since Original Recovery Plan	0.28	79.00	-142.22	3.44	0.01
Critical Habitat + Information + Mean Funding – Years Since Listing - Years Since Original Recovery Plan	0.28	78.99	-142.19	3.46	0.01
Critical Habitat + Mean Funding – Years Since Listing + Years Since Current Recovery Plan - Years Since Original Recovery Plan	0.28	78.90	-142.02	3.64	0.01
Information + Mean Funding + Years Since Current Recovery Plan - Years Since Original Recovery Plan	0.25	77.65	-141.98	3.67	0.01
Critical Habitat + Information	0.20	75.19	-141.78	3.88	0.01
Information – Years Since Listing	0.20	75.16	-141.71	3.94	0.01
Critical Habitat + Mean Funding + Years Since Current Recovery Plan	0.22	76.30	-141.68	3.97	0.01
Information – Years Since Current Recovery Plan	0.20	75.14	-141.68	3.97	0.01

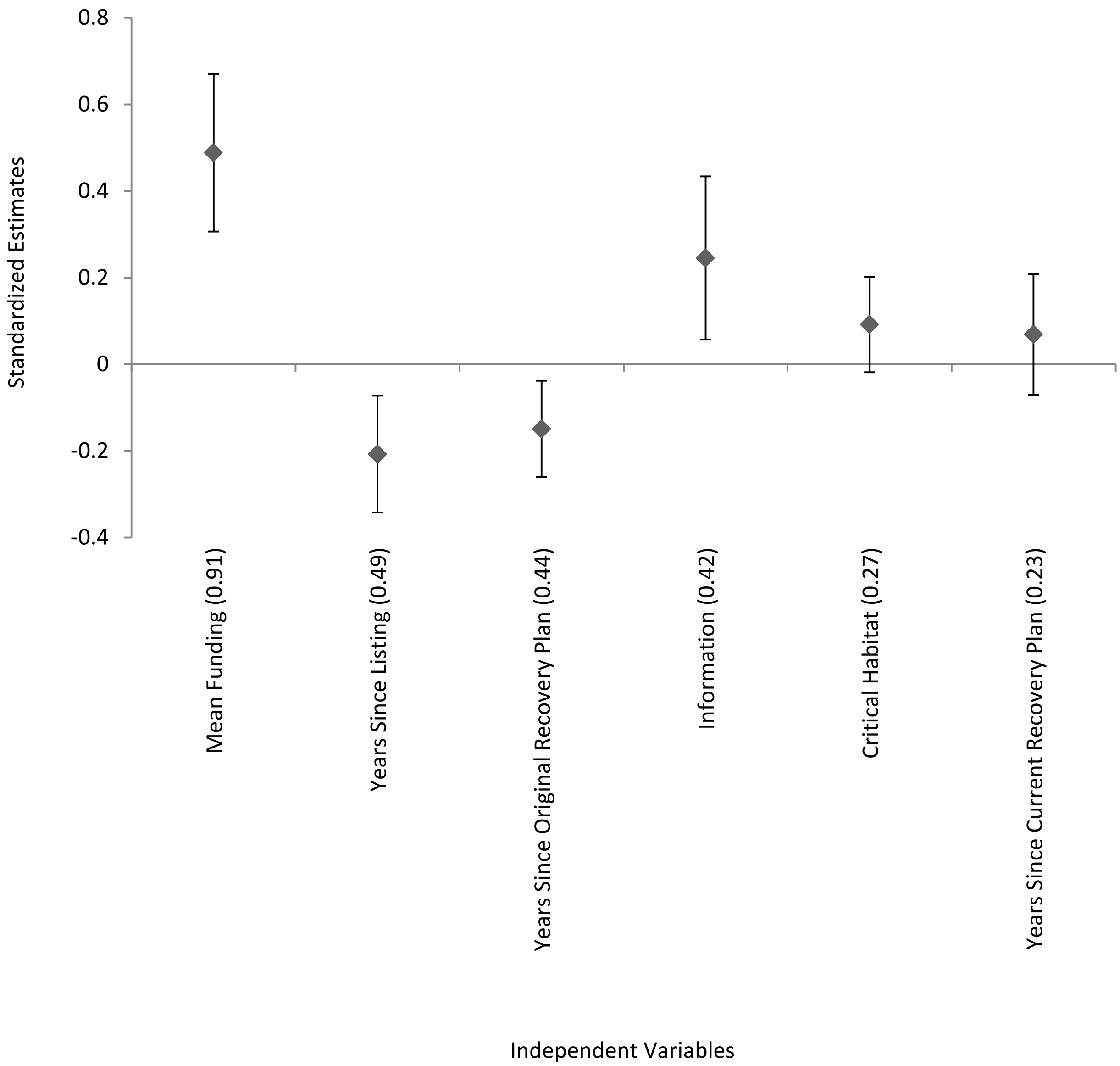

Figure O.1. Standardized model average coefficients (+ SE) over all U.S. ESA tools models with Δ AIC < 4 for RS_1 calculated at the species level (N = 71). Variables are listed according to relative importance, which is presented in parentheses.

Table O.2. The top-ranked U.S. ESA tools models (Δ AIC < 4) predicting arithmetic mean Recovery Slope inversely weighted by SE, calculated for years since species' U.S. ESA listing date to 2013. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	72.12	-140.07	14.26	0.00
Mean Funding – Years Since Listing	0.23	81.47	-154.33	0.00	0.14
Mean Funding	0.20	80.26	-154.16	0.17	0.13
Information + Mean Funding – Years Since Listing	0.24	81.70	-152.48	1.85	0.05
Mean Funding + Years Since Current Recovery Plan	0.21	80.53	-152.46	1.87	0.05
Information + Mean Funding	0.21	80.53	-152.45	1.88	0.05
Mean Funding – Years Since Current Recovery Plan – Years Since Listing	0.24	81.68	-152.44	1.89	0.05
Critical Habitat + Mean Funding	0.21	80.50	-152.39	1.94	0.05
Critical Habitat + Mean Funding – Years Since Listing	0.23	81.57	-152.22	2.11	0.05
Mean Funding – Years Since Listing – Years Since Original Recovery Plan	0.23	81.49	-152.06	2.27	0.04
Mean Funding – Years Since Original Recovery Plan	0.21	80.27	-151.94	2.39	0.04
Critical Habitat + Mean Funding + Years Since Current Recovery Plan	0.22	80.78	-150.64	3.69	0.02
Information + Mean Funding + Years Since Current Recovery Plan	0.22	80.75	-150.57	3.76	0.02
Critical Habitat + Information + Mean Funding	0.21	80.70	-150.47	3.86	0.02
Information + Mean Funding – Years Since Listing + Years Since Current Recovery Plan	0.24	81.87	-150.43	3.90	0.02
Mean Funding + Years Since Current Recovery Plan – Years Since Original Recovery Plan	0.21	80.66	-150.39	3.94	0.02

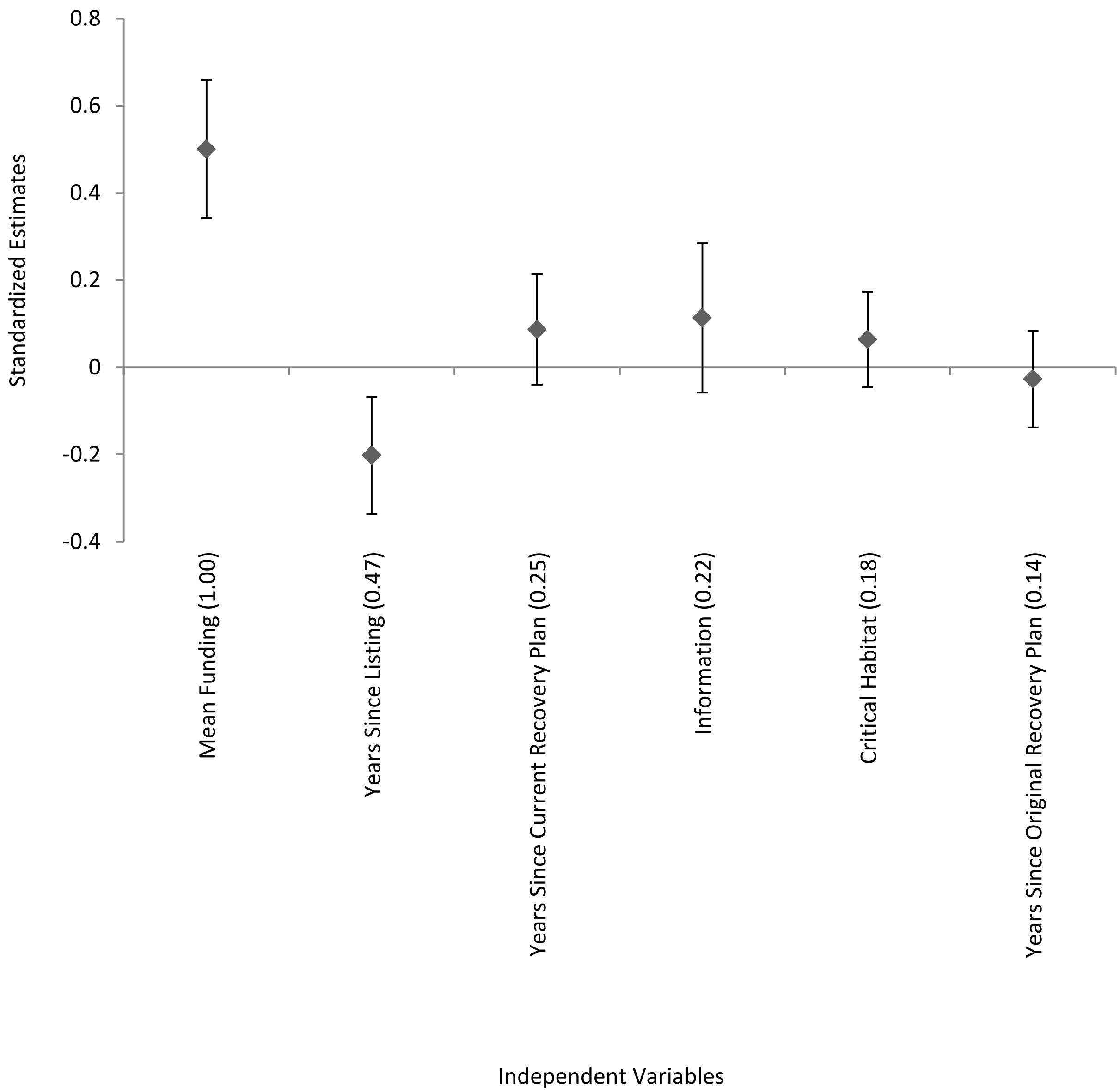

Figure O.2. Standardized model average coefficients (+ SE) over all U.S. ESA tools models with Δ AIC < 4 for RS_2 calculated at the species level (N = 71). Variables are listed according to relative importance, which is presented in parentheses.

Appendix P – Top-ranked U.S. ESA tools models predicting BRI.

Table P.1. The top-ranked U.S. ESA tools models (Δ AIC < 4) predicting Biennial Recovery Index (BRI). Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (W_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	W_i
Null	0.00	-226.12	456.42	15.28	0.00
- Critical Habitat + Information + Year Since Original Recovery Plan + Years Since Original Recovery Plan	0.27	-215.11	441.14	0.00	0.15
Information + Years Since Original Recovery Plan + Years Since Original Recovery Plan	0.23	-216.99	442.59	1.45	0.07
- Critical Habitat + Information + Years Since Current Recovery Plan + Years Since Original Recovery Plan	0.27	-214.84	442.99	1.85	0.06
- Critical Habitat + Information + Years Since Listing + Years Since Original Recovery Plan	0.27	-214.92	443.16	2.02	0.05
- Critical Habitat + Information	0.22	-217.36	443.33	2.19	0.05
- Critical Habitat + Information – Mean Funding + Years Since Original Recovery Plan	0.27	-215.11	443.53	2.39	0.04
- Critical Habitat + Information + Years Since Current Recovery Plan	0.24	-216.44	443.81	2.67	0.04
Information	0.19	-218.76	443.87	2.73	0.04
Information + Years Since Listing + Years Since Original Recovery Plan	0.24	-216.58	444.07	2.94	0.03
Information + Years Since Current Recovery Plan + Years Since Original Recovery Plan	0.23	-216.68	444.29	3.15	0.03
Information + Years Since Current Recovery Plan	0.21	-217.87	444.34	3.20	0.03
- Critical Habitat + Information + Years Since Listing + Years Since Current Recovery Plan + Years Since Original Recovery Plan	0.28	-214.49	444.75	3.62	0.02
Information – Mean Funding + Years Since Original Recovery Plan	0.23	-216.98	444.89	3.75	0.02
Information + Years Since Listing + Years Since Current Recovery Plan	0.23	-217.02	444.95	3.82	0.02
- Critical Habitat + Information + Years Since Listing + Years Since Current Recovery Plan	0.25	-215.89	445.10	3.96	0.02

APPENDIX Q – TOP RANKED THREATS AND RECOVERY ACTIONS MODELS FOR BIRDS, FISHES, MAMMALS AND PLANTS TAXONOMIC GROUPS, PREDICTING RECOVERY SLOPE CALCULATED SINCE U.S. ESA LISTING DATE.

Table Q.1. The top-ranked threats and recovery actions models for Birds (Δ AIC < 4) predicting Recovery Slope calculated since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	21.52	-38.52	6.40	0.01
Energy Production & Mining – Natural Systems Modifications	0.37	27.41	-44.92	0.00	0.20
Invasive & Other Problematic Species, Genes & Diseases – Natural Systems Modifications	0.36	27.35	-44.80	0.12	0.19
Energy Production & Mining + Invasive & Other Problematic Species, Genes & Diseases - Natural Systems Modification	0.42	28.69	-44.38	0.53	0.15
- Natural Systems Modifications	0.28	25.71	-44.32	0.59	0.15
Eradication or Reduction of Non-Point Source Pollution	0.20	24.43	-41.76	3.16	0.04
Energy Production & Mining – Restoration or Rehabilitation of Habitat	0.27	25.67	-41.44	3.48	0.04
- Restoration or Rehabilitation of Habitat + Species Reintroduction	0.27	25.58	-41.25	3.67	0.03
Energy Production & Mining + Invasive & Other Problematic Species, Genes & Diseases	0.27	25.54	-41.18	3.74	0.03
Eradiation or Reduction of Non-Point Source Pollution - Restoration or Rehabilitation of Habitat	0.27	25.53	-41.15	3.77	0.03
Invasive & Other Problematic Species, Genes & Diseases - Restoration or Rehabilitation of Habitat	0.26	25.43	-40.95	3.97	0.03

Table Q.2. The top-ranked threats and recovery actions models for Fishes (Δ AIC < 4) predicting Recovery Slope calculated since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	20.92	-37.32	0.00	0.23
Biological Resource Use	0.05	21.62	-36.14	1.18	0.13
Species Reintroduction	0.05	21.59	-36.08	1.24	0.12
- Active Enhancement of Habitat	0.04	21.51	-35.93	1.39	0.11
Reduction of Direct Commercial Exploitation	0.03	21.31	-35.54	1.79	0.09
- Energy Production & Mining	0.02	21.21	-35.32	2.00	0.08
- Residential & Commercial Development	0.02	21.19	-35.29	2.03	0.08
Biological Resource Use – Energy Production & Mining	0.06	21.67	-33.44	3.88	0.03
– Active Enhancement of Habitat - Energy Production & Mining	0.05	21.64	-33.37	3.96	0.03

Table Q.3. The top-ranked threats and recovery actions models for Mammals (Δ AIC < 4) predicting Recovery Slope calculated since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	37.08	-69.68	4.58	0.03
- Natural Systems Modifications + Species Reintroduction	0.30	42.00	-74.26	0.00	0.29
- Invasive & Other Problematic Species, Genes & Diseases + Species Reintroduction	0.25	41.15	-72.57	1.69	0.12
Species Reintroduction	0.16	39.58	-72.16	2.10	0.10
- Natural Systems Modification + Species Reintroduction – Transportation & Service Corridors	0.30	42.01	-71.28	2.98	0.07
- Human Intrusions & Disturbance	0.12	38.90	-70.80	3.47	0.05
Direct Biological Control - Invasive & Other Problematic Species, Genes & Diseases	0.20	40.07	-70.40	3.86	0.04

Table Q.4. The top-ranked threats and recovery actions models for Plants (Δ AIC < 4) predicting Recovery Slope calculated since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	18.99	-33.45	5.34	0.03
Species Reintroduction	0.26	22.94	-38.80	0.00	0.46
Reduction of Indirect Subsistence or Recreational Exploitation + Species Reintroduction	0.31	23.73	-37.55	1.25	0.25
Species Reintroduction – Transportation & Service Corridors	0.29	23.50	-37.10	1.70	0.20

APPENDIX R – RESULTS FROM THREATS AND RECOVERY ACTIONS MODELS FOR BIRDS, FISHES, MAMMALS AND PLANTS TAXONOMIC GROUPS, PREDICTING MEAN RECOVERY SLOPE WEIGHTED BY INVERSE STANDARD ERROR.

Table R.1. The top-ranked threats and recovery actions models for Birds (Δ AIC < 4) predicting arithmetic mean Recovery Slope, inversely weighted by SE, since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	17.31	-29.99	6.79	0.01
Energy Production & Mining – Natural Systems Modifications	0.44	23.56	-36.77	0.00	0.30
Energy Production & Mining + Invasive & Other Problematic Species, Genes & Diseases - Natural Systems Modification	0.50	24.98	-36.21	0.56	0.22
Invasive & Other Problematic Species, Genes & Diseases - Natural Systems Modification	0.39	22.76	-35.17	1.60	0.13
- Natural Systems Modifications	0.29	21.14	-34.95	1.82	0.12

Table R.2. The top-ranked threats and recovery actions models for Fishes (Δ AIC < 4) predicting arithmetic mean Recovery Slope, inversely weighted by SE, since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	18.31	-31.28	1.93	0.14
Reduction of Direct Commercial Exploitation	0.37	21.11	-33.21	0.00	0.36
- Active Enhancement of Habitat	0.25	20.05	-31.11	2.10	0.13
Species Reintroduction	0.21	19.69	-30.39	2.82	0.09
Biological Resource Use	0.20	19.66	-30.31	2.90	0.08

Table R.3. The top-ranked threats and recovery actions models for Mammals (Δ AIC < 4) predicting arithmetic mean Recovery Slope, inversely weighted by SE, since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	39.77	-74.97	11.79	0.00
- Natural Systems Modifications + Species Reintroduction	0.51	48.43	-86.76	0.00	0.47
- Invasive & Other Problematic Species, Genes & Diseases + Species Reintroduction	0.50	48.13	-86.15	0.61	0.35
- Natural Systems Modification + Species Reintroduction – Transportation & Service Corridors	0.52	48.45	-83.56	3.20	0.10

Table R.4. The top-ranked threats and recovery actions models for Plants (Δ AIC < 4) predicting arithmetic mean Recovery Slope, inversely weighted by SE, since U.S. ESA listing date. Model R^2 analog, Log Likelihood, Second order Akaike Information Criterion (AICc), Δ AIC and Akaike weights (w_i) are shown.

Model Independent Variables	R^2 analog	Log-Likelihood	AICc	Δ AIC	w_i
Null	0.00	13.52	-21.96	1.70	0.18
Species Reintroduction	0.30	16.03	-23.66	0.00	0.43
Captive Breeding or Propagation	0.18	14.94	-21.49	2.17	0.15
Species Reintroduction – Transportation & Service Corridors	0.31	16.15	-19.86	3.80	0.06

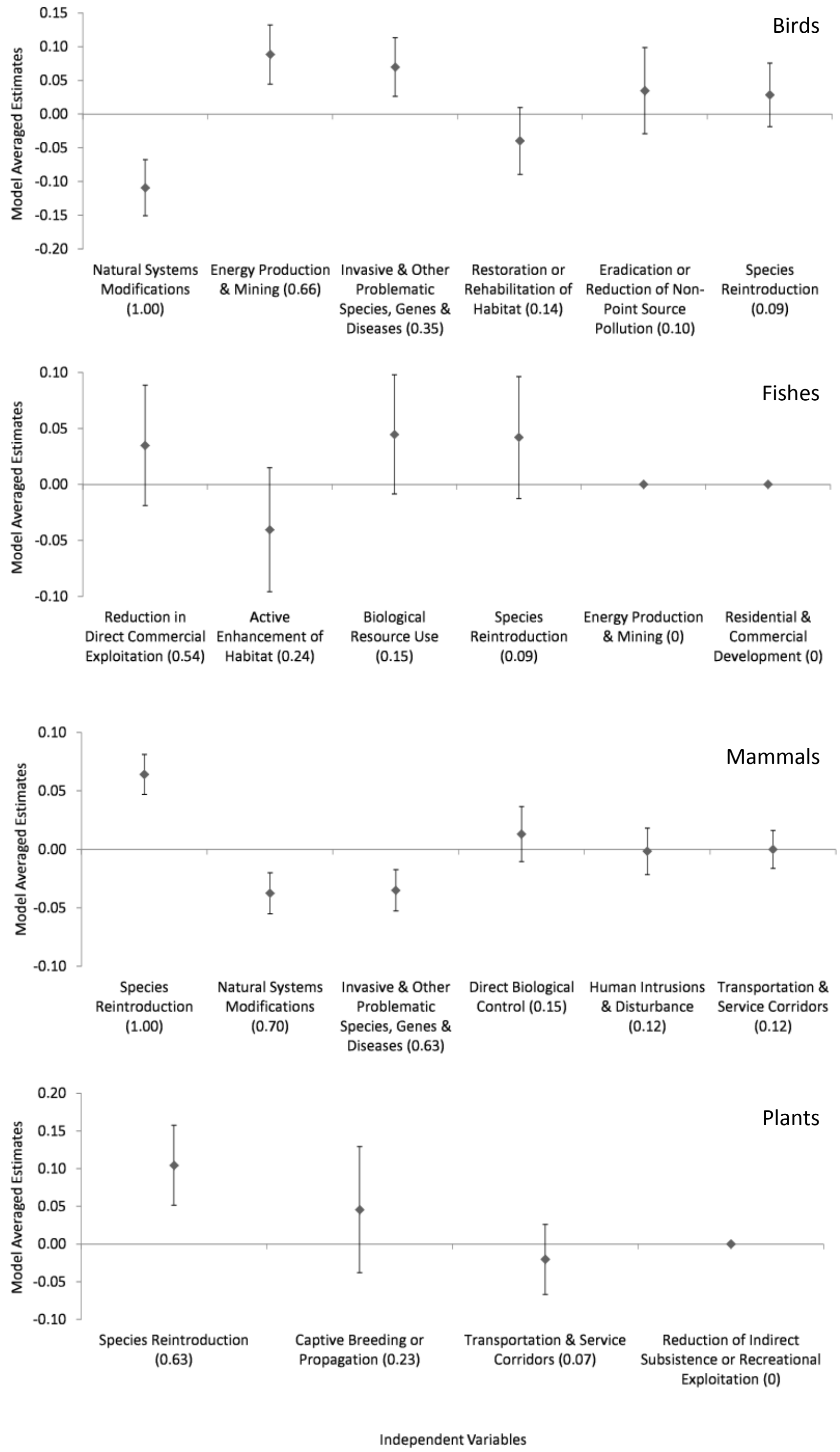

Figure R.1. Model averaged coefficients (+ SE) based on threats and recovery actions models fitted for mean RS_2, calculated at the species level. Variables are listed according to relative importance, which is presented in parentheses. Mean pseudo-R^2 of averaged models with Δ AIC < 4 for Birds = 0.41 (SD = 0.07; N = 22), Fishes = 0.28 (SD = 0.15; N = 12), Mammals = 0.53 (SD = 0.03; N = 24) and Plants = 0.22 (SD = 0.12; N = 14).

APPENDIX S – TEST FOR INTERACTION BETWEEN THREATS AND TARGETED THREAT-REDUCTION RECOVERY ACTIONS.

We tested for an interaction effect between threats and their associated threat-reduction recovery actions. We did not have sufficient sample size to test for the effect within taxonomic groups, so we tested for an interaction by pooling all species' datasets together. As a measure of recovery, we calculated the difference in Recovery Slope (calculated since U.S. ESA listing at the individual dataset level) from the taxonomic group mean Recovery Slope (termed DevRS), as a way to avoid effects from differences in taxonomy.

Three threats and their set of recovery actions were tested: Biological Resource Use, Invasive & Other Problematic Species, Genes & Diseases, and Pollution (Table T.1). Threats were coded binomially (1 = reviewed documents state explicitly that the species has been exposed to the threat; 0 = reviewed documents state explicitly that the species has not been exposed to the threat or that the threat is insignificant, or there is no explicit mention of the threat whatsoever). For each set of associated recovery actions, two recovery action variables were created. The first is a dummy variable termed "RA Cat", where 1 = one or more of the recovery actions have been employed, and 0 = none of the recovery actions have been employed. The second is a numeric variable termed "RA Sum", indicating the sum of the number of recovery actions taken.

We tested for interactions between each threat and recovery actions variables, independently, using a linear regression.

Linear regression models: DevRS ~ Threat*RA Cat

DevRS ~ Threat*RA Sum

The only interaction determined to be statistically significant existed between the Pollution threat and RA Sum variable; though, effect sizes for all models were small (Table T.2).

Table T.1. Species threats and their associated threat-reduction recovery actions, tested for an interaction effect.

Threat	Associated Recovery Actions
Biological Resource Use	1. Reduction of Direct Commercial Exploitation 2. Reduction of Direct Subsistence or Recreational Exploitation 3. Reduction of Indirect Commercial Exploitation 4. Reduction of Indirect Subsistence or Recreational Exploitation
Invasive & Other Problematic Species, Genes & Diseases	1. Direct Biological Control 2. Indirect Biological Control 3. Vector Reduction
Pollution	1. Elimination or Reduction of Point Source Pollution 2. Elimination or Reduction of Non-Point Source Pollution

Table T.2. Results from linear regressions testing for interaction effects between threats and their associated threat-reduction recovery actions, with DevRS as the dependent variable (N = 135). Resulting model p-values for interaction terms are presented, with model effect size (R^2).

Dependent Variable	Threat Variable	Recovery Action Variable	Interaction p-value	Model R^2
DevRS	Biological Resource Use	RA Cat	0.17	0.07
		RA Sum	0.15	0.06
DevRS	Invasive & Other Problematic Species, Genes & Diseases	RA Cat	0.81	0.01
		RA Sum	0.74	0.02
DevRS	Pollution	RA Cat	0.06	0.05
		RA Sum	0.04	0.05