

**Does additional habitat protection facilitate the recovery of species
protected by the Endangered Species Act?**

**By
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Foreword

I have prepared my thesis as a manuscript for submission to a peer-review journal. Consequently, I have used the first person plural active voice, rather than a third person singular passive voice. I have also kept the main body of the document short, and I have provided additional details in appendices.

Abstract

Earlier studies have found that endangered species recovery is only weakly associated with the tools enabled by the U.S. Endangered Species Act (ESA). With habitat loss often cited as a leading cause of species declines, we tested whether the recovery of ESA-listed species is instead associated with the protection of critical habitat (CH) by protected areas. We tested the relationship for 299 species using recovery indices derived from the biennial status reports to Congress (1990-2010), as well as NatureServe and IUCN population status data. We found no overall relationship between recovery and the extent to which CH is protected. However, restricting the analysis to recovering species, listed species with larger areas of protected ($R^2 = 0.158$) or strictly protected ($R^2 = 0.194$) CH fared better than species with less protected or strictly protected CH areas. Declining species (199 of 273 species studied) fared no better with more protected habitat. We conclude that the abatement of habitat loss alone does not necessarily facilitate recoveries for the majority of ESA-listed species. We also note that the weak relationships we observed in this study may be reflective of poor recovery status estimates.

Résumé

Des études passées ont trouvé que le rétablissement des espèces listées par le Endangered Species Act (ESA) n'est que faiblement associé aux outils développés par l'Acte. La perte d'habitat étant souvent citée comme la cause principale du déclin des espèces, nous demandons si le rétablissement des espèces listées par l'ESA est plutôt associé à la protection de leurs habitats critiques (HC) par une aire protégée. Nous avons évalué le rétablissement de 299 espèces avec la protection de leurs HC en utilisant trois indices dérivés des rapports au Congrès (1990-2010), NatureServe et de l'UICN. Les espèces en rétablissement font mieux lorsque leur HC est protégé ($R^2 = 0.158$) ou strictement protégé ($R^2 = 0.194$). Les espèces en déclin (197 des 273 espèces) ne bénéficiaient pas de plus d'habitat. Nous concluons que le renversement de la perte d'habitat ne facilite pas nécessairement le rétablissement de la majorité des espèces listées par l'ESA. Nous observons aussi que le pouvoir prédictif est faible et que la relation reflète possiblement de mauvais estimés des statuts de rétablissement.

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1. Introduction

Despite extensive conservation efforts worldwide, global biodiversity declines persist amidst steadily increasing global anthropogenic pressures (Butchart et al. 2010; Hoffmann et al. 2010). Resources invested to arrest and/or reverse species declines extend into billions of dollars (Male & Bean 2005; Ferraro & Pattanayak 2006; Schwartz 2008; Taylor et al. 2011). To protect imperilled species, conservation practitioners have widely employed two keystone strategies: the enactment of protective legislations and the establishment of protected areas.

1.1. The Endangered Species Act

The United States (U.S.) Endangered Species Act (ESA) of 1973 is one of the oldest and most powerful legislative tools implemented to protect declining species (Schwartz 2008; Gibbs & Currie 2012) (see Appendix A for state-level legislation). Among the most important tools enabled by the ESA are: protection from harm (i.e. prohibitions on ‘taking’ species, jeopardizing activity, and adverse habitat modification), recovery plan development, and critical habitat designation (Schwartz 2008; Gibbs & Currie 2012). It is often argued that, without the protection that federal legislation affords, many listed species would have gone extinct (Kerkvliet & Langpap 2007; Schwartz 2008; Suckling 2011).

Yet, many species protected by the ESA continue to decline. Earlier studies have investigated what distinguishes recovering species from those that remain in decline (as assessments of the effectiveness of ESA tools) with mixed results (Schwartz 2008; Gibbs & Currie 2012). In general, improving species are positively correlated with years since listing, funding, recovery plan development, and the number of recovery plan objectives completed (Abbitt & Scott 2001; Boersma et al. 2001; Taylor et al. 2005; Male & Bean 2005; Schwartz 2008). However, the effect sizes are very small: improvements in species' statuses are only weakly associated with these tools enabled by the ESA (Gibbs & Currie 2012).

It is possible that a species may continue to decline because, although its critical habitat (CH) has been designated, that habitat is not effectively protected. With habitat loss often identified as the most prevalent threat driving species losses in the U.S. (Foin et al. 1998; Wilcove et al. 1998), designation of CH should be one of the more powerful protection tools enabled by the ESA. CH designation not only protects the geographical areas occupied by a listed species at the time of listing, but also the unoccupied areas deemed essential to the persistence of the species (Hagen & Hodges 2006; Schwartz 2008). Studies examining the extent of species recovery in relation to CH designation, however, have reported conflicting results. Taylor et al. (2005) found species recovery to be positively associated with CH designation, whilst Male & Bean (2005), Kerkvliet & Langpap (2007) and Gibbs & Currie (2012) did not.

1.2. Establishment of Protected Areas

Protected areas (PAs) also provide protection for imperilled species from habitat loss. With imposed restrictions on land-use and development, PAs serve (at least in principle) as a safe haven for species to persist in the absence of anthropogenic pressures (Margules & Pressey 2000; Gaston et al. 2008). PAs are effective in mitigating habitat degradation by reducing land-cover clearing (Bruner et al. 2001; Nagendra 2008) as well as retaining forest habitat cover (Geldmann et al. 2013). PAs can also help species recovery through the reduction of the threats of poaching (Geldmann et al. 2013), logging, and grazing (Bruner et al. 2001). In some cases, PAs have been found to improve endangered species' population statuses and reduce or stabilize the rates of species losses (see Brooks et al. 2006; Gaston et al. 2008; Geldmann et al. 2013). More recently, Taylor et al. (2011) found that of the conservation efforts employed towards species' recoveries in Australia, only strictly protected areas (viz. IUCN categories Ia-IV; see Appendix B) were associated with improvements in species recovery.

1.3. Study Objective

Since earlier studies have found that ESA-listed species for which CH had been designated were not more likely to be recovering than species for which CH has not been designated (Male & Bean 2005; Kerkvliet & Langpap 2007; Gibbs & Currie 2012), we asked whether recovery is only promoted when CH is protected by additional means. We hypothesize that

ESA-listed species are more likely to recover when their designated critical habitat is located in protected areas.

In this study, we test whether the variability in recovery among ESA-listed species is associated with the amount of its CH that is located within a PA. Secondly, we test whether species recovery is associated with the length of time the species has been protected by a PA. Finally, we test whether recovery probability is improved if PAs that include a species' CH are created after CH has been designated.

2. Methodology

For our analyses, we considered species, subspecies, varieties or distinct population segments that were listed under the ESA before 2002, for which at least 10 years of population status data were available. We excluded species that are delisted, in captivity and/or presumed extinct, as well as species with multiple listed populations with 'mixed' statuses. To test hypotheses about the protection of CH, we used the set of species for which CH had been designated.

2.1. Measures of Recovery

We calculated an index of recovery using the population statuses reported to Congress biennially, for the period of 1990 and 2010, by the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS). These are the same recovery data used by Male & Bean (2005) and Gibbs & Currie (2012), updated to include the statuses reported in 2010. The population status of each ESA-listed species in a given Biennial Report is described as 'declining', 'stable', 'increasing' or 'unknown'. As per Male & Bean (2005), we assigned values of -1, 0 and 1 respectively to 'declining', 'stable' and 'increasing' status reports, and we then summed the values for each species to obtain a recovery score. In cases where a status report for a given species was missing, we adjusted the scores, following Gibbs & Currie (2012). We divided each species' score by the proportion of reported statuses out of 11 possible Biennial Reports to Congress. Thus, the possible range

of scores in the recovery index, for any species, is -11 (declining in all reports) to +11 (increasing in all reports). This adjustment assumes that the recovery status in periods for which no estimate was available is equal to the mean recovery trend over the entire period (Gibbs & Currie 2012). We refer to this index hereafter as the Biennial Report Recovery Index (BRRI). In our preliminary analyses, we found that assigning greater weight to more recent reports, following Taylor et al. (2005), did not qualitatively change the final results (see Appendix C). We also considered whether the slope of recovery scores as a function of time might be a better index of recovery. We found that recovery scores were significantly related to time for only 21% of species in the study (i.e. 64 of 299 species). The relationships between the slope of species' recovery trends over time and critical habitat protection measures weaker than those using BRRI, we present only results using the BRRI measure of species recovery.

Some observers have postulated that the population status assessments in the biennial reports to Congress may be unreliable, subject to influences having little to do with species' abundances (anon. pers. comm.). However, we know of no better data on the status of listed species (see also Wilcove et al. 1998; Abbitt & Scott 2001; Boersma et al. 2001; Male & Bean 2005; Taylor et al. 2005; Male et al. 2006; Gibbs & Currie 2012), nor of any published evidence that the quality of the biennial assessments is systematically questionable (Taylor et al. 2005). Following previous studies, we will therefore assume that the reported statuses do mainly reflect changes in species population trends. However,

because of this concern, we also extracted species status estimates for ESA-listed species from two additional organizations: NatureServe and the International Union for Conservation of Nature (IUCN). We compared the population trend assessments from the three sources. These indices, and the BRRI, are not independent: data are clearly shared among these organizations (compare, for example, NatureServe and IUCN entries for the Wyoming toad). However, to the extent that ESA status assessments of species population trends may be subject to political and economic consideration, the NatureServe and IUCN assessments should be independent of those influences. It is important to note, however, that both NatureServe and IUCN recovery assessments refer to the global status of a given species. In contrast, ESA assessments pertain only to populations occurring within the U.S.

To create a NatureServe Index, we used the short-term population trends found online in the NatureServe Explorer database (www.natureserve.org/explorer/). The NatureServe database is said to offer the most comprehensive data on imperilled species in the U.S. (Wilcove & Master 2005). For each species, we assigned ranked values of -1, 0 and 1 to the trends designated by NatureServe as 'declining', 'relatively stable' or 'increasing', respectively. We excluded population trends that were unclear (e.g. where statuses were reported as both increasing and stable) or 'unknown' from the study.

To create an IUCN Index, we used the population trend statuses reported in the IUCN Red List version 2013.1 (www.iucnredlist.org). The IUCN is a widely recognized international

organization that provides conservation status classifications for imperilled species worldwide (Harris et al. 2012). For each species, we assigned ranked values of -1, 0 and 1 to the population trends reported by IUCN as ‘decreasing’, ‘stable’ or ‘increasing’, respectively. We excluded population trends for species that were reported as ‘unknown’ or ‘needs updating’.

2.2. Critical Habitat

Next, we determined the proportion of each species’ designated CH that occurs within protected areas (PA). We used CH maps as Geographical Information System (GIS) polygon and polyline shapefiles, provided in the USFWS Critical Habitat Portal (<http://ecos.fws.gov/crithab/>). We treated CH polygon and polyline feature classes separately throughout the study.

2.3. Protected Areas

We acquired PA spatial data from the U.S. Geological Survey’s Gap Analysis Program (USGS GAP) (‘PAD-US version 1.3 Combined’, <http://gapanalysis.usgs.gov/padus/data/>). The PA’s date of establishment and level of protection were available as attribute information. The USGS categorizes each PA with both an IUCN management ranking and a GAP Status Code (a measure of the extent of biodiversity protection mandated within the PA). Only PAs classified with GAP Status Codes 1 and 2 are assigned IUCN categories by the GAP Program, as only these PAs are considered to be managed for long-term biodiversity protection (Lisa

Duarte, USGS Gap Analysis Program, pers. comm). We grouped the PAs into three levels of protection based on their assigned IUCN rankings: strictly protected (IUCN categories Ia-IV); protected (Ia to VI); or unprotected (not IUCN classified) (Margules & Pressey 2000; Rodrigues et al. 2004; Jenkins & Joppa 2009; Brooks et al. 2009; Taylor et al. 2011). Following Clark et al. (2013), we excluded PAs without dates of establishment from the analyses pertaining to the duration of PA protection, but we included them in analyses comparing protected/unprotected areas.

In some cases, there were multiple management regimes within a given PA (e.g. overlapping state and federal policies) (Lisa Duarte, USGS Gap Analysis Program, pers. comm.). In these cases, we used the higher level of PA protection (i.e. lower IUCN management category) (Jenkins & Joppa 2009; Clark et al. 2013) and the earliest date of PA establishment (Butchart et al. 2012). In instances where dates of protection differed as well as the IUCN level of protection, we used the date of establishment associated with the highest level of protection.

2.4. Spatial Analyses

For each species, we used ArcGIS 10.0 software to overlay maps of critical habitat (CH) and protected areas (PAs). We determined the total area of CH, and the areas of CH that fell within each IUCN protection category (strictly protected, protected, unprotected). Area

was subsequently log transformed, after adding a small constant to all values to avoid zeroes. We also calculated the proportion of each species' CH that falls within PAs.

For each species, we also obtained the date of establishment for the PA protecting its CH. Some species were protected by multiple PAs that were established at different points in time. In these cases, we calculated an average date of establishment, weighted by the area of CH within each PA.

Species whose CH was described as linear (e.g., riverine species) were excluded from analyses of effects of absolute area of CH. These species, however, were considered in analyses of the effects of the proportion and duration of CH that is protected by a PA. Species whose CH was designated as a combination of linear and areal habitats ($n = 3$) were considered only in analyses pertaining to the proportion and duration of CH protection.

2.5. Statistical Analyses

We performed all statistical analyses using R version 3.0.2 (R Development Core Team 2013). We first compared the three indices of recovery (BRRI, NatureServe Index and IUCN Index) using Spearman Rank Correlations (ρ). For all ESA-listed species, we then related the measures of recovery to CH protection using generalized linear models.

Initial inspection of the data suggested that ESA-listed species that were improving might relate to CH protection differently than species that are declining. We therefore also analyzed 'improving' species (stable and improving recovery scores) and 'declining' species independently.

We also assessed whether recovery scores were related to other factors that might add variance to a relationship between recovery and protected CH areas (Appendix D). We tested whether recovery scores differ systematically among taxonomic groups, habitat, biogeography, or among regions within the U.S. We also tested whether species that are endemic to the U.S. differ from those whose distributions extend outside the U.S. Finally, we examined the residuals of the BRRl – critical habitat regressions for spatial autocorrelation.

3. Results

3.1. Measures of Species Recovery

Of the 844 species ESA-listed prior to 2002, we found 359 species also listed in the NatureServe database (42.5%), and 184 on the IUCN Red List (21.8%). Despite the fact that our three measures of species recovery may have relied upon similar data, they were only moderately correlated with each other (Table 1).

3.2. ESA Species Selected

Among ESA-listed species, 299 species had designated CH and met our selection criteria. Species in our dataset had BRRI recovery scores ranging from -11 to 11, with 220 (73.6%) of the species declining (i.e. negative BRRI scores), 33 (11.0%) species stable (i.e. BRRI scores of 0) and 46 (15.4%) species improving (i.e. positive BRRI scores). See Appendix E for additional data summaries.

3.3. Tests of Hypotheses

We found that species were not consistently more likely to be assessed as improving or as declining in relation to the amount of CH protection (Table 2). In cases where species recovery was significantly associated with habitat protection, the relationships were very

weak. We conclude that species recovery overall is, at best, weakly related to the area of protected CH (see also Appendix F).

Among improving species, however, we found that better recovery scores were associated with larger total CH area ($R^2 = 0.147$; $p = 0.001$; $n = 74$; Figure 1), larger unprotected area ($R^2 = 0.106$; $p = 0.005$; $n = 74$; Figure 2), larger protected CH area ($R^2 = 0.158$; $p = 0.0004$; $n = 74$; Figure 3), and larger strictly protected CH area ($R^2 = 0.194$; $p = 0.0001$; $n = 74$; Figure 4). In contrast, we found that recovery among declining species was significantly associated with only larger total CH area ($R^2 = 0.056$, $p = 0.001$; $n = 199$; Figure 1) and unprotected area ($R^2 = 0.036$, $p = 0.008$; $n = 199$; Figure 2). However, these relationships were both negative: species with greater CH areas were declining more rapidly than species with smaller CH areas.

Separating species into taxonomic groups, we found that no group's recovery was more likely to be associated with CH protection (Table 3). Once we corrected for multiple comparisons using a Bonferroni correction ($n=28$), we found that recovery was only associated (negatively) for plants within total CH areas (Spearman's $\rho = -0.288$; adjusted $p = 0.005$; $n = 166$; Table 3) and unprotected CH areas (Spearman's $\rho = -0.327$; adjusted $p = 0.0005$; $n = 166$; Table 3). Once again, most relationships were very weak.

Species recovery was also not strongly associated with our other measures of CH protection. For all three measures of recovery, the relationship between species recovery and the proportion of protected CH was either absent, or weaker than the relationships with absolute CH area (see Appendix G). Similarly, for all three measures of recovery, we found no significant relationship between species recovery and the length of time a species' CH had been protected by a PA (Appendix H), or whether a new PA (that included a species' CH) was established after CH designation (Appendix H).

4. Discussion

We find ourselves in the same uncomfortable situation as did Gibbs & Currie (2012): either protection of critical habitat (CH) *per se* does relatively little to improve the recovery probability of most ESA-listed species, or the recovery data are too noisy to reveal that relationship. Our use of three more-or-less independent indices of recovery was intended to reduce the risk of the latter conclusion. Either way, there is no compelling evidence that, for most ESA-listed species, the probability of decline is reduced when greater amounts of CH are designated, whether that habitat is protected or not.

We did, however, detect a relationship between recovery and protection of critical habitat for a small set of species. We found that, among improving species (i.e. with stable or improving recovery statuses: 74 of 273 species), those with the greatest amounts of critical habitat, protected or not, were also those recovering the best. Among these are species that have clearly rebounded from low abundance following habitat protection. For example, the Louisiana black bear had already lost 80% of its bottomland hardwood forest habitat at the time of listing (U.S. Fish and Wildlife Service 2009). However, efforts to protect additional forest habitat and to restore agricultural land through significant hardwood reforestation, have decreased threats on improving populations (U.S. Fish and Wildlife Service 2009). The Mauna Loa silversword, on the other hand, provides an example where habitat protection mitigates a specific threat. Fenced enclosures protect silversword

populations from ungulate predation and habitat degradation (U.S. Fish and Wildlife Service 2012). Given the silverswords' naturally slow maturation and reproductive cycle, measures such as cross-pollination and seedling reintroduction programs have also been implemented to complement the habitat protection measures (U.S. Fish and Wildlife Service 2012). There appears to be a set of species that do recover when habitat protection and restoration directly mitigate the predominant threats (see additional examples in Appendix I).

For the majority of ESA-listed species, however, species fare no better despite being afforded additional habitat protection by PAs (Figure 3 and Figure 4). Declining species comprise the majority of species in our study (73.5%), and among these species, recovery was significantly negatively correlated with both total areas of designated CH (Figure 1) and large areas of unprotected CH (Figure 2). For instance, consider the Northern Spotted Owl. The Northern Spotted Owl is threatened by inter-specific competition from invading Barred Owls (U.S. Fish and Wildlife Service 2011), a factor that is unlikely to be addressed through habitat protection. The USFWS even notes in the Northern Spotted Owl's revised recovery plan that additional habitat procurement would not enable the recovery of the species (U.S. Fish and Wildlife Service 2011). In the case of the Coachella Valley fringe-toed lizard, on-going modifications to key ecological processes appear to continue to threaten the species despite the habitat protection measures in place. In this case, the species requires unstable, moving sand dune. Development and infrastructure (e.g. windbreaks) stabilize

the blowsand transport systems that are essential to maintain the lizard's naturally dynamic blowsand habitat (U.S. Fish and Wildlife Service 2010). For declining species (see Appendix I for additional examples), the availability of larger CH and/or PA areas has apparently not directly mitigated the threats of endangerment. It is possible that recovery and critical habitat are negatively related for these species because the threats to these species are harder to mitigate over larger expanses of habitat (e.g. changes to key ecological processes) (Abbitt & Scott 2001; Lawler et al. 2002; DeFries et al. 2007) and are unrelated to the habitat availability alone (e.g. invasive species). It is also possible that habitat loss may have proceeded past the point where increasing habitat area can positively impact recovery for these species that remain in decline.

We postulate that, while arresting habitat losses may facilitate the recovery of some species, it simply does not serve as a silver bullet solution to promote the recovery of most endangered species. While habitat losses have probably contributed to the declines of most endangered species (Czech et al. 2000), our findings suggest that its abatement does not necessarily facilitate recoveries for the majority of ESA-listed species. Others have similarly noted that endangered species recovery is unlikely to occur from increasing species' current ranges (Abbitt & Scott 2001) and site protection (Hoffmann et al. 2010) alone. Future species recoveries are more likely to require active management efforts (Foin et al. 1998), and in some cases, on-going management efforts even after recovery is achieved (Scott et al. 2005). As previously mentioned, it is possible that threats unrelated

to habitat area constrain the recovery of most ESA-listed species. Alternatively, by the time imperilled species are listed under the ESA and critical habitat is designated, many species may already be in inexorable decline (Schwartz 2008; Harris et al. 2012).

One way forward in conservation planning may be to identify sets of species for which particular conservation actions are likely to be effective. We did not find any specific taxonomic group to be strongly associated with habitat protection measures (Table 3); however, this may be because our study lacked statistical power due to limited sample sizes for many of the taxonomic groups represented. Nevertheless, it would be strategic to identify species characteristics that are associated with habitat area-dependent recovery, and to then utilize CH and PA as the primary measures of protection for species with those characteristics. Specifically addressing recovery measures for relevant sets of species would be more efficient than the current practice (in principle) of designating CH for all listed species, especially as there is no current consensus as to the effectiveness of critical habitat designation. Habitat area-dependent endangered species may share similar characteristics such as life history traits (Boersma et al. 2001; Minor & Lookingbill 2010; Murray et al. 2011), as well as demographic, ecological and evolutionary correlates (Hutchings et al. 2012). Note that the idea to manage species recovery based on trait similarity differs from the current practice of developing multi-species recovery plans. We postulate that habitat-area dependent species would be more likely to respond similarly to particular

management strategies, as opposed to the current groups of species that simply share a common geographic location (see Boersma et al. 2001; Taylor et al. 2005).

We were unable to detect a relationship between species recovery and the years of PA protection or new PA protection). A recent systematic review highlighted that the collective evidence as to whether PAs are effective at conserving species populations remains inconclusive (Geldmann et al. 2013). Detectability of these factors' effects might have been weakened by incomplete data within the USGS GAP PA database (i.e. dates of PA establishment). However, the USGS PA database remains the best available source of PA data to date (Minor & Lookingbill 2010).

Part of the poor predictive power of our relationships may have to do with the nature of CH and its CH designation process. Firstly, the CH designation process has long been criticized for being subject to political or economic influence (Taylor et al. 2005; Hagen & Hodges 2006; Schwartz 2008). Second, the biological criteria associated with CH designation are also subject to interpretation and are applied inconsistently (Hodges & Elder 2008). It is possible that habitat truly critical to the persistence of a given species may not have been included in the final CH designation. The USFWS and NMFS are reported to be updating their definitions for *critical habitat* in 2014, which may help reduce errors and subjectivity (and provide transparency) in the habitat identification and legal designation processes (Clark 2013). It should also be noted that while CH designation provides an indication of the

habitat requirements vital to the persistence of a given species, it remains possible that changes in population abundances are poorly related to the amount of habitat designated as critical (Hagen & Hodges 2006).

The poor predictive power of our relationships may also reflect the quality of available recovery status estimates. Similar criticisms could undoubtedly be levelled at the NatureServe and IUCN status designations. It is not encouraging that the three measures of recovery were only moderately correlated with one another (Spearman's $\rho = 0.454-0.680$). O'Grady et al. found a similarly moderate correlation (Spearman's $\rho = 0.69$) between the NatureServe and IUCN species assessments in the species they studied (O'Grady et al. 2004). A survey of 50 experts on individual ESA-listed species, many of whom contributed recovery information to the USFWS, found reasonably high agreement between the biennial Congress statuses and expert opinion of recovery (S. Khair, Biology Dept., University of Ottawa, unpublished data). Experts can be wrong, of course, but very few thought that the BRRRI recovery index seriously misrepresented the status of the species with which the expert was familiar, despite the fact that the status designations reflect both species' abundance trends and changes in threats.

Our study attempts to bridge the gap between the study of localized small-scale species-specific recovery and broad-scale analyses of species recoveries (Gaston et al. 2008; Hutchings et al. 2012; Geldmann et al. 2013), in order to find general patterns relevant for

policy implications. Yet, as with much of conservation biology, the availability and quality of suitable data has limited our ability to accurately test general hypotheses about whether conservation actions are effective. Without actual species' population trajectories and time-series data, it is difficult to assess objectively the accuracy recovery progress. By using several indices, we endeavoured to mitigate this problem. And, although species' status data may be imperfect, it is no justification for failing to evaluate which conservation strategies are most effective in facilitating endangered species' recoveries.

5. Conclusion

Endangered species recovery, at best, appears to be related to critical habitat area protection for only a limited number of species. We found that the inclusion of CH in protected areas cannot serve as a silver bullet solution for the recovery of ESA-listed species, as the abatement of habitat losses is only associated with the recovery of some species. It may be necessary to tailor specific recovery strategies for sets of ESA-listed species based on similar recovery characteristics. We also note that the poor predictive power of our relationships may reflect poor recovery status estimates due to insufficient underlying data.

6. References

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Tables and Figures

Table 1: Spearman Rank Correlations values (ρ) for three measures of endangered species recovery: Biennial Report Recovery Index (BRII) and the status designations of NatureServe and International Union for Conservation of Nature's (IUCN) Red List. BRII was derived from species statuses in the U.S. Fish & Wildlife Service biennial reports to Congress. NatureServe and IUCN indices were derived from population status designations reported online as: declining, stable or increasing. All correlations are highly significant ($p < 10^{-5}$), but they are weaker than one might expect.

Spearman Rank Correlations (ρ)	BRII	NatureServe
BRII	-	0.530 (n = 359)
IUCN	0.454 (n=183)	0.680 (n = 107)

Table 2: Tests of the relationships between species recovery status and measures of critical habitat (CH) protection by protected areas (PAs). Three measures of endangered recovery status were used: the Biennial Report Recovery Index (BRRI), and the status designations of NatureServe and International Union for Conservation of Nature (IUCN) Red List. BRRI was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. NatureServe and IUCN indices were derived from population status designations reported online as: declining, stable or increasing. For this analysis, we coarse-grained all three indices into two categories: declining, versus stable or increasing. We grouped the PAs into three levels of protection based on their assigned IUCN rankings: strictly protected (IUCN categories Ia-IV); protected (Ia to VI); or unprotected (not IUCN classified). We tested the relationship between species recovery and CH area protection measures using logistic regressions to compare species that are declining (i.e. decreasing recovery scores) against those that are improving (i.e. stable or improving recovery scores). Relationships that are individually statistically significant are highlighted in bold. All relationships are positive, except those marked with a minus sign in parentheses. After Bonferroni correction for multiple unplanned comparisons, none of the relationships are significant.

Measures of CH Area Protection	BRRI		NatureServe		IUCN	
	Declining versus stable or increasing		Declining versus stable or increasing		Declining versus stable or increasing	
Total CH area (log)	Pseudo R ²	(-) 0.002	(-) 0.081	(-) 0.021		
	p	0.44	0.005	0.27		
	n	273	86	53		
	AIC	322.4	110.8	63.9		
Unprotected CH area (log)	Pseudo R ²	(-) 0.012	(-) 0.051	(-) 0.007		
	p	0.05	0.02	0.50		
	n	273	86	53		
	AIC	319.1	114.3	64.8		
Protected CH area (log)	Pseudo R ²	0.003	(-) 0.049	(-) 0.008		
	p	0.37	0.02	0.47		
	n	273	86	53		
	AIC	322.2	114.5	64.7		
Strictly protected CH area (log)	Pseudo R ²	0.019	(-) 0.003	0.041		
	p	0.01	0.55	0.12		
	n	273	86	53		
	AIC	316.9	119.9	62.7		

Table 3: Spearman Rank Correlations (ρ), as Biennial Report Recovery Index (BRII) scores for endangered species recovery and measures of Critical Habitat (CH) protection, by taxonomic group. BRII was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Analogous Spearman Rank Correlations were also calculated using the species status designations from NatureServe and from the International Union for Conservation of Nature's (IUCN) Red List. The Spearman Rank Correlations for NatureServe and IUCN indices were also mainly insignificant, once Bonferroni corrections were applied, and largely lacked statistical power given low sample sizes. After Bonferroni correction for multiple unplanned comparisons, relationships that are statistically significant are highlighted in bold.

Measures of CH Area Protection	Taxonomic Group											
		Amphibians	Birds	Fish	Invertebrates	Mammals	Plants	Reptiles				
Total CH area (log)	Spearman's ρ	-0.400	-0.172	0.018	-0.434	0.240	-0.288	-0.394				
	p	0.52	0.52	0.92	0.05	0.39	0.0002	0.23				
	n	5	16	39	21	15	166	11				
Unprotected CH area (log)	Spearman's ρ	-0.400	-0.182	-0.034	-0.463	0.550	-0.327	-0.505				
	p	0.52	0.50	0.84	0.03	0.03	0.00002	0.11				
	n	5	16	39	21	15	166	11				
Protected CH area (log)	Spearman's ρ	-0.400	-0.111	0.155	-0.218	0.100	-0.051	-0.053				
	p	0.52	0.68	0.35	0.34	0.72	0.51	0.88				
	n	5	16	39	21	15	166	11				
Strictly protected CH area (log)	Spearman's ρ	-0.400	-0.047	0.147	-0.125	0.315	0.152	-0.251				
	p	0.52	0.86	0.37	0.59	0.25	0.05	0.46				
	n	5	16	39	21	15	166	11				

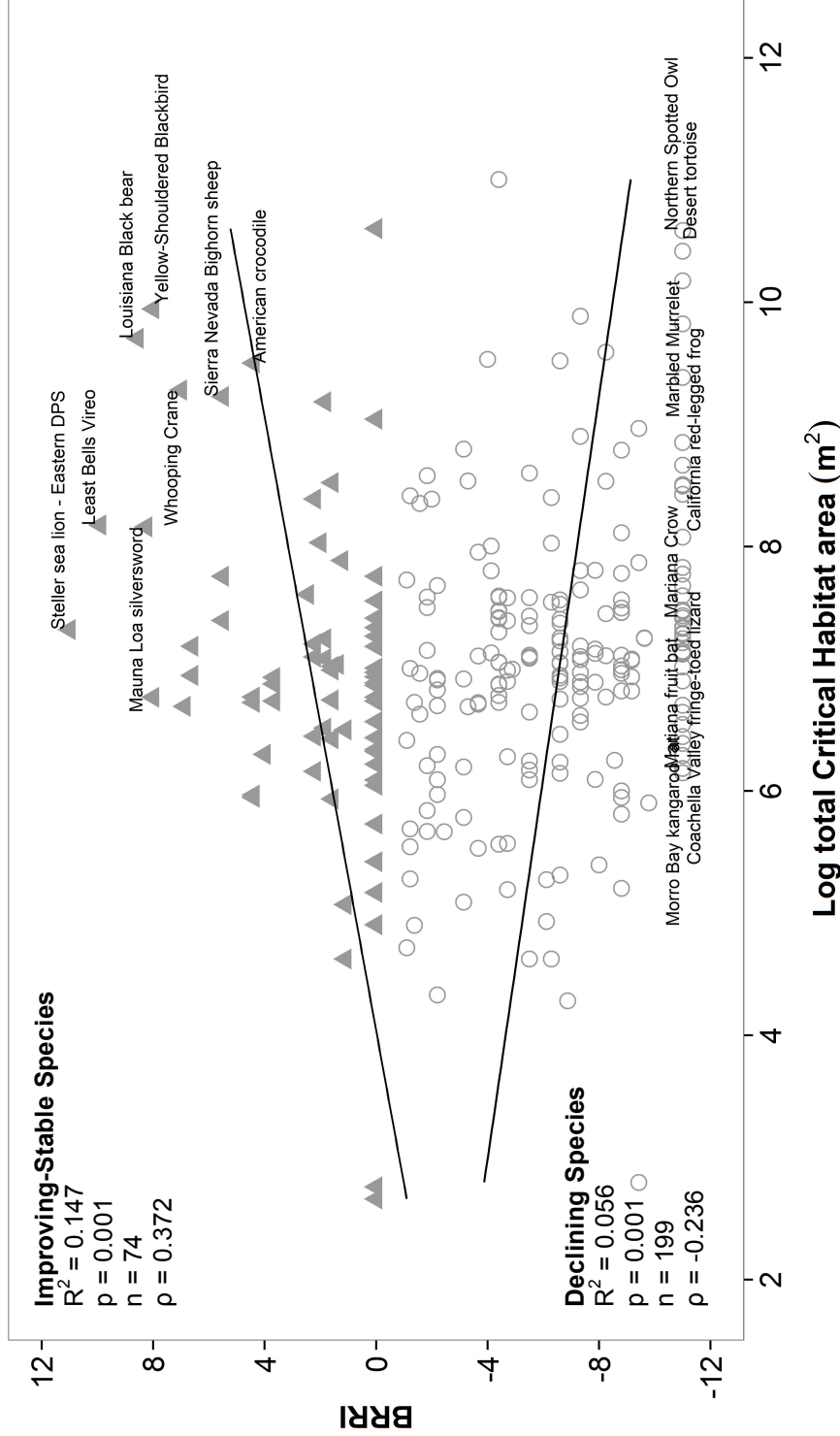


Figure 1: The Biennial Report Recovery Index (BRR I) as a function of total critical habitat (CH) area. BRR I was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Open circles denote species with overall declining recovery statuses, and gray triangles denote improving-stable species (with stable-increasing BRR I scores). We added a small constant to all areas to avoid undefined $\log(0)$. The ρ values represent Spearman Rank Correlations.

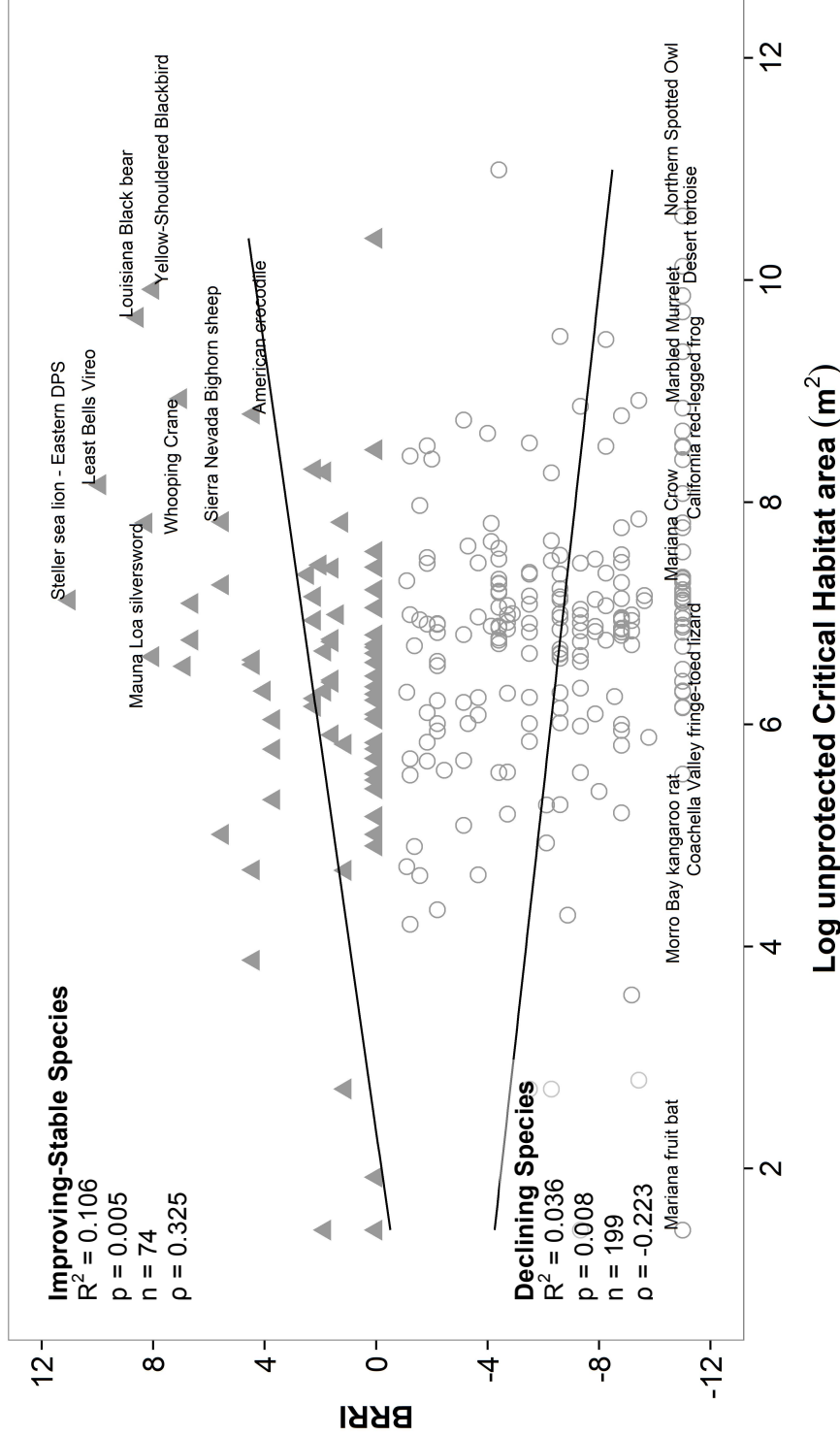
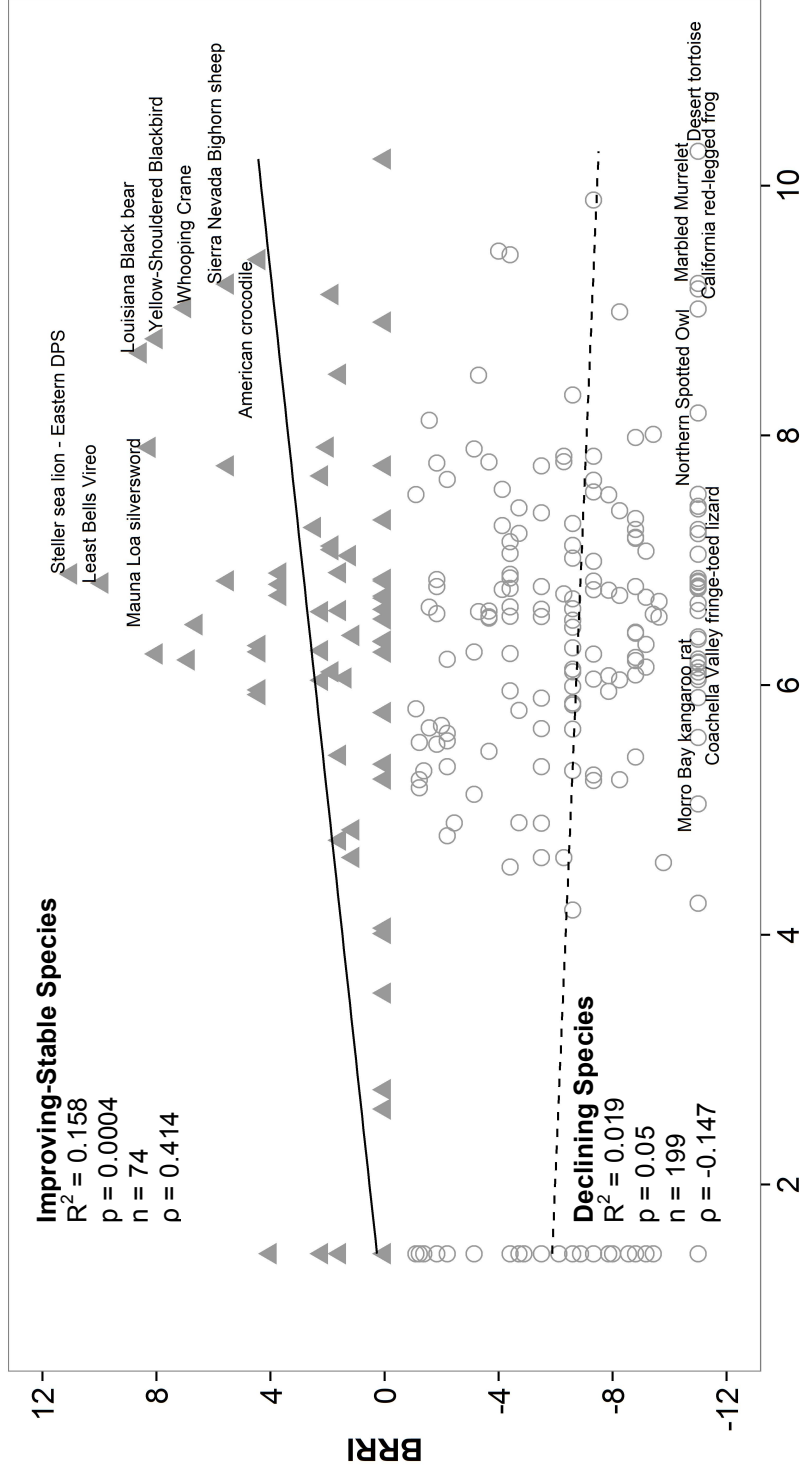


Figure 2: The Biennial Report Recovery Index (BRR I) as a function of unprotected critical habitat (CH) area. BRR I was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Open circles denote species with overall declining recovery statuses, and gray triangles denote improving-stable species (with stable-increasing BRR I scores). We treated areas outside of any protected area (PA) ranked by the International Union for Conservation of Nature (IUCN) between I and VI as unprotected. We added a small constant to all areas to avoid undefined $\log(0)$. The ρ values represent Spearman Rank Correlations.



Log protected Critical Habitat area (m²)

Figure 3: The Biennial Report Recovery Index (BRR I) as a function of protected critical habitat (CH) area. BRR I was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Open circles denote species with overall declining recovery statuses, and gray triangles denote improving-stable species (with stable-increasing BRR I scores). The dotted line is statistically non-significant. We treated protected areas (PAs) ranked by the International Union for Conservation of Nature (IUCN) between I and VI as protected CH areas. We added a small constant to all areas to avoid undefined log(0). The ρ values represent Spearman Rank Correlations.

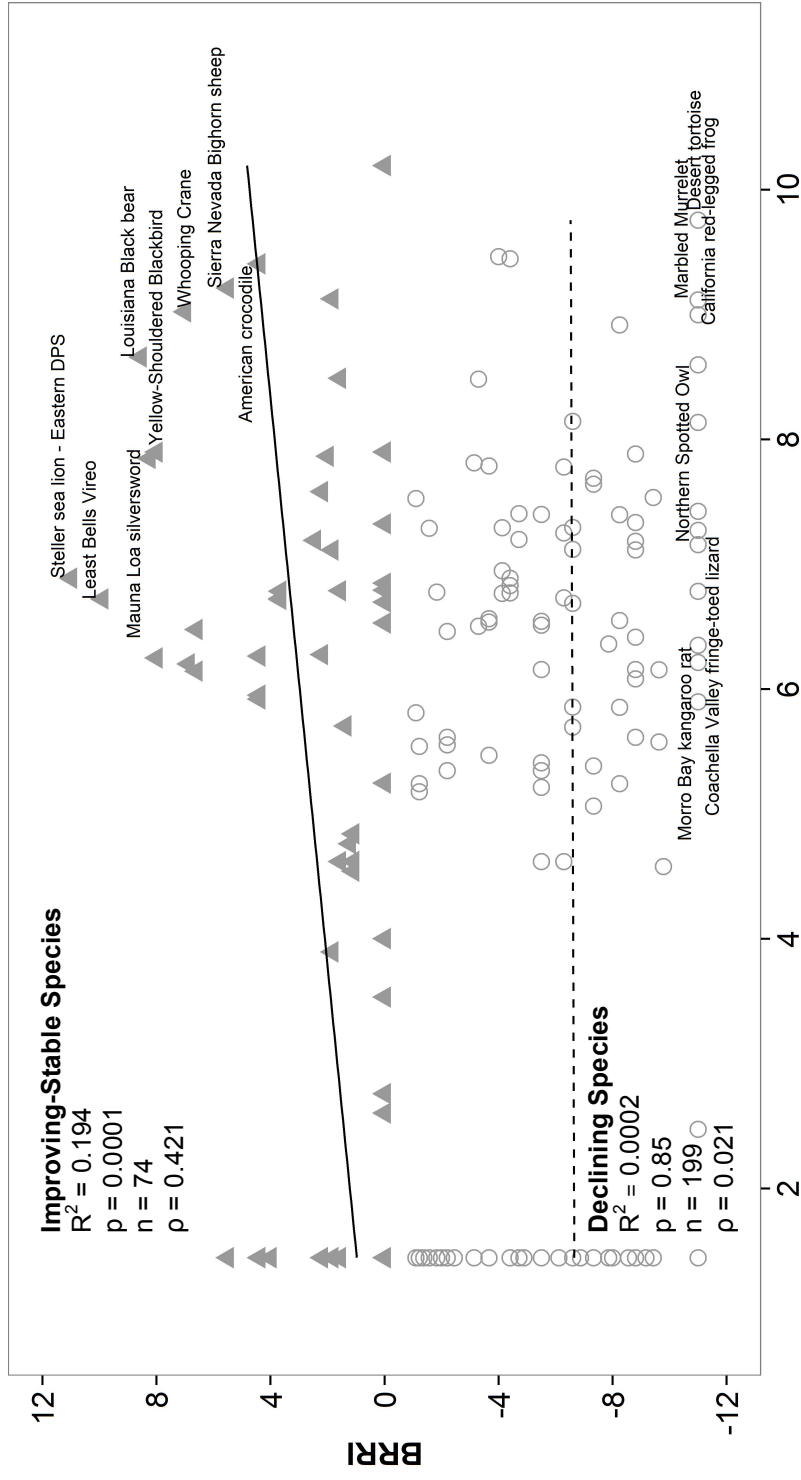


Figure 4: The Biennial Report Recovery Index (BRRI) as a function of strictly protected critical habitat (CH) area. BRRI was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Open circles denote species with overall declining recovery statuses, and gray triangles denote improving-stable species (with stable-increasing BRRI scores). The dotted line is statistically non-significant. We treated protected areas (PAs) ranked by the International Union for Conservation of Nature (IUCN) between I and IV as strictly protected CH areas. We added a small constant to all areas to avoid undefined $\log(0)$. The ρ values represent Spearman Rank Correlations.

Appendix A: State-Level Legislative Endangered Species Protection

Some species listed in the Endangered Species Act (ESA) receive additional protection through other legislated protection measures, such as ESA conservation agreements; species protection acts; and state-level endangered species acts. Conservation agreements, such as Habitat Conservation Plans and Safe Harbour Agreements also legislated under the ESA, can provide federal agencies with alternate means to protect listed species (Schwartz 2008), but are used on a 'case by case' basis (Gibbs & Currie 2012) as opposed to a primary means of protection. Species protection laws, such as the Bald and Golden Eagle Protection Act, Migratory Bird Treaty Act and Marine Mammal Protection Act, can provide additional protection for some taxonomic groups (Scott et al. 2005). However, these measures are clearly not applicable to all listed taxa; less comprehensive than the main tools enacted by the ESA; and, may lack habitat protection measures (Scott et al. 2005). State-level conservation laws have been widely enacted in the U.S. to provide protection for endangered species, with only five states lacking such protection provisions (George & Snape 2010). However, federal legislations supersede state-level enactments (Goble et al. 1999). Moreover, state-level endangered species acts are highly variable between states (Welsh 2004; George & Snape 2010); are far less comprehensive and offer little by the way of critical habitat protection, recovery plan development and consultations (Goble et al. 1999; George & Snape 2010). While conservation agreements, species-specific protection acts and state-level conservation acts, are complimentary to federal protections enacted by the ESA, these tools are unlikely to be a primary mechanism in driving species recoveries.

Appendix A References

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Appendix B: International Union for Conservation of Nature's (IUCN) Protected Areas (PA) Classification System

Protected Areas (PAs) are classified by the International Union for Conservation of Nature (IUCN) in Categories ranging from I to VI (Table B-1). PAs classified as I-IV are considered as strictly managed and provide ecosystem and habitat conservation value (Rodrigues et al. 2004; Brooks et al. 2009; Minor & Lookingbill 2010; Taylor et al. 2011; Clark et al. 2013). PAs classified as IUCN V-VI are managed to allow for cultural, recreational and sustainable resource use. See Leroux et al. (2010) for detailed descriptions regarding IUCN management categories.

Table B-1: International Union for Conservation of Nature's (IUCN) Protected Areas (PA) Classification System

Category	Protected Area Type
Ia	Strict Nature Reserve
Ib	Wilderness Area
II	National Park
III	Natural Monument or Feature
IV	Habitat/Species Management Area
V	Protected Landscape/Seascape
VI	Protected area with sustainable use of natural resources

Appendix B References

- Brooks, T. M., S. J. Wright, and D. Sheil. 2009. Evaluating the success of conservation actions in safeguarding tropical forest biodiversity. *Conservation Biology* **23**:1448–1457.
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Appendix C: Results for Species Recovery and Critical Habitat (CH) Protection Measures as determined by a Weighted Recovery Index (WRI)

Similar to Gibbs & Currie (2012), Taylor et al. (2005) also used ESA population status data to develop a similar measure of recovery. However, Taylor et al. (2005) split their study period into three time periods and then calculated a final recovery score averaged for the three periods. They assigned greater weights to the more recent recovery scores and multiply the most recent by 1.5, middle scores by 1.0, and oldest scores by 0.5. They then calculated an average value for the three time periods and categorized the final values as improving, stable or declining.

Following Taylor et al. (2005), we partitioned our data into the same three time periods from 1990-1992 (oldest), 1996 (middle), and 1998-2002 (recent). We also added a fourth time period for the newer data, 2004-2010 (most recent). As conducted for the Biennial Report Recovery Index (BRRRI), we used population statuses reported in the Endangered Species Act (ESA) biennial reports to Congress and we assigned values of -1, 0 and 1 respectively to 'declining', 'stable' and 'increasing' status reports. We then multiplied the most recent scores by 2, recent scores by 1.5, middle scores by 1 and oldest scores by 0.5. Following Gibbs & Currie (2012), we then adjusted the scores by dividing each species' score by the proportion of reported statuses out of 11 possible Biennial Reports to Congress. We refer to this index hereafter as the Weighted Recovery Index (WRI).

Tests of the relationships between recovery status as WRI and measures of CH protection are summarized in (Table C-1). We found that assigning greater weight to more recent reports through the WRI index, following Taylor et al. (2005), did not qualitatively change the final results in comparison to the BRRi index.

Table C-1: Tests of the relationships between species recovery status and measures of Critical Habitat (CH) protection by Protected Areas (PAs) using the Weighted Recovery Index (WRI) as the measure of recovery. WRI was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress, and weighted to assign greater weights to the more recent recovery scores. We grouped the PAs into three levels of protection based on their assigned International Union for Conservation of Nature (IUCN) rankings: strictly protected (IUCN categories Ia-IV); protected (Ia to VI); or unprotected (not IUCN classified). We tested the relationship between species recovery and CH area protection measures using linear regressions to assess all species, declining species, and stable or increasing species. We also used logistic regressions to compare species that are declining (i.e. decreasing recovery scores) against those that are improving (i.e. stable or improving recovery scores). Relationships that are individually statistically significant are highlighted in bold. All relationships are positive, except those marked with a minus sign in parentheses.

Measures of CH Area Protection		WRI			
		All species	Declining species	Stable or increasing species	Declining versus stable or increasing
Total CH area (log)	R ² /Pseudo R ²	(-) 0.004	(-) 0.039	0.146	(-) 0.001
	p	0.32	0.01	0.001	0.56
	n	273	202	71	273
	AIC	1940.6	1268.6	408.3	316.6
Unprotected CH area (log)	R ² /Pseudo R ²	(-) 0.013	(-) 0.033	0.105	(-) 0.010
	p	0.06	0.01	0.01	0.08
	n	273	202	71	273
	AIC	1937.9	1269.9	411.6	313.8
Protected CH area (log)	R ² /Pseudo R ²	0.004	(-) 0.010	0.193	0.004
	p	0.30	0.17	0.0001	0.28
	n	273	202	71	273
	AIC	1940.5	1274.6	404.2	315.7
Strictly protected CH area (log)	R ² /Pseudo R ²	0.049	0.006	0.210	0.021
	p	0.0002	0.29	0.0001	0.01
	n	273	202	71	273
	AIC	1928.0	1275.4	402.8	310.5

Appendix C References

Gibbs, K. E., and D. J. Currie. 2012. Protecting endangered species: do the main legislative tools work? PLoS ONE 7:DOI:10.1371/ journal.pone.0035730.

Taylor, M. F. J., K. F. Suckling, and J. J. Rachlinski. 2005. The effectiveness of the Endangered Species Act: a quantitative analysis. BioScience 55:360–367.

Appendix D: Homogeneity within Dataset Selected

Comparing Reported Population Trends for Endemic and Global Species

Method

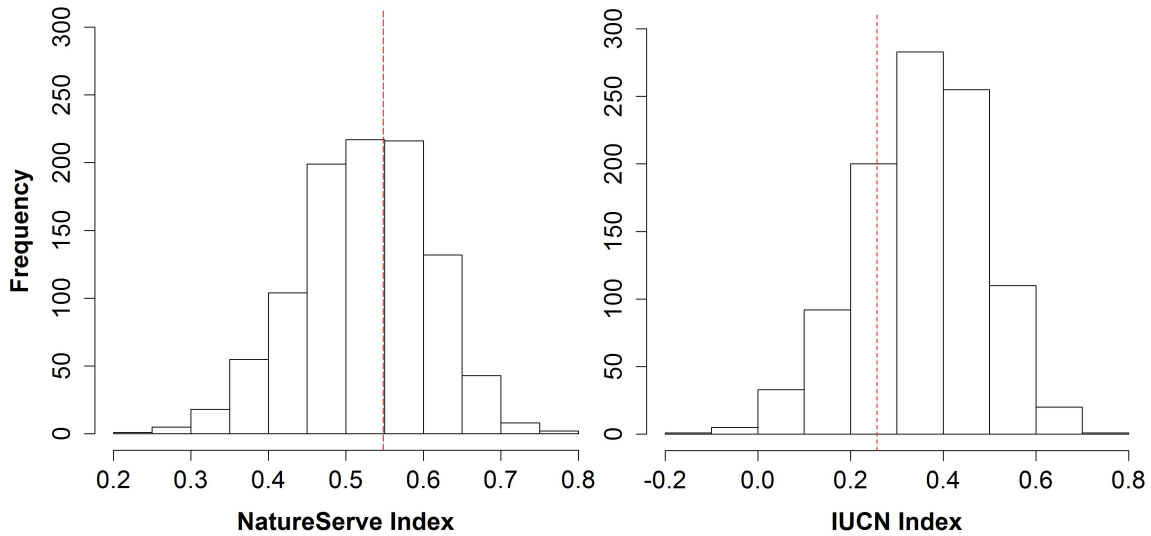
NatureServe and the International Union for the Conservation of Nature (IUCN) Red List report population status trends at continental and global scales, respectively, whilst the Endangered Species Act (ESA) Congress reports population trends within the U.S. To test whether the inclusion of species that are endemic to the U.S. differ from those whose distributions extend outside the U.S., we compared population trends reported for endemic species with the overall dataset.

We assessed the correlation (Spearman Rank Correlation, ρ) between the Biennial Report Recovery Index (BRRRI) and the NatureServe index, as well as the BRRRI and IUCN indices for species endemic to the U.S. We then compared the calculated correlation coefficients for the endemic species to correlation coefficients calculated for 1000 randomly generated random subsamples of the full set of data (containing both endemic and global species).

Results

The large-scale population statuses reported by NatureServe and IUCN did not differ from status trends reported for endemic species at the national-scale (i.e. BRRRI). Correlation coefficients calculated for endemic species did not significantly differ from correlation

coefficients calculated for 1000 randomly generated subsets from the overall dataset (Figure D-1).



Spearman's Rho for 1000 randomly generated subsamples

Figure D-1: Histogram of Spearman Rank Correlations (ρ) calculated for 1000 randomly generated subsets of **(a)** NatureServe and the Biennial Report Recovery Index (BRRI) recovery scores ($n=80$); and, **(b)** International Union for Conservation of Nature (IUCN) and BRRI recovery scores ($n=51$). BRRI was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. NatureServe and IUCN indices were derived from population status designations reported online as: declining, stable or increasing. Dotted lines depict observed correlation coefficients for the endemic set of species for NatureServe ($\rho = 0.548$) and IUCN ($\rho = 0.257$), respectively.

Comparing for Differences in Species

Method

We assessed whether species' recovery scores were related to other factors that might add variance to a relationship between recovery and protected critical habitat (CH) areas. We performed ANOVAs to test whether the Biennial Report Recovery Index (BRRRI) scores for Endangered Species Act (ESA) species included in this study, differed systematically among taxonomic groups (amphibians, birds, fish, invertebrates, mammals, plants, or reptiles), habitat (terrestrial, freshwater, or marine), biogeography (mainland, island, or marine), or among regions within the U.S. (Alaska, Hawaii, Mariana Islands, Puerto Rico, contiguous U.S.).

We also examined BRRRI recovery scores and residuals for spatial autocorrelation using Conditional Autoregressive models (CARs) using 'Spatial Autocorrelation in Macroecology' software (SAM version 4.0, available via www.ecoevol.ufg.br/sam; Rangel et al. 2010). We tested for spatial autocorrelation in the strongest relationships observed between the measures of CH area protection and recovery (see Appendix F) in improving species (i.e. strictly protected CH area) and declining species (i.e. total CH area).

Results

Recovery scores for the 299 ESA-listed species, as measured by BRRRI, were homogeneous with respect to habitat (terrestrial, freshwater or marine) and biogeography (mainland,

island or marine) (Table D-1). Species recoveries, on the other hand, significantly differed among taxonomic groups ($F_s = 5.5$; $df = 6, 292$; $p > 0.0001$; Table D-1) and regions within the U.S. ($F_s = 4.0$; $df = 4, 294$; $p = 0.003$; Table D-1). However, regional differences were no longer statistically significant once taxonomic differences were accounted for, although a region X taxon interaction remained marginally significant (Table D-2). Additional taxonomic differences may not have been detected due to the underrepresentation of taxa in regions outside of the continental U.S. (e.g. only 1 Hawaiian mammal and 2 Hawaiian invertebrates). While we consider taxonomic differences in species recoveries in our study (see Table 3 in the main report), note that Gibbs & Currie (2012) have previously examined such taxonomic differences in ESA-listed species' recoveries in greater detail.

Spatial autocorrelation in the overall dataset was negligible, as observed by the correlogram for all 299 species' BRRI scores (Figure D-2). For increasing species, the residuals from the relationship between recovery scores and strictly protected CH area model (Figure D-3) showed negligible spatial autocorrelation. For declining species, spatial autocorrelation between recovery scores and total CH areas was negligible (Figure D-4).

Table D-1: Tests of the relationships between the Biennial Report Recovery Index (BRRRI) recovery scores and potential confounding factors. We tested whether species' BRRRI recovery scores differ systematically among taxonomic groups, habitat, biogeography or regions within the U.S. BRRRI was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Statistically significant relationships are highlighted in bold.

		ANOVA				
Model	df	Sum of Squares	Mean Sq	F _s -value	p-value	
Taxonomic group (n = 299)	6	759	126.5	5.5	> 0.0001	
Residuals	292	6685	22.9			
Habitat (n = 299)	3	108	36.1	1.5	0.23	
Residuals	295	7336	24.9			
Biogeography (n = 299)	2	142	70.9	2.9	0.06	
Residuals	296	7302	24.7			
U.S. Regions (n = 299)	4	387	96.9	4.0	0.003	
Residuals	294	7057	24.0			

Table D-2: Tests of the relationships between the Biennial Report Recovery Index (BRRRI) recovery scores versus differences in taxonomic groups and regions within the U.S. BRRRI was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Relationships that are statistically significant are highlighted in bold.

ANOVA – Type III				
Model	df	Sum of Squares	F _s -value	p-value
Taxonomic group	6	751.4	5.7	> 0.0001
Region	4	164.6	1.9	0.11
Taxa:Region (Interaction)	5	244.2	2.2	0.05
Residuals	283	6167.7		

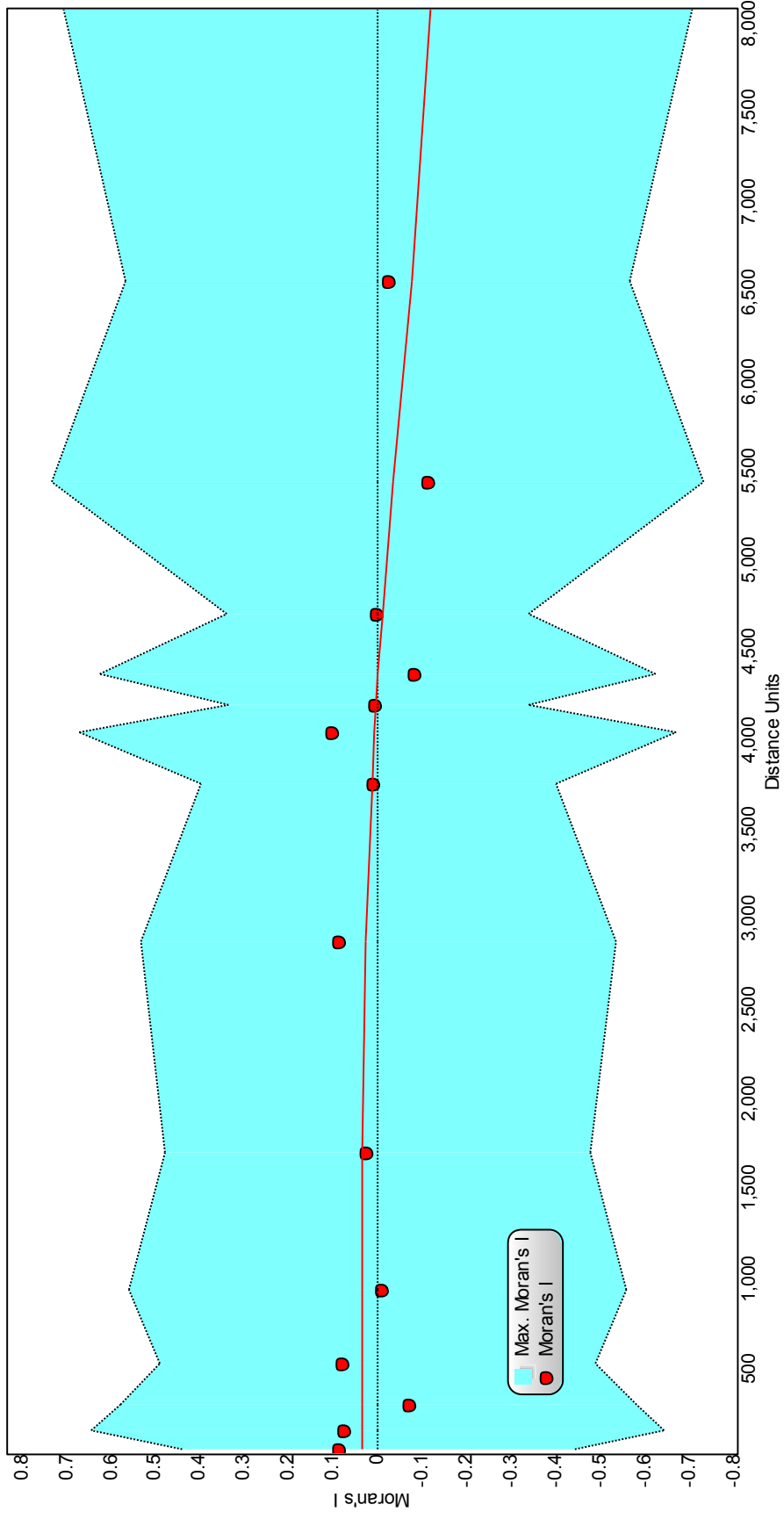


Figure D-2: Correlogram for the raw Biennial Report Recovery Index (BRRRI) scores (n = 299) using Moran's I to test nearest neighbour relationships.

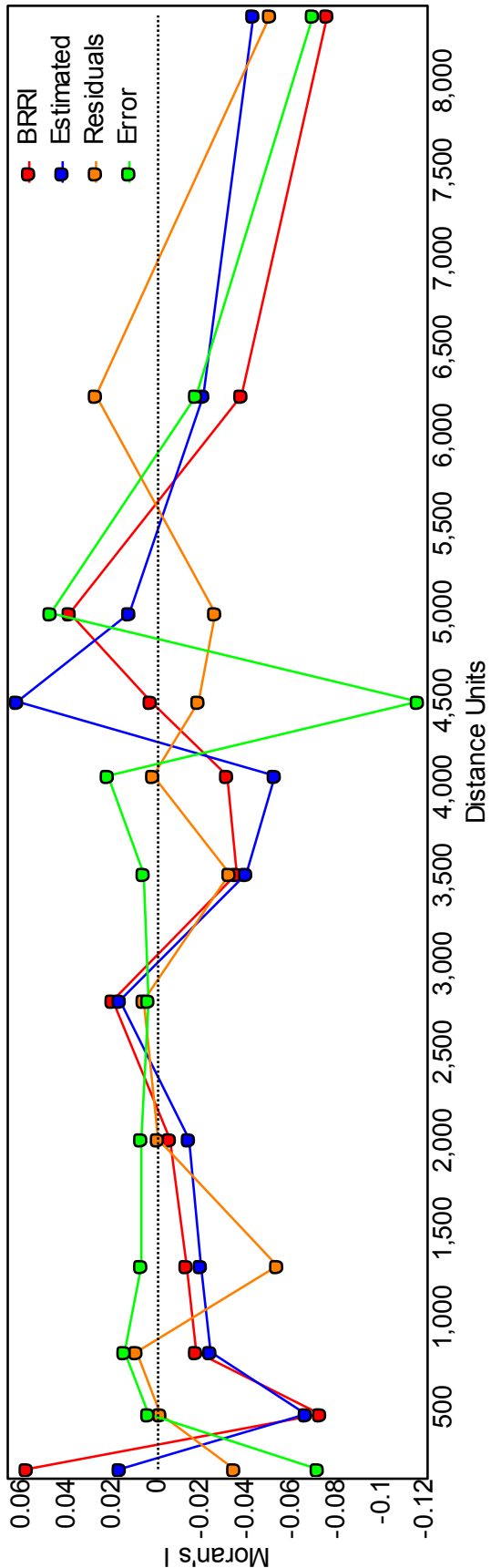


Figure D-3: Spatial autocorrelation of recovery scores for species with improving Biennial Report Recovery Index (BRRIs) scores (n = 74) and log transformed strictly protected critical habitat areas. BRRIs was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. We treated Protected Areas (PAs) ranked by the International Union for Conservation of Nature (IUCN) between I and IV as strictly protected CH areas. Distance units are in kilometres.

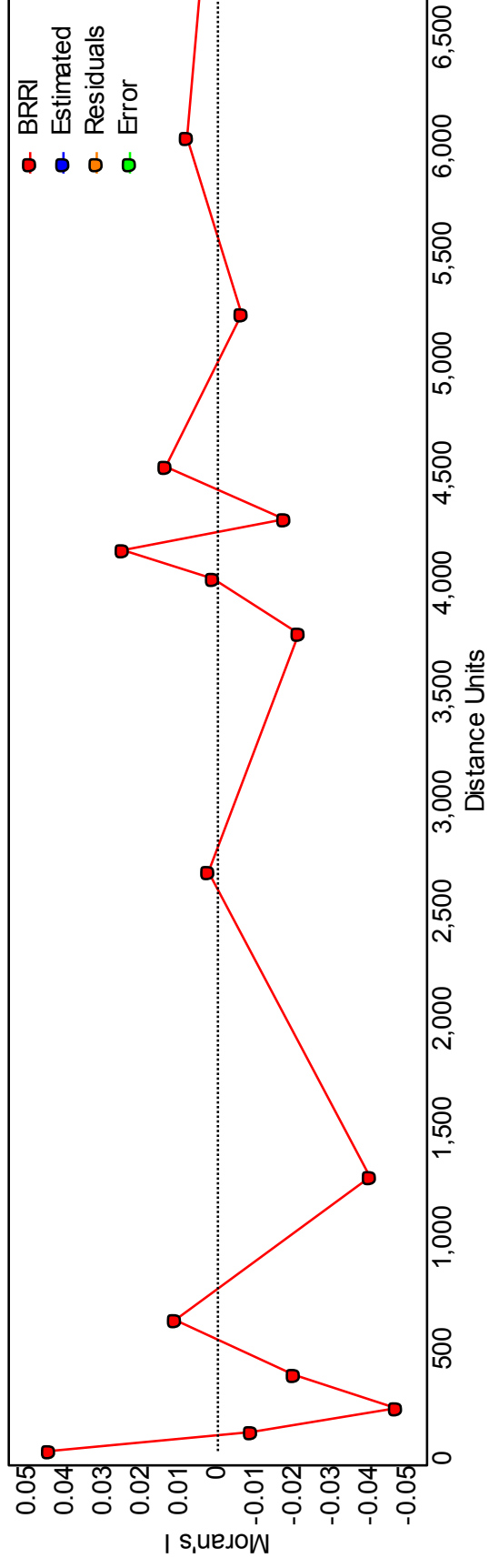


Figure D-4: Spatial autocorrelation of recovery scores for species with decreasing Biennial Report Recovery Index (BRRi) scores (n = 199) and log transformed total critical habitat areas. BRRi was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Distance units are in kilometres.

Appendix D References

Gibbs, K. E., and D. J. Currie. 2012. Protecting endangered species: do the main legislative tools work? PLoS ONE **7**:DOI:10.1371/ journal.pone.0035730.

Rangel, T. F., J. A. F. Diniz-Filho, and L. M. Bini. 2010. SAM: a comprehensive application for Spatial Analysis in Macroecology. *Ecography* **33**:46–50. Available from <http://doi.wiley.com/10.1111/j.1600-0587.2009.06299.x> (accessed January 20, 2014).

Appendix E: Additional Data Summaries

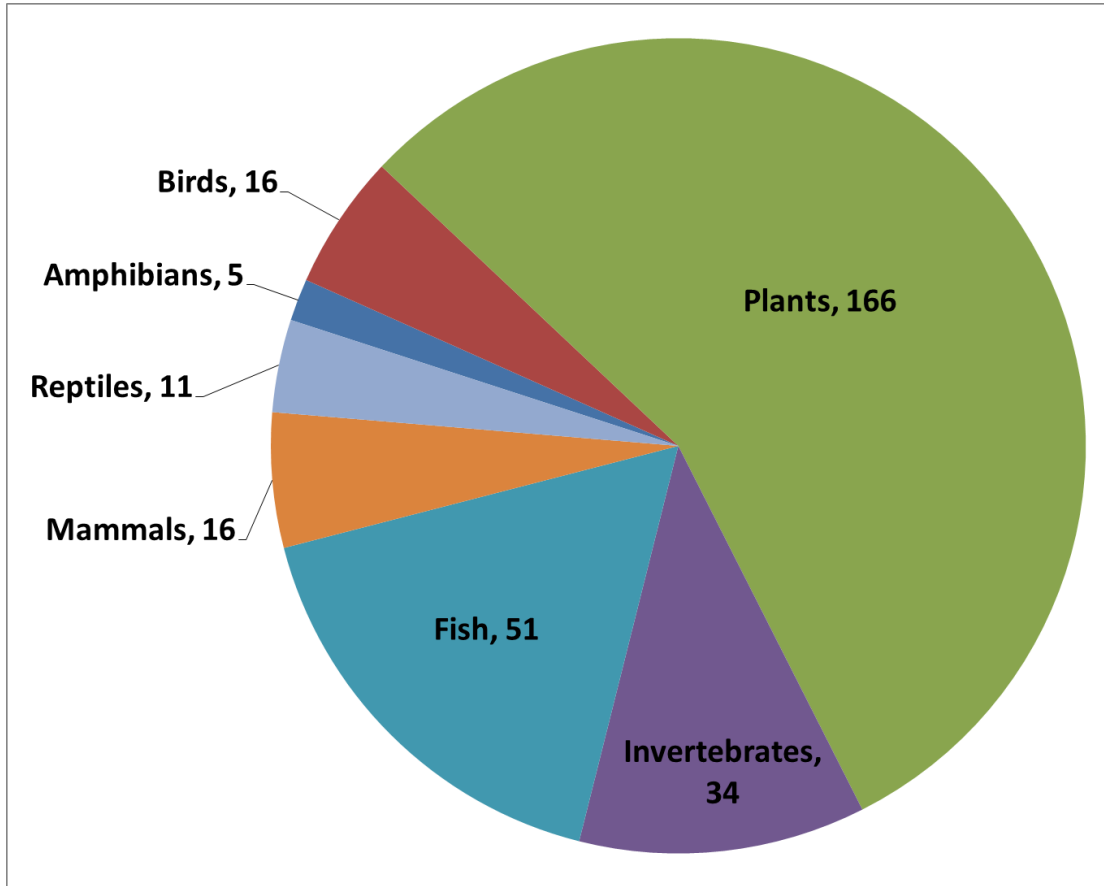


Figure E-1: Endangered Species Act (ESA) species included in our study (n = 299). We considered species, subspecies, varieties or distinct population segments that were listed under the ESA before 2002, for which at least 10 years of population status data were available. We excluded species that are delisted, in captivity and/or presumed extinct, as well as species with multiple listed populations with statuses reported as “mixed”.

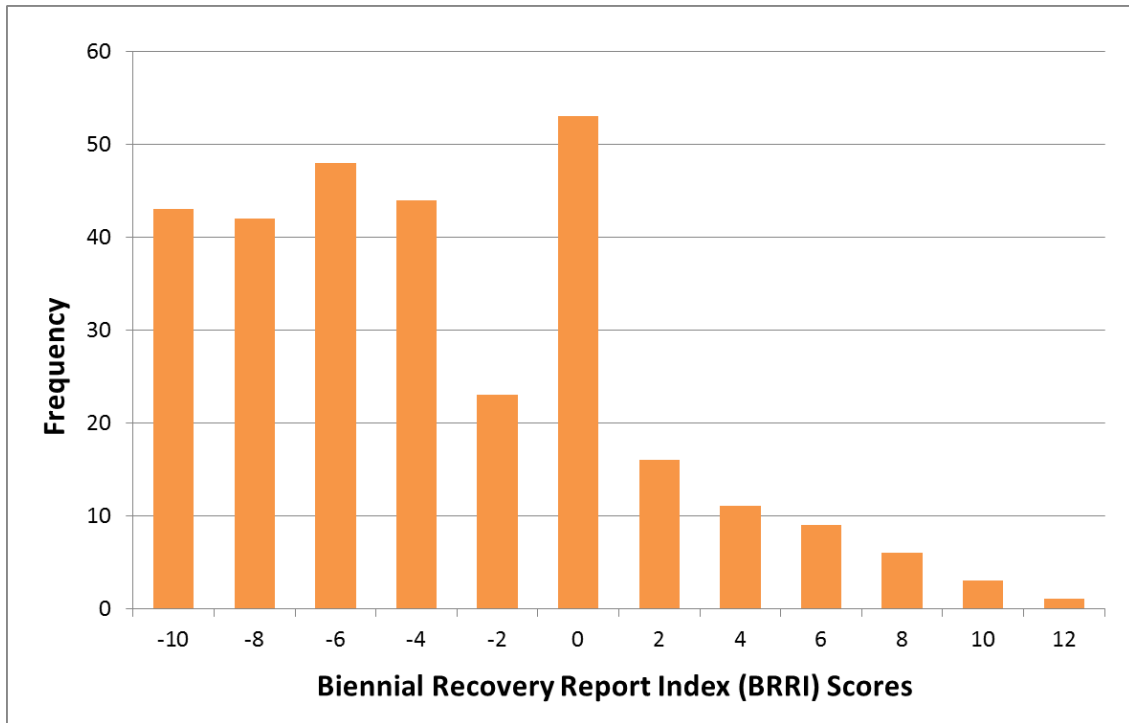


Figure E-2: Histogram of the Biennial Report Recovery Index (BRR) status scores for species in our dataset (n = 299). We used population status designations reported in the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) biennial reports to Congress, as required by the Endangered Species Act (ESA). We assigned values of -1, 0 and 1 to respective ‘declining’, ‘stable’ and ‘increasing’ species and summed the values to obtain an overall recovery score. We then accounted for missing status reports by dividing each species' score by the proportion of known statuses for the reporting period (i.e. of 11 Biennial Reports).

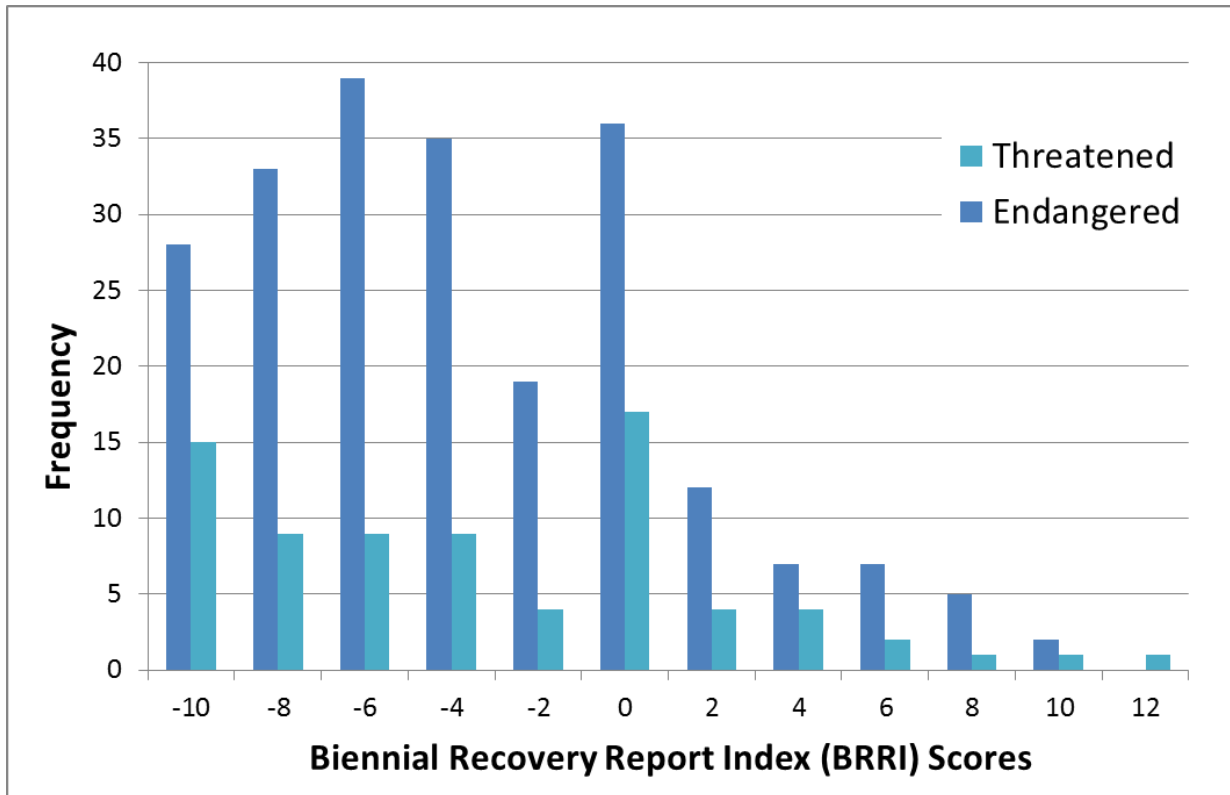


Figure E-3: Histogram of the Biennial Report Recovery Index (BRR) status scores associated with ‘threatened’ and ‘endangered’ species in our dataset (n = 299). We used population status designations reported in the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) biennial reports to Congress, as required by the Endangered Species Act (ESA). We assigned values of -1, 0 and 1 to respective ‘declining’, ‘stable’ and ‘increasing’ species and summed the values to obtain an overall recovery score. We then accounted for missing status reports by dividing each species' score by the proportion of known statuses for the reporting period (i.e. of 11 Biennial Reports).

In practice, the USFWS and NMFS do not generally distinguish protection measures between species listed as ‘threatened’ and ‘endangered’ (Clark 2013). As such, our analyses also do not distinguish between listed species categorized as ‘threatened’ or ‘endangered’ (Figure E-3). An ANOVA test found no statistical difference between species recoveries (as BRR scores) and listing status ($F_s = 0.153$; $df = 1, 297$; $p = 0.696$).

Appendix E References

Clark, J. R. 2013. The Endangered Species Act at 40: opportunities for improvements. *BioScience* **63**:924–925.

Spatial Distributions of Species' Critical Habitats included in the Study

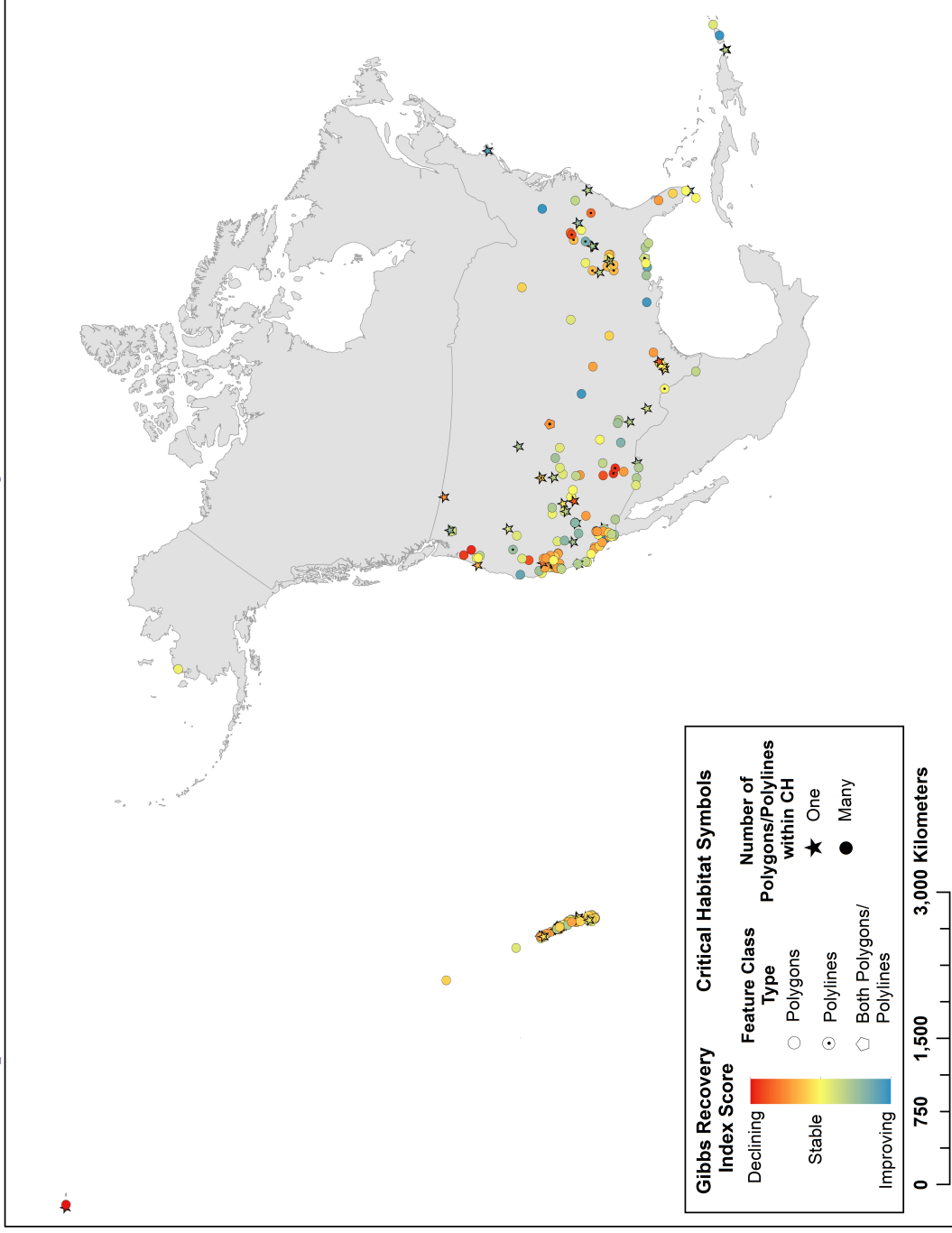


Figure E-4: Spatial distribution of Critical Habitats (CH) designated for all 299 species. One true centroid for each species is represented with its Biennial Recovery Report Index (BRR) score.

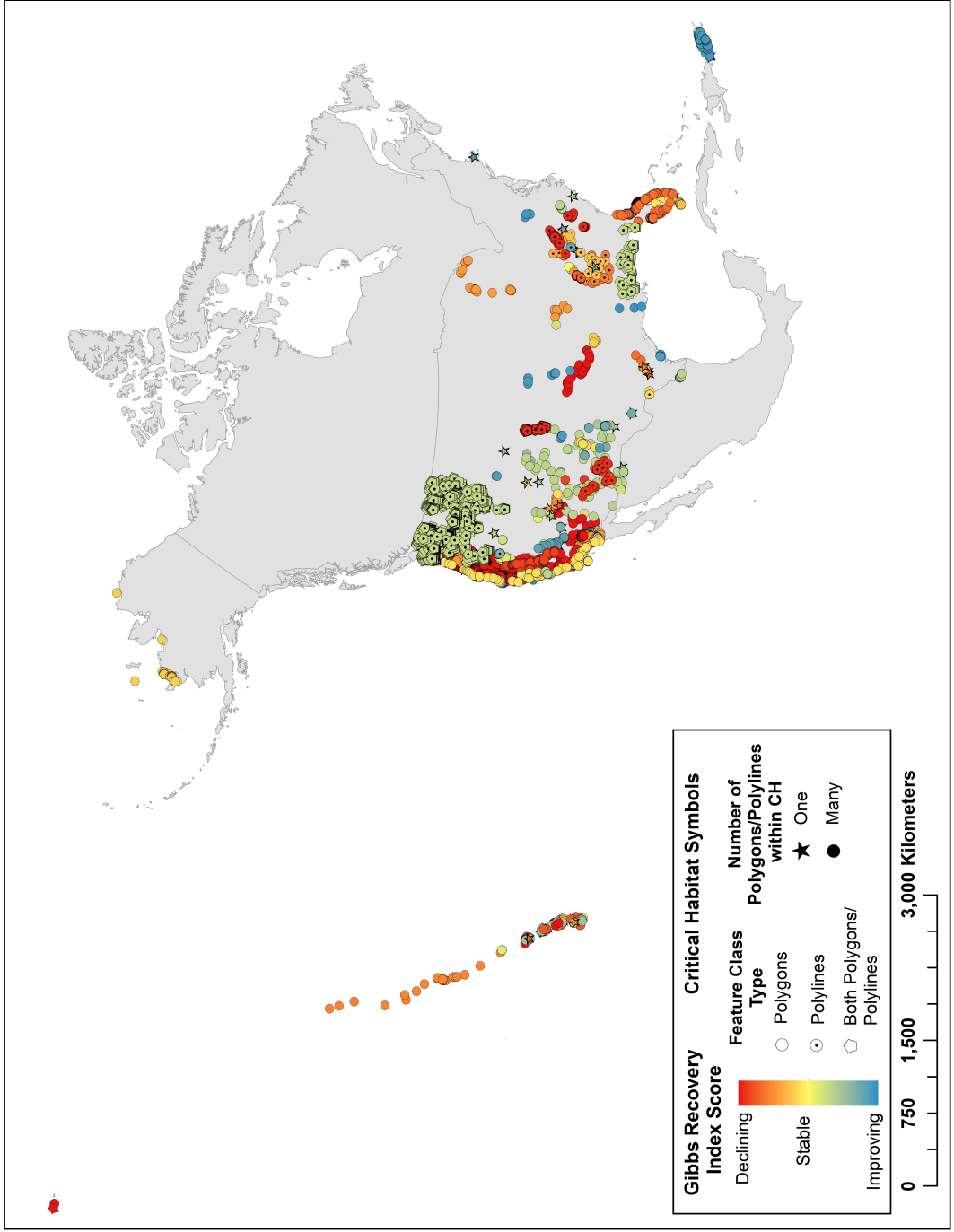


Figure E-5: Spatial distribution of Biennial Recovery Report Index (BRR) scores for all true centroids for 299 species' Critical Habitat (CH) polygon and polyline features (n = 43789).

Appendix F: Linear Regression Results for Measures of Critical Habitat (CH) Area Protection, as measured by the Biennial Report Recovery Index (BRR)

Table F-1: Tests of the relationships between species recovery status and measures of Critical Habitat (CH) protection by Protected Areas (PAs). We used the Biennial Report Recovery Index (BRR) as the measure of endangered recovery status. BRR was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. We grouped the PAs into three levels of protection based on their assigned International Union for Conservation of Nature (IUCN) rankings: strictly protected (IUCN categories Ia-IV); protected (Ia to VI); or unprotected (not IUCN classified). We tested the relationship between species recovery and CH area protection measures using linear regressions, for: all species, declining species (i.e. decreasing recovery scores) and improving species (i.e. stable or improving recovery scores). Relationships that are individually statistically significant are highlighted in bold. All relationships are positive, except those marked with a minus sign in parentheses.

Measures of CH Area Protection		BRR		
		All species	Declining species	Stable or increasing species
Total CH area (log)	R^2	(-) 0.006	(-) 0.056	0.147
	p	0.21	0.001	0.001
	n	273	199	74
	AIC	1659.6	1014.4	357.0
Unprotected CH area (log)	R^2	(-) 0.015	(-) 0.036	0.106
	p	0.05	0.01	0.005
	n	273	199	74
	AIC	1657.1	1018.7	360.5
Protected CH area (log)	R^2	0.002	(-) 0.019	0.158
	p	0.49	0.05	0.0004
	n	273	199	74
	AIC	1660.7	1022.1	356.1
Strictly protected CH area (log)	R^2	0.038	0.0002	0.194
	p	0.001	0.85	0.0001
	n	273	199	74
	AIC	1650.7	1025.9	352.8

Appendix G: Linear Regression Results for Proportions of Critical Habitat (CH) Area Protection, as measured by the Biennial Report Recovery Index (BRRl)

Table G-1: Tests of the relationships between species recovery status and measures of Critical Habitat (CH) protection by Protected Areas (PAs). Three measures of endangered recovery status were used: Biennial Report Recovery Index (BRRl), and the status designations of NatureServe and International Union for Conservation of Nature's (IUCN) Red List. BRRl was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. NatureServe and IUCN indices were derived from population status designations reported online as: declining, stable or increasing. We grouped the PAs into three levels of protection based on their assigned IUCN rankings: strictly protected (IUCN categories Ia-IV); protected (Ia to VI); or unprotected (not IUCN classified). We tested the relationship between species recovery and proportion of CH area protected and used linear regressions to assess all species, declining species, and stable or increasing species for the BRRl scores. For the NatureServe and IUCN recovery measures, we used logistic regressions to compare species that are declining (i.e. decreasing recovery scores) against those that are improving (i.e. stable or improving recovery scores). Relationships that are individually statistically significant are highlighted in bold. All relationships are positive, except those marked with a minus sign in parentheses.

Proportion of CH Protection	BRRl				NatureServe		IUCN
	All species	Declining species	Stable or increasing species	Declining versus stable or increasing	Declining versus stable or increasing	Declining versus stable or increasing	
% CH Protected	R^2 /Pseudo R^2	0.047	0.002	0.003	0.003	0.019	
	p	0.0002	0.53	0.66	0.48	0.23	
	n	299	220	79	107	67	
	AIC	1801.3	1127.1	390.6	143.9	76.2	
% CH Strictly Protected	R^2 /Pseudo R^2	0.085	0.018	0.010	0.016	0.081	
	p	> 0.0001	0.04	0.38	0.14	0.02	
	n	299	220	79	107	67	
	AIC	1789.1	1123.4	390.1	142.2	71.7	
% CH Unprotected	R^2 /Pseudo R^2	(-)0.047	(-)0.002	(-)0.003	(-)0.003	(-)0.019	
	p	0.0002	0.53	0.66	0.48	0.23	
	n	299	220	79	107	67	
	AIC	1801.3	1127.1	390.6	143.9	76.2	

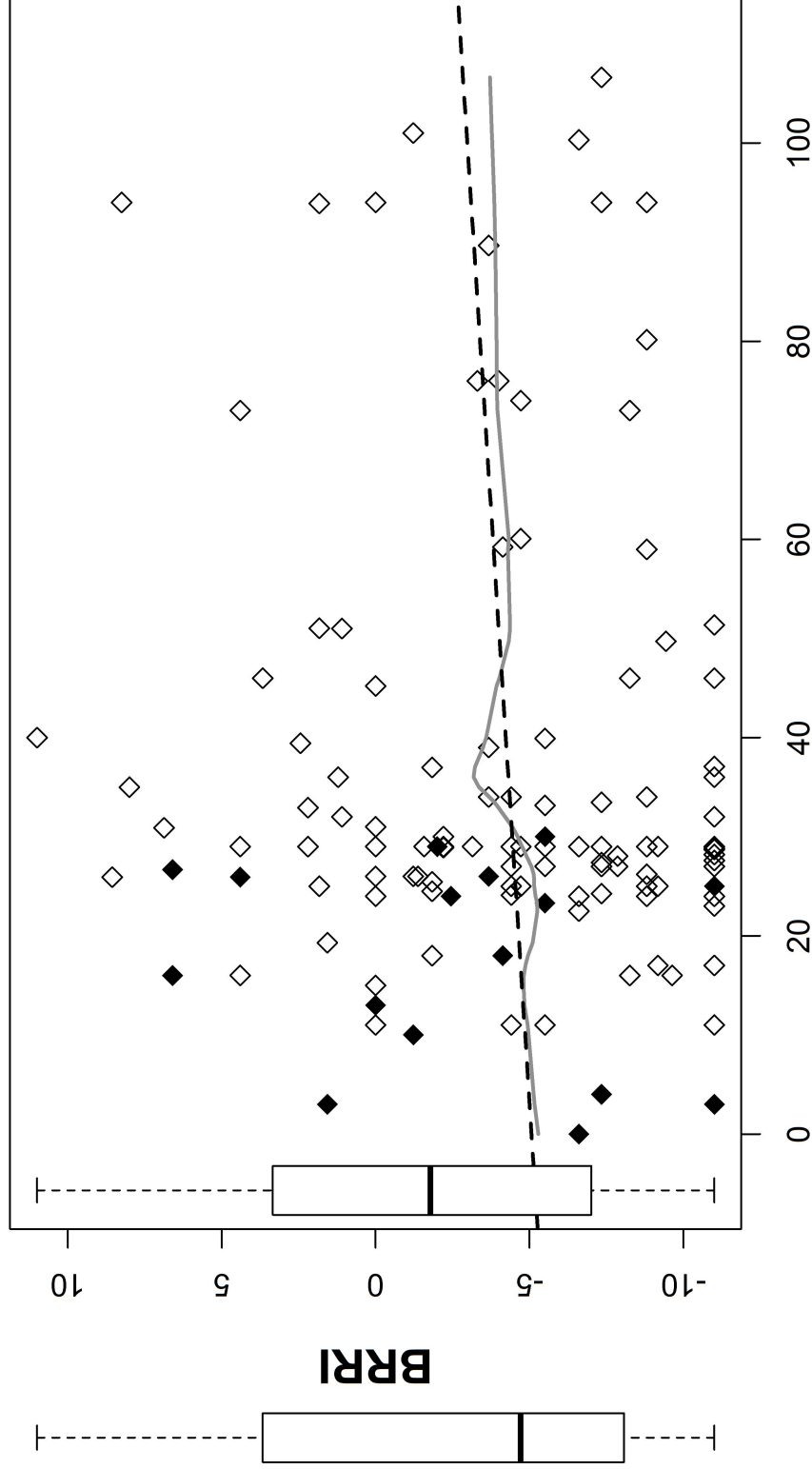
Appendix H: Years of Critical Habitat (CH) protection by a Protected Area (PA)

For all three measures of recovery, we found that species recovery was not associated with the length of time the species' critical habitat (CH) has been protected by a protected area (PA) (Table H-1).

We found that species afforded additional PA protection following CH designation (filled points, Figure H-1) were not significantly different ($F_s = 2.16$; $df = 1, 140$; $p = 0.14$) from species already receiving PA protection at the time of CH designation (hollow points, Figure H-1). We also compared the three groups of species: 1) fully unprotected species (i.e. no PA protection, only CH); 2) species with existing PAs established prior to CH designation (hollow points, Figure H-1); and, 3) species with new PAs established following CH designation (filled points, Figure H-1). Species recovery, as measured by BRR1, did not significantly differ between the three groups ($F_s = 0.99$; $df = 2, 210$; $p = 0.38$).

Table H-1: Tests of the relationships between species recovery status and the years protected by a Protected Area (PA). Three measures of endangered recovery status were used: Biennial Report Recovery Index (BRR1), and the status designations of NatureServe and International Union for Conservation of Nature’s (IUCN) Red List. BRR1 was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. NatureServe and IUCN indices were derived from population status designations reported online as: declining, stable or increasing. We tested the relationship between species recovery and years of CH protection using linear regressions to assess all species, declining species, and stable or increasing species for the BRR1 scores. We also used logistic regressions to compare species that are declining (i.e. decreasing recovery scores) against those that are improving (i.e. stable or improving recovery scores) for all three measures of recovery. Years protected was derived from an average date of establishment, weighted by the area of critical habitat (CH) within each PA. Relationships that are individually statistically significant are highlighted in bold. All relationships are positive, except those marked with a minus sign in parentheses.

Years Protected	BRR1			NatureServe		IUCN
	All Species	Declining	Stable-Increasing	Declining versus Stable-Increasing	Declining versus Stable-Increasing	Declining versus Stable-Increasing
R²/Pseudo R²	0.008	0.007	0.018	0.001	(-) 0.024	0.002
p	0.30	0.38	0.44	0.68	0.30	0.83
n	142	107	35	142	34	28
AIC	871.0	553.0	182.4	162.4	49.5	33.1



Years Protected

Figure H-1: Biennial Report Recovery Index (BRR) as a function of the years of protection by a Protected Area (PA) (n = 142). BRR) was derived from species status designations in the U.S. Fish & Wildlife Service biennial reports to Congress. Years protected was derived from an average date of establishment, weighted by the area of critical habitat (CH) within each PA. The boxplot outside of the scatterplot (left) represents species without PA establishment dates. The inner boxplot (right) represents species for which critical habitat has been designated, but none is any PA. The filled points denote species granted additional PA protection following CH designation; the hollow points denote species with existing PA protection prior to CH designation. The dotted line represents the fitted linear regression, and the solid gray line represents a fitted loess curve of locally weighted sums of squares.

Appendix I: Additional Examples of Improving and Declining Species

Improving Species

Examples of improving species, with some of the higher Biennial Report Recovery Index (BRR) scores or greater areas of protected critical habitat (CH), include recovering species such as the Yellow-Shouldered Blackbird (*Agelaius xanthomus*), Louisiana black bear (*Ursus americanus luteolus*), Whooping Crane (*Grus americana*), Mauna Loa silversword (*Argyroxiphium kauense*), and the distinct population segment (DPS) of the American crocodile in Florida (*Crocodylus acutus*). In the case of the Whooping Crane, habitat preservation, restoration and protection of wintering grounds, complemented by hunting bans and international cooperation, have enabled the AWBP Whooping Cranes to steadily increase since listing (U.S. Fish and Wildlife Service 2012). Moreover, the persistence of the only wild population known as the Aransas-Wood Buffalo population (AWBP) has been attributed to the protection and continued availability of its summer nesting grounds in Canada's Wood Buffalo National Park (U.S. Fish and Wildlife Service 2012). As for the American crocodile DPS in Florida, the species has improved to such an extent following habitat protection through land acquisition as well as nesting ground enhancement and protection, that it was downlisted in 2007 (U.S. FWS Federal Register 2007).

In the case of the Puerto Rican Yellow-Shouldered Blackbird, its decline resulted from extensive deforestation for sugar cane plantations and housing development as well as the arrival and subsequent brood parasitism by the Shiny Cowbird (*Molothrus bonariensis*) (U.S.

Fish and Wildlife Service 2011a). Habitat management efforts have played a pivotal role in facilitating species recovery in the case of the Yellow-Shouldered Blackbird, as the populations that have showed improvement (to the point of range expansion) are those within managed areas, e.g. Boquerón Commonwealth Forest, where Shiny Cowbird parasitism is controlled and artificial nesting structures for Yellow-Shouldered Blackbirds have been constructed (Cruz et al. 2005; U.S. Fish and Wildlife Service 2011a).

Decreasing Species

Examples of some decreasing species, with the lowest recovery scores (i.e. -11), include the Marbled Murrelet (*Brachyramphus marmoratus*), Northern Spotted Owl (*Strix occidentalis caurina*), Coachella Valley fringe-toed lizard (*Uma inornata*), woundfin (*Plagopterus argentissimus*), and Morrow Bay kangaroo rat (*Dipodomys heermanni morroensis*). In the case of the woundfin, populations continue to suffer from introduced red shiner populations and changes in river flows and temperatures (U.S. Fish and Wildlife Service 2009a). In the case of the Marbled Murrelet, despite reductions in the rate of old growth deforestation, Marbled Murrelets continue to face significant threats by fragmentation and increasing corvid predation in their terrestrial environments and increasing anthropogenic disturbances and changes in prey availability in their marine environment (U.S. Fish and Wildlife Service 2009b). On the other hand, other species such as the Coachella Valley fringe-toed lizard (CVFTL) and Morrow Bay kangaroo rat (MBKR) may not have fully benefitted from habitat protection given the continued modification of key ecological processes that sustain their habitat requirements. In the case of the CVFTL, alterations to

the blowsand transport systems, invasive vegetation and groundwater hydrological changes threaten to stabilize dynamic blowsand dune habitats (U.S. Fish and Wildlife Service 2010); whilst the continued fire suppression has replaced the optimal early successional MBKR coastal dune scrub habitat with dense and mature plant communities (U.S. Fish and Wildlife Service 2011b).

Appendix I References

- Cruz, A., R. López-Ortiz, E. A. Ventosa-Febles, J. W. Wiley, T. K. Nakamura, K. R. Ramos-Alvarez, and W. Post. 2005. Ecology and management of Shiny Cowbirds (*Molothrus bonariensis*) and endangered Yellow-shouldered Blackbirds (*Agelaius xanthomus*) in Puerto Rico. *Ornithological Monographs* **57**:38–44.
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