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RESEARCH ARTICLE

Prioritizing Species by Conservation Value and Vulnerability: A New Index Applied to Species Threatened by Sea-Level Rise and Other Risks in Florida

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ABSTRACT: Land-use change, climate change, and sea-level rise (SLR) pose substantial threats to biodiversity. Conservation resources are limited and must be directed toward the species and ecosystems that are most vulnerable, biologically distinct, likely to respond favorably to conservation interventions, and valuable ecologically, socially, or economically. Many prioritization and vulnerability assessment schemes exist, each emphasizing different types of vulnerabilities and values and often yielding disparate evaluations of the same species. We developed an integrative and flexible framework that incorporates existing assessments and is useful for illuminating the differences between systems such as the IUCN Red List, the US Endangered Species Act, and NatureServe's Conservation Status Assessment and Climate Change Vulnerability Index. The Standardized Index of Vulnerability and Value Assessment (SIVVA) includes five advancements over existing tools: (1) the ability to import criteria and data from previous assessments, (2) explicit attention to SLR, (3) a flexible system of scoring, (4) metrics for both vulnerability and conservation value, and (5) quantitative and transparent accounting of multiple sources of uncertainty. We apply this system to 40 species in Florida previously identified as being vulnerable to SLR by the year 2100, describe the influence of different types of uncertainty on the resulting prioritizations, and explore the power of SIVVA to evaluate alternative prioritization schemes. This type of assessment is particularly relevant in low-lying coastal regions where vulnerability to SLR is predictable, severe, and likely to interact synergistically with other threats such as coastal development.

Index terms: climate change, conservation prioritization, extinction risk, sea-level rise, vulnerability assessment

INTRODUCTION

Although the benefits of ecosystem-based conservation and management are widely acknowledged among practitioners (Grumbine 1994; Noss 1996; Slocombe 1998; Rodríguez et al. 2011), laws such as the U.S. Endangered Species Act and similar statutes require that species listed as threatened or endangered receive priority attention. Furthermore, ecologists agree that species generally respond in an "individualistic" way *(sensu* Gleason 1926) to environmental change, which must be taken into account during the development and implementation of conservation and recovery plans (Che-Castaldo and Neel 2012). The "fine filter" of protecting and managing individual species thus remains a necessary complement to the "coarse filter" of protecting and managing ecosystems such as vegetation types, natural communities, and geophysical features (Jenkins 1985; Noss 1987; Hunter et al. 1988).

Biodiversity faces threats from habitat loss and degradation (Brooks et al. 2002), invasive species (McKinney and Lockwood 1999), overexploitation (Loehle and Eschenbach 2012), disease (Smith et al. 2006), pollution (Lovett et al. 2009), and climate change (e.g., Hughes 2000; Parmesan and Yohe 2003; Thomas et al. 2004; Bellard et al. 2012). Because conservation resources are limited, conservation action plans often employ vulnerability assessments (VA) to inform decisions about which threats are most important in a given case and how to prioritize species based on their vulnerability to those threats (Miller et al. 2006). It can be difficult for decision-makers to choose the appropriate tool(s) from among the confusing array of prioritization protocols, including the International Union for Conservation of Nature (IUCN) Red List, the U.S. Endangered Species Act (ESA), and analogous laws in other countries, and NatureServe's Conservation Status Assessment (CSA, the familiar global-state [G/S] ranking system; Faber-Langendoen et al. 2009), among others (see Table 1). In addition, most existing assessments ignore or only superficially account for the effects of sea-level rise (SLR), which in many coastal regions may pose a greater and more urgent threat to biodiversity than temperature or precipitation change, land-use change, or other threats. Rather than develop yet another prioritization protocol strictly for SLR, we developed a vulnerability assessment and prioritization system that incorporates the types of threats and values used in existing tools into a single, transparent, and flexible quantitative framework, while also explicitly addressing SLR.

We chose Florida as a case study for application of our framework because Florida houses some of the highest levels

Table 1. Examples of Species Prioritization Protocols.

Name	Units	Extent	Citation
IUCN Red List	Species	Global	(IUCN 2010)
NatureServe Conservation Status Assessment (CSA)	Species and Natural Communities	Regional, National, and Global	(Faber-Langendoen et al. 2009)
Climate Change Vulnerability Index (CCVI)	Species	Global	(Young et al. 2009)
US Endangered Species Act (US ESA)	Species	USA	(ESA 1973)
Climate Change Vulnerability Assessment for California's Birds	Avian species	California	(Gardali et al. 2012)
NA	Species and lineages of livestock	Global	(Boettcher et al. 2010)
Population Adaptive Index	Populations	Global	(Bonin et al. 2007)
NA	Plant species	Tasmania	(Burgman et al. 1999)
Millsap Protocol	Vertebrate species	Florida, USA	(Millsap et al. 1990)
Project Prioritization Protocol	Species	New Zealand	(Joseph et al. 2008)
NA	Species	New Zealand	(Molloy et al. 2002)
NA	Plant species	Estonia	(Partel et al. 2005)
Prioritization based on evolutionary value	Avian species	Global	(Redding and Mooers 2006)
NA	Species	California, USA	(Regan et al. 2008)
NA	Species	USA	(Marsh et al. 2007)

of endemism among plants (James 1961; Estill and Cruzan 2001; Sorrie and Weakley 2001; Knight et al. 2011), vertebrates (Stith and Branch 1994; Herring and Davis 2004), and insects (Peck 1989) in North America north of Mexico. This wealth of biodiversity is threatened by rapid human population growth (Mackun and Wilson 2011), conversion of natural areas for urban or agricultural purposes (Mulkey 2007), climate change (Christensen et al. 2007; Von Holle et al. 2010), and sea-level rise (Ross et al. 2009; Donoghue 2011; Geselbracht et al. 2011; Zhang et al. 2011; Strauss et al. 2012). Much of Florida's flora and fauna have persisted through climatic changes and dozens of meters of SLR over thousands of years. Whereas historically species were able to shift their distributions inland with moving coastlines, more than 75% of human population growth in Florida has occurred along the coasts (Wilson and Fischetti 2010), precluding the natural movement of populations and squeezing species "between the devil and the deep blue sea" (Harris and Cropper 1992; Noss 2011).

Here, we propose a Standardized Index for Vulnerability and Value Assessment (SIVVA), a novel vulnerability assessment and prioritization tool in the form of a questionnaire completed as a Microsoft Excel worksheet. SIVVA provides five advancements over previous assessment tools: (1) criteria and assessments from existing VAs can be incorporated into the SIVVA framework; (2) SIVVA explicitly accounts for SLR; (3) criteria can be emphasized or de-emphasized based on user needs; (4) SIVVA accounts for ecological, conservation, economic, and evolutionary value of species rather than focusing solely on rarity, declining populations, or threats from a single source; and (5) SIVVA accounts for uncertainty in the assessment process. First, we characterize the variation present in the conservation rankings of 15 species found in Florida and previously assessed using the Climate Change Vulnerability Index (CCVI; Dubois et al. 2011), IUCN Red List, the US ESA, and CSA. Second, we use expert opinion guided by published literature to assess these 15 species, plus an additional 25 species in SIVVA. We propose five example approaches to prioritizing species for conservation action using the SIVVA framework, and an example of how to assess variation in species priorities depending on how different types of vulnerabilities and values are emphasized.

MATERIALS AND METHODS

SIVVA structure and development

SIVVA contains four sets of criteria (modules): (1) Vulnerability (sensitivity + exposure); (2) Adaptive Capacity (lack thereof); (3) Conservation Value; and (4) Information Availability (Table 2). Criteria within each module resulted from extensive review of the threats considered and valuations used in previous conservation planning exercises.

Table 2. SIVVA's four criteria categories (referred to as "modules" in text), the criteria within each module, and their relative weighting. X's denote presence of the criteria in existing vulnerability assessments including the Climate Change Vulnerability Index (CCVI), International Union for the Conservation of Nature Red List (IUCN), NatureServe Conservation Status Assessment (CSA), and US Endangered Species Act (US ESA).

Criteria	SIVVA Weight	CCVI	IUCN	CSA	US ESA
Vulnerability					
1. Sea Level Rise	4	X		X	X
2. Erosion	0.5				X
3. Barriers to Movement	4	X			X
4. Temperature	1	X			
5. Precipitation	1	X			
6. Portion of Range Protected	1	X			X
7. Population Fragmentation	1	X	X	X	X
8. Increasing Salinity	1				X
9. Storm Surge or Run-off	1				
10. Biotic Interactions	2	X		X	X
11. Synergistic Threats	1				
12. Disturbance Regime	2	X		X	X
Lack of Adaptive Capacity					
13. Migration	2	X			
14. Phenotypic Plasticity	2	X			
15. Genetic Diversity	1	X			
16. Adaptive Rate	1		X	X	X
17. Demographic Capacity	1	X	X	X	X
18. Colonization Potential	1	X	X		
Conservation Value					
19. Level of Endemism	2		X	X	
20. Disjunct Population	1			X	
21. Keystone Species	2				X
22. Phylogenetic Distinctiveness	2				
23. Economic Value	1				
24. State or Federal Listing	1				X
25. Probability of Recovery	1				
Information Availability					
26. Published Literature	2				
27. Demographic/Niche Models	1	X	X		
28. Population Genetic Studies	1				
29. Response to Sea Level Rise	1				
30. Response to Climate Change	1	X			

We evaluated species based on a mixture of quantitative measures and expert knowledge, following Martin et al. (2012). For each assessment, we identified individuals (listed in order of preference) who authored studies on the species, were directly involved in the management of the species, or read the available literature on the species. Experts were provided with a bibliography and synopsis of known material for each species as summarized on the Florida Natural Areas Inventory tracking list (www.fnai.org). Despite the drawbacks sometimes associated with expert-opinion based assessments (e.g., McKelvey et al.

2008; Charney 2012), expert opinion, in combination with published literature, has been shown to be quite accurate (Clevenger et al. 2002), especially when expert uncertainty is accounted for (Johnson and Gillingham 2004). Experts were asked to rank species on a scale from 1 to 6 for each of thirty criteria (Table 2), where a score of zero means that insufficient information exists to assess that criterion, a score of 3 corresponds to no effect, scores of 4, 5, and 6 correspond to increasingly negative effects, and scores of 2 and 1 correspond to increasingly positive effects. SIVVA is not dependent on any particular numerical scale; users can apply any scale they choose, including both positive and negative values.

Each species was assessed by at least two experts. To assess biases among experts we conducted an ANOVA to determine if a significant portion of the variation in final scores for each of the four modules in SIVVA was explained by variation among expert assessors. We reconciled two independent valuations of each species by first testing if the difference between the two assessors for the final score of each module was less than 95% of the distribution of pairwise differences among all other species. This approach is based on the expectation that variation among assessors is less than variation among species. We then reported the average score of the two valuations.

In addition to the scores, each criterion was given a weight that corresponds to our estimation of its relative importance (Table 2), although weights can be easily changed for other applications of SIVVA. A summary score was computed for each module as the total number of points (weight of the criteria multiplied by the score from 1 to 6) divided by the total possible number of points if each criterion scored had received the maximum score. Summary scores are calculated for each of the four modules, and pie charts are used to display contrasting scores across modules (R-code in Appendix A1) (Appendix A1 posted on BioOne website: <http://www.bioone.org/>). Users can average scores across modules for a summary statistic, allowing each module to contribute equally to the final score (arithmetic mean), or use a weighted average, for example, emphasizing relative conservation value over vulnerability.

We asked assessors to evaluate the impacts of future climate and sea-level rise based on detailed projections that we provided. We applied statistically downscaled global projections using the NatureServe Climate Wizard (an online tool available for any user to replicate in their region of interest; www.climatewizard.org), a 'medium' (A1B) Emission Scenario, and an Ensemble Average General Circulation Model following the IPCC Fourth Assessment. We calculated the change in mean annual temperature in Florida from data modeled from 1900 to 2000, compared to temperature projections modeled from 2000 to 2100. We compared mean annual precipitation under the same GCM and ES above from modeled 1900 – 2000 and modeled 2000 – 2100 data. We calculated the difference between wet (June, July, and August) and dry season (December, January, and February) rainfall modeled over 1900 to 2000, and compared that to the difference between wet and dry season rainfall modeled over 2000 to 2100. This is informative of seasonal variability in rainfall, irrespective of total annual rainfall. We assessed land-use change using the projections of the Florida 2060 report (Zwick and Carr 2006), the only statewide projection of population growth and land-use conversion available at the time of this research. Sea-level rise scenarios were based on a static ("bathtub") inundation model. We used a relatively conservative estimate of 1.0 m of SLR by 2100 (Pfeffer et al. 2008; Vermeer and Rahmstorf 2009; Strauss et al. 2012).

Accounting for uncertainty

We identify three types of uncertainty: (1) scoring uncertainty (e.g., when an expert feels that more than one value is equally likely to represent vulnerability of a species); (2) insufficient knowledge (when a small number of criteria are assessed due to limited knowledge about the species); (3) weighting uncertainty (when one or two criteria contribute disproportionately to the vulnerability or value score for a species). Some VAs such as CCVI account for scoring uncertainty, but most ignore the latter two types of uncertainty. We account for scoring uncertainty with a check-box next to each criterion, where experts can note if they are not sure of the proper score. In the final computing of scores, we add 0, +1, or -1 to the score that the expert provided for each criterion labeled as uncertain and recalculate the effect on the overall score using 1000 Monte Carlo simulations. We account for knowledge uncertainty by reporting on the proportion of criteria scored, and also by comparing the summary score in the manner described above (total points divided by maximum points possible for all criteria scored) to the proportion calculated as the total points divided by the maximum possible points if all criteria had been scored. Finally, we assess weighting uncertainty through 1000 Monte Carlo simulations where criterion weights are randomly drawn from the set of user-defined weights (in our example, weights are 0.25, 0.5, 1, 2, and 4). One additional type of uncertainty is that surrounding predictions of change in climate (e.g., temperature, precipitation) or other environmental factors. While not directly assessed in our study, a SIVVA user could require that experts estimate the level of uncertainty surrounding any projection of environmental change.

Assessing variation in existing prioritization schemes

We compiled a list of threat categories (e.g., "Threatened, "Endangered," etc.) and compared them across the IUCN, ESA, NatureServe CSA, and CCVI assessments (Table 3). We created a "crosswalk" (Table 3) that matched relevant categories across the ESA, CSA, CCVI, and IUCN. To demonstrate the variability in valuations of the same species across different valuation tools, we compared the rankings of 15 species across the CCVI, IUCN, ESA, and CSA (Table 4) along a standardized scale from zero to one. We numbered each threat category from 1 to 6 by order of increasing threat/vulnerability/value, and plotted the proportion of maximum threat given to each species. We tested the prediction that the rank order of species based on their level of conservation concern would be similar in pairwise comparisons of the CCVI,

Table 3. List of threat categories under four prioritization schemes. To the left of each threat category is the numerical score used for translation in Appendix A2. Also presented parenthetically are the numerical scores that underlie each category in the CCVI.

IUCN		ESA		CSA G-score		CCVI	
-	Extinct	6	Listed Endangered	-	GX- presumed extirpated	6	Extremely Vulnerable (10-89)
-	Extinct in Wild	6	Proposed Endangered	-	GH- possibly extirpated	5	Highly Vulnerable (7-10)
6	Critically Endangered	5	Listed Threatened	6	G1-Critically imperiled	4	Moderately Vulnerable (4-7)
5	Endangered	5	Proposed Threatened	5	G2-Imperiled	3	Presumed Stable (-2-4)
4	Vulnerable	4	Candidate	4	G3-Vulnerable	2	Increase Likely (-7-2)
3	Near Threatened	4	Species of Concern	3	G4-Apparently secure	1	Not Evaluated/Data deficient
2	Least Concern	3	Proposed for delisting	2	G5-Secure		
1	Data Deficient	3	Proposed for listing	1	GU-Unranked		
		2	Nonessential population				
		1	Null Value				

IUCN, ESA, and CSA using Kendall's τ at an $\alpha = 0.05$ (Kendall 1976).

Using SIVVA to assess and visualize vulnerabilities and values for conservation prioritization

We used SIVVA to evaluate all 15 species from Table 4 and an additional 25 species chosen from the Florida Natural Areas Inventory tracking list to provide broader taxonomic, geographic, and ecological coverage of Florida's biodiversity. As an example implementation of SIVVA, we report on the relative conservation priority of each of forty taxa under five different approaches:

1. Stepwise Prioritization:

We identified from our list of 40 species those that were above a threshold of Conservation Value by looking for natural breaks in the distribution of Conservation Value scores arranged from high to low (see Results). From these species, we prioritized those with the highest scores for the combination of Vulnerability and Lack of Adaptive Capacity, where each module was weighted by the number of criteria (12 Vulnerability criteria versus 6 for Lack of Adaptive Capacity). Lastly, we examined Information Availability scores to identify the types of data gaps critical to fill for the species at highest risk of extinction.

2. Equal Weighting:

Each of the four SIVVA modules contributed equally to the final scores; criteria within each module were weighted as shown in Table 2 (criteria weights remain unchanged in the following options as well).

3. Emphasis on Vulnerability:

The overall rank or score for each species is the weighted average of scores across all four modules, where Vulnerability (45%) and Lack of Adaptive Capacity (25%) together make up 70% of the final score, Conservation Value contributes an additional 20%, and Information Availability contributes the final 10%.

4. Emphasis on Conservation Value:

Conservation Value contributed 50% of the final score, with 20% from Vulnerability, 20% from Lack of Adaptive Capacity, and 10% from Information Availability.

5. Emphasis on Vulnerability and Information Availability:

Vulnerability and Lack of Adaptive Capacity each contributes 15%, and Conservation Value and Information Availability each contribute 35% towards the final score.

RESULTS

SIVVA structure

The four modules in SIVVA and all criteria present in each module are listed in Table 2. Also presented are areas of overlap with several existing prioritization and vulnerability protocols, and the weight that we applied to each criterion in our broader assessment of 40 species. Maps relating to projected changes in Florida by 2100 are given in Supplemental Figures 1, 2, 3 and 4 (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>). Four criteria in SIVVA are not present in any of the other reviewed assessments, including vulnerability to storm surge or groundwater runoff, synergistic threats, expert opinion on the probability of recovery (see Marsh et al. 2007), and demonstrated response to SLR. Relative to the IUCN Red List criteria, SIVVA differs primarily in focusing on sources of vulnerability rather than on response trends. Similarly, the CSA focuses on rarity, restricted distribution, and population trend, whereas SIVVA includes these factors only to the extent that they pose threats to the species. The most difficult assessment to compare to SIVVA is the ESA because it is highly political (Noss and Murphy 1995; Harris et al. 2012), whereas other assessments depend more on the best available science.

Accounting for uncertainty

Results of the effects of each type of uncertainty are difficult to generalize because they are species-specific (see Discussion).

Table 4. Fifteen species assessed by the CCVI, IUCN, CSA G-score, and US ESA.

Taxonomic Group	Latin	Common Name	CCVI	CSA-G	US ESA	IUCN
Mammal	*Sylvilagus palustris hefneri*	Keys marsh rabbit	12.8; Extremely Vulnerable	Critically Imperiled	Endangered	Not Assessed
Reptile	*Nerodia clarkia taeniata*	Atlantic salt marsh snake	11.7; Extremely Vulnerable	Critically Imperiled	Threatened	Least Concern
Bird	*Sternula antillarum*	Least tern	12.3; Extremely Vulnerable	Apparently Secure	Endangered	Least Concern
Reptile	*Caretta caretta*	Loggerhead	11.8; Extremely Vulnerable	Vulnerable	Threatened	Endangered
Amphibian	*Rana capito*	Gopher frog	8.6; Highly Vulnerable	Vulnerable	Endangered	Near Threatened
Bird	*Rallus longirostris insularum*	Clapper rail	10.3; Highly Vulnerable	Vulnerable	Not Listed	Least Concern
Mammal	*Odocoileus virginianus clavium*	Key deer	10.0; Highly Vulnerable	Critically Imperiled	Endangered	Not Assessed
Bird	*Coccyzus minor*	Mangrove cuckoo	6.11; Moderately Vulnerable	Secure	Not Listed	Least Concern
Bird	*Buteo brachyurus*	Short-tailed hawk	4.1; Moderately Vulnerable	Critically Imperiled	Not Listed	Least Concern
Mammal	*Eumops floridanus*	Florida bonneted bat	3.7; Stable	Critically Imperiled	Candidate	Critically endangered
Mammal	*Puma concolor coryi*	Florida panther	2.6; Stable	Critically Imperiled	Endangered	Endangered
Amphibian	*Hyla squirella*	Squirrel treefrog	-0.1; Stable	Secure	Not Listed	Least Concern
Reptile	*Malaclemys terrapin rhizophorarum*	Mangrove terrapin	13.6; Extremely Vulnerable	Apparently Secure	Not Listed	Lower Risk/Near Threatened
Amphibian	*Ambystoma cingulatum*	Flatwoods salamander	11.7; Extremely Vulnerable	Imperiled	Threatened	Vulnerable
Reptile	*Crocodylus acutus*	American crocodile	12.9; Extremely Vulnerable	Imperiled	Threatened	Vulnerable

The ability to visualize and quantify the impact of weighting uncertainty and insufficient knowledge is critical; but, for most users, uncertainty in the scoring process is likely the most challenging or troubling component of the assessment. The effects of these three types of uncertainty on the SIVVA scores for all 40 species are presented in Supplemental Figures 5, 6, and 7 (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>). An important byproduct of this kind of uncertainty analysis is identification of the types of information consistently missing across taxa (Figure 1).

Assessing variation in existing prioritization schemes

Fifteen species show little to no consistency in how they rank (high or low) across IUCN, CSA, ESA, and the CCVI (Table 4, Figure 2); none of the pairwise comparisons among these four assessments show significant correlation in rank order of species (Kendall's τ, α all $P > 0.1$). This variation demonstrates the need for a prioritization and assessment framework that allows users to manipulate criteria weighting to identify the source of variation. For example, are differences between the ESA and IUCN entirely political, due to different underlying criteria, or do they treat similar criteria differently? More importantly, which species score consistently high across all prioritization schemes, and why?

Using SIVVA to assess and visualize vulnerabilities and values for conservation prioritization

SIVVA scores and the list of all 40 species are presented in Table 5. The five prioritization options listed below (presented in the same order in Table 5) show the influence of alternative prioritization schemes on species rankings. Table 5 demonstrates the power of SIVVA to identify how robust species priority lists are to uncertainty and to the emphasis placed on different types of information (options 2 through 5), and how alternatives such as stepwise approaches may yield different results. Instead of

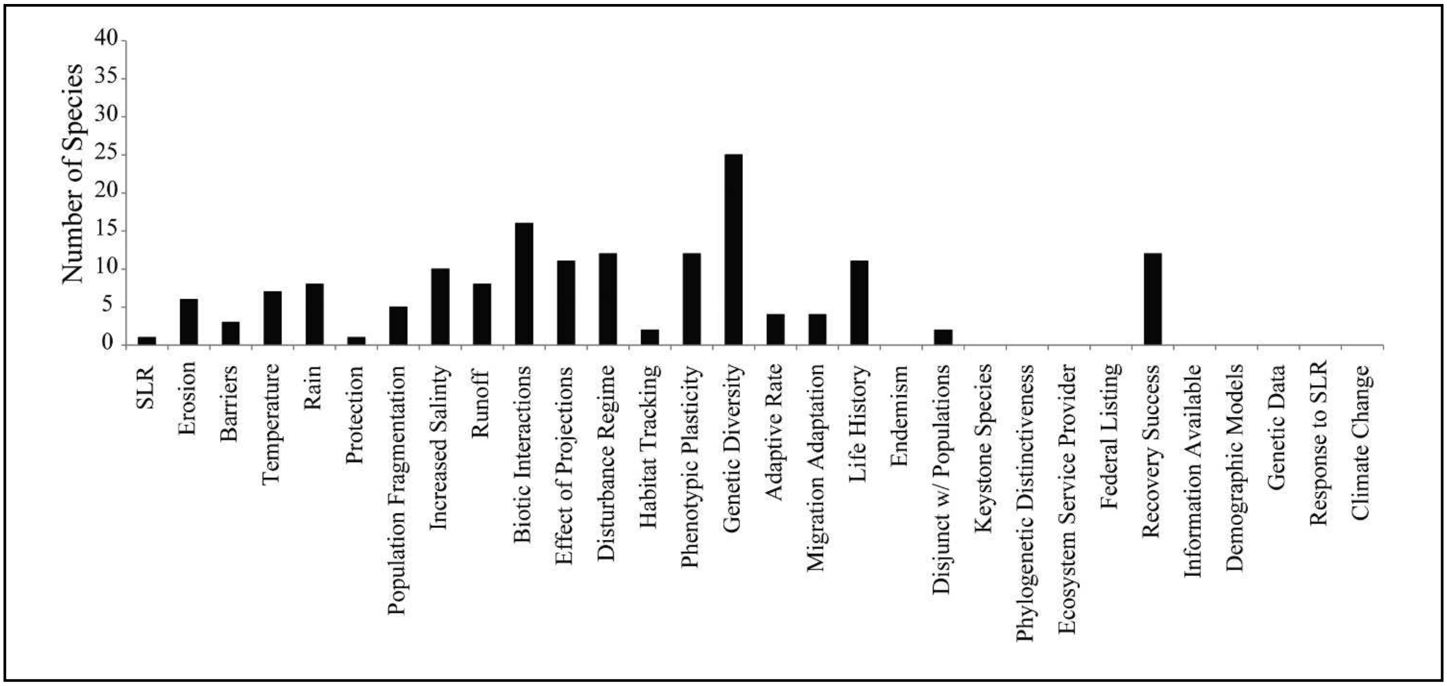

Figure 1. Bar chart of the number of species with missing information for each of 30 SIVVA criteria.

focusing on the specific ranking of each species, we grouped species into quartiles so that a user could visualize whether or not a species, ranked in the top quartile under one value scheme, remained in that quartile under alternative value schemes (Table 5).

1. Stepwise Prioritization:

Fifteen species fell above a conservation value score of 0.47, which was a natural break in the values for this dataset (Supplemental Figure 8) (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>). Table 5 depicts the relative rankings of these fifteen species (and the 25 remaining species that fell below the threshold in conservation value). Notably, several of the highest ranked species, including Sherman's short-tailed shrew (*Blarina shermani* W.J. Hamilton), the Lower Keys brown snake (*Storeria dekayi* subspecies O.P. Hay), and the Lower Keys ribbon snake (*Thamnophis sauritus sackenii* R. Conant), displayed such low levels of information availability as to make it nearly impossible to craft meaningful conservation plans.

2. Equal Weighting:

This approach yielded qualitatively different results than the Stepwise Approach, with movement of species between quartiles of vulnerability and value. For example, the American crocodile (*Crocodylus acutus* G. Cuvier) moved from a relative rank of 15/40 to 37/40, due primarily to its predicted high ability to adapt to projected changes (i.e., low Lack of Adaptive Capacity), lower overall Vulnerability to projected climate change and sea-level rise, but still high Conservation Value. Notably, this approach consistently lowered the status of plants and invertebrates, which tended to have lower Conservation Value and Information Availability.

3. Emphasis on Vulnerability:

This approach was largely consistent with the Equal Weighting approach, suggesting that for this particular assemblage of species, emphasizing the vulnerability of species over other metrics yields similar priorities.

4. Emphasis on Conservation Value

This approach was also more consistent with Equal Weighting and Emphasis on Vulnerability approaches, but did reinstate the high priority of species such as the Florida bonneted bat (*Eumops floridanus* G.M. Allen) and the striped newt (*Notophthalmnus perstiratus* Bishop) due to higher scores for endemism, phylogenetic distinctiveness, and/or state listing status (*Eumops floridanus* is Endangered in Florida).

5. Emphasis on Vulnerability and Information Availability

The option of Emphasizing Vulnerability and Information Availability showed the strongest effect of lowering the priority of species with high vulnerabilities to threats and high value for conservation, but with low levels of knowledge about life history and the types of conservation measures needed to prevent extirpation. For example, species such as Florida toadwood (*Cupania glabra* Swartz) and *Blarina shermani*, which show estimated high Vulnerability and Lack of Adaptive Capacity, but very low Information Availability, drop sharply in priority under this option.

Overall, Table 5 shows more consistency among options #2 – 5 than between any of them and the Stepwise Approach (option #1). Importantly, this approach allows users to identify how consistently a given species ranks across different ways of analyzing the same underlying vulnerabilities and values. Figure 3 shows an example of the

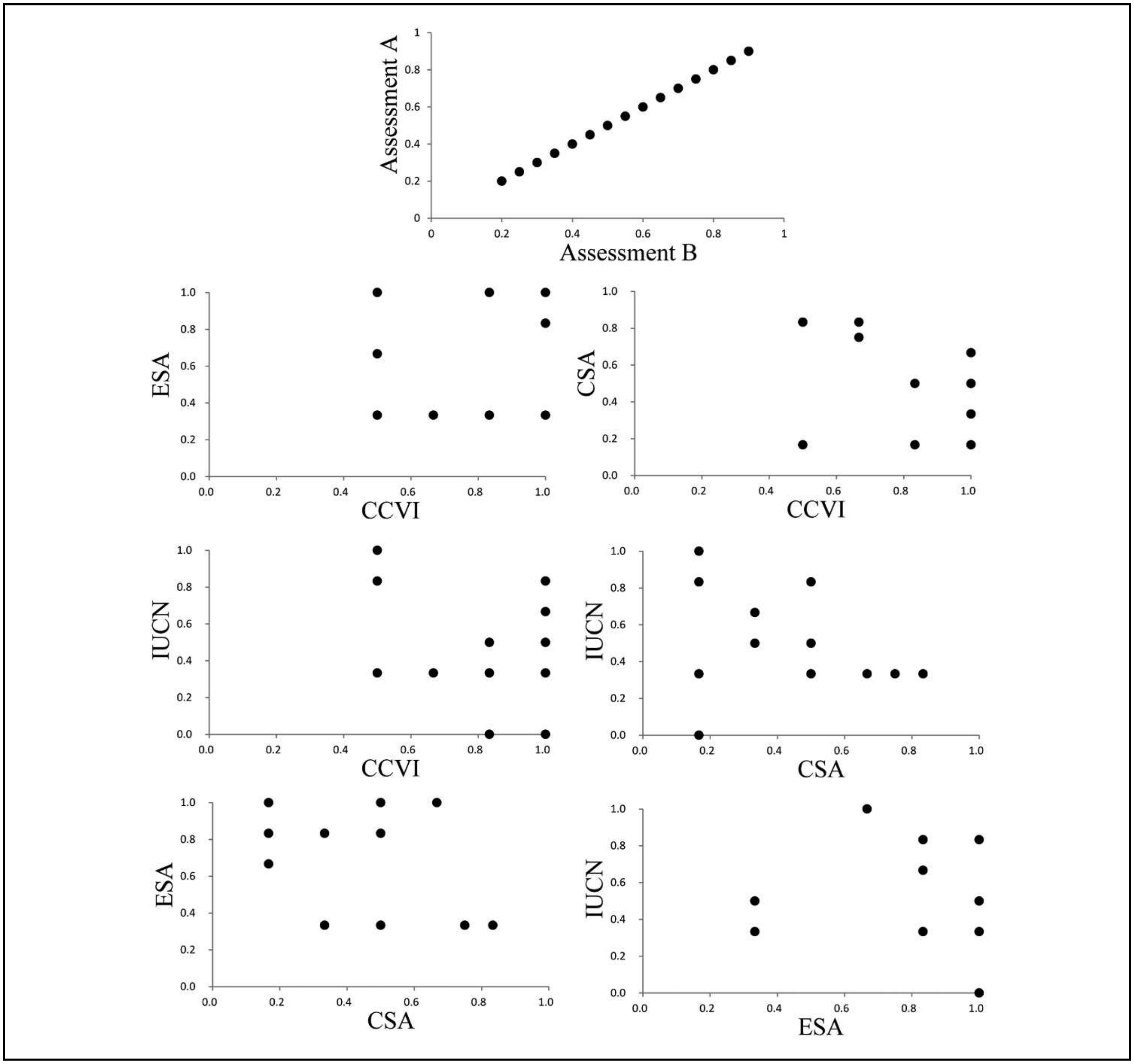

Figure 2. Pairwise comparisons for 15 species assessed for vulnerability or imperilment by the NatureServe Conservation Status Assessment (CSA), US Endangered Species Act (ESA), Climate Change Vulnerability Index (CCVI), and International Union for Conservation of Nature Red List (IUCN). Some plots show fewer than 15 points due to overlapping values. Each assessment was standardized to a scale from zero to one according to Table 3, where a value of 1 indicates the highest vulnerability or value attributable. The upper plot presents a hypothetical relationship, where species rank consistently across two different assessments; however, none of the pairwise comparisons conforms to this pattern due to variability in the relative rank of each species across assessments.

top six species as prioritized by the stepwise method and how each of their scores and relative rankings vary under prioritization procedures that emphasize vulnerabilities and values differently. This allows users to visualize, for example, how emphasizing vulnerability over conservation value impacts prioritization.

DISCUSSION

We developed SIVVA to incorporate information from multiple existing species prioritization schemes as part of our research to assess the vulnerability of species to SLR in combination with other impacts of climate change and land-use change in Florida. After surveying a variety of prioritization schemes (Table 1), we determined that, individually, the CSA, ESA, CCVI, and IUCN systems do not adequately address these combined threats. We also found a lack of consistency and transparency in how species were ranked across these four assessments (see Harris

Table 5. List of 40 species, their SIVVA scores for Vulnerability (VU), Lack of Adaptive Capacity (LAC), Conservation Value (CV), and Information Availability (IA), based on criterion scores from Table 2. Colored squares on the right side of the table indicate the relative ranks of species by quartiles, where the highest ranked 1-10 species are red, 11-20 are orange, 21-30 are yellow, and 31-40 are green. Ranking option #1 is based on stepwise prioritization, with options #2-5 simultaneously using all modules with the following weighting schemes: option #2: 25% of mean from each of the four modules; option #3: 45% VU, 25% LAC, 20% CV, and 10% IA; option #4: 20% VU, 20% LAC, 50% CV, and 10% IA; option #5: 15% VU, 15% LAC, 35% CV, and 35% IA. This graphic illustrates changes in rankings across different ways of emphasizing the same underlying vulnerabilities and values. When all approaches result in identical rankings, the colors depicting the rank of each species are consistent across all five options.

Taxon Group	Species	VU	LAC	CV	IA	1	2	3	4	5
Reptile	*Malaclemys t. rhizophorarum*	0.86	0.81	0.48	0.64					
Mammal	*Odocoileus v. clavium*	0.87	0.69	0.61	0.73					
Reptile	*Thamnophis s. sackenii*	0.85	0.69	0.50	0.31					
Mammal	*Sylvilagus p. hefneri*	0.90	0.54	0.51	0.78					
Bird	*Coccyzus minor*	0.82	0.69	0.50	0.33					
Mammal	*Puma c. coryi*	0.73	0.79	0.70	0.67					
Reptile	*Caretta caretta*	0.72	0.72	0.63	0.74					
Reptile	*Storeria dekayi*	0.74	0.63	0.50	0.28					
Plant	*Halophila johnsonii*	0.75	0.53	0.51	0.33					
Mammal	*Eumops floridanus*	0.73	0.56	0.63	0.44					
Amphibian	*Notophthalmus perstriatus*	0.60	0.71	0.52	0.53					
Bird	*Buteo brachyurus*	0.69	0.53	0.47	0.36					
Mammal	*Blarina shermani*	0.54	0.76	0.48	0.17					
Fish	*Etheostoma okaloosae*	0.52	0.75	0.52	0.53					
Reptile	*Crocodylus acutus*	0.72	0.33	0.48	0.51					
Reptile	*Diadophis p. acricus*	0.91	0.88	0.40	0.31					
Invertebrate	*Eburia stroheckeri*	0.85	0.88	0.43	0.17					
Plant	*Cupania glabra*	0.89	0.77	0.47	0.17					
Invertebrate	*Polyphylla woodruffi*	0.80	0.90	0.46	0.31					
Reptile	*Nerodia c. taeniata*	0.82	0.74	0.47	0.38					
Bird	*Rallus l. insularum*	0.80	0.78	0.41	0.50					
Bird	*Rynchops niger*	0.80	0.76	0.33	0.46					
Bird	*Setophaga d. paludicola*	0.89	0.57	0.38	0.44					
Mammal	*Procyon l. auspicatus*	0.80	0.73	0.38	0.44					
Invertebrate	*Procambarus attiguus*	0.76	0.74	0.39	0.28					
Plant	*Argusia gnaphalodes*	0.82	0.63	0.31	0.28					
Plant	*Symphoricarpos orbiculatus*	0.79	0.67	0.30	0.33					
Plant	*Catesbaea parviflora*	0.79	0.50	0.41	0.28					
Plant	*Helianthus d. vestitus*	0.78	0.43	0.38	0.28					
Invertebrate	*Paraphrynus raptator*	0.78	0.38	0.44	0.17					
Invertebrate	*Cotinis aliena*	0.72	0.50	0.46	0.22					
Amphibian	*Rana okaloosae*	0.58	0.73	0.43	0.54					
Invertebrate	*Procambarus milleri*	0.62	0.61	0.40	0.33					
Amphibian	*Ambystoma cingulatum*	0.60	0.60	0.39	0.33					
Invertebrate	*Cyclocephala miamiensis*	0.60	0.57	0.33	0.17					
Amphibian	*Ambystoma bishopi*	0.57	0.60	0.39	0.33					
Fish	*Ctenogobius pseudofasciatus*	0.60	0.53	0.31	0.33					
Bird	*Sternula antillarum*	0.64	0.44	0.35	0.58					
Amphibian	*Hyla squirella*	0.57	0.53	0.32	0.49					
Amphibian	*Rana capito*	0.51	0.57	0.34	0.42					

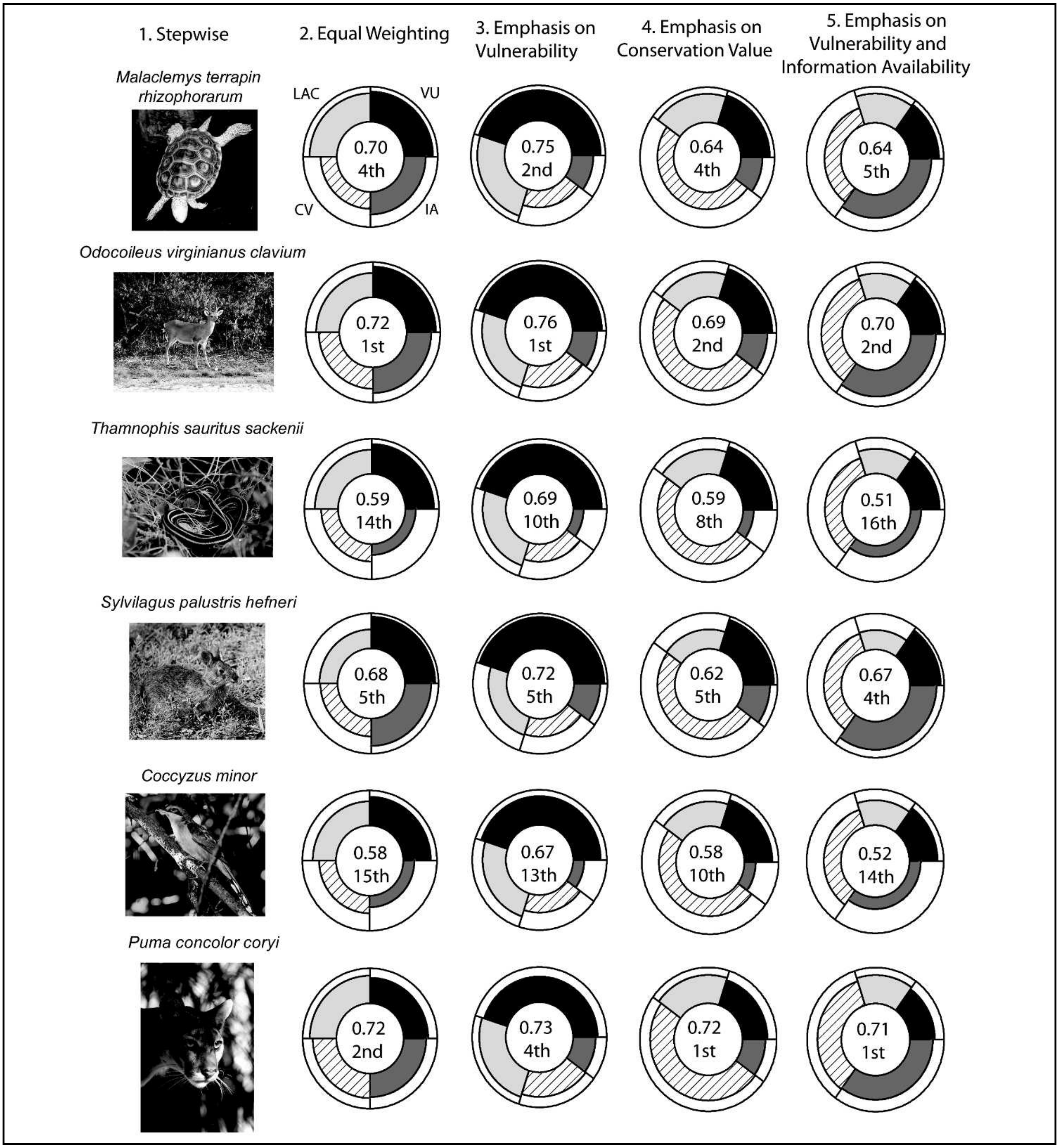

Figure 3. Comparative proportion of criteria contributing to SIVVA scores under four different weighting schemes. On the left are the six species of highest priority as identified by the stepwise prioritization method (option #1) and listed from highest to lowest priority. Pie charts to the right depict options #2-5 from Table 5. Pie slices represent Vulnerability (VU) in black, Lack of Adaptive Capacity (LAC) in light gray, Conservation Value (CV) in lined pattern, and Information Availability (IA) in dark gray. The width of each slice depicts the emphasis given to the module under options #2-5. The portion of the slice that is filled in represents the SIVVA score for that module, where high scores result in larger portions of the slice being filled. In the center of each pie chart is the overall SIVVA score on a scale from zero to one based on the information emphasized under each option and the relative ranking of the species with that score. Note that species with consistently high scores across all modules, such as *Odocoileus virginianus clavium* and *Puma concolor coryi*, show consistently high rankings, while species with high scores in only one or two modules vary in their rankings (e.g., *Thamnophis sauritus sackenii*).

et al. 2012 for a more detailed comparison of the IUCN and ESA). For example, among the 15 species assessed by multiple evaluation protocols, the endemic *Eumops floridanus* received the highest non-extinct ranking under the IUCN and CSA schemes, but was of intermediate priority (Candidate for Listing) under the ESA, and was ranked relatively low under the CCVI (Presumed Stable; Table 4). SIVVA provides a framework for explaining such discrepancies: this species shows only small variation in vulnerability and value due to scoring uncertainty (Supplemental Figure 5) (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>), missing information (Supplemental Figure 6) (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>), or emphasis on different types of information (Supplemental Figure 7) (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>). Thus, in this case the IUCN, CSA, ESA, and CCVI apparently yield such divergent rankings due to non-overlapping criteria as opposed to uncertainty. In contrast, *Crocodylus acutus* scores consistently high with a CCVI ranking of Extremely Vulnerable, a CSA score of Imperiled, an IUCN rank of Vulnerable, and ESA listing as Threatened. Our results indicate that this moderate variation may be due to alternative emphasis on similar criteria (Supplemental Figure 7) (Supplemental Figures posted on BioOne with Appendices: <http://www.bioone.org/>), but not scoring uncertainty or missing information because these types of uncertainty do not strongly affect the resulting valuation. For many species, discrepancies between assessed vulnerability and legal status as Endangered or Threatened likely results from the influence of economics and politics on the ESA listing process (e.g., Rohlf 1991; Noss and Murphy 1995). SIVVA provides a platform to explore variation in valuations among prioritization protocols.

Benefits of SIVVA

We designed SIVVA to provide improvements over existing VAs and prioritization protocols. Five advancements are evident in our results. First, SIVVA is flexible and can incorporate criteria from existing assessment protocols. An example of how existing assessments can be translated into the SIVVA framework is provided using the CCVI in Appendix A2 (Appendix A2 posted on BioOne website: <http://www.bioone.org/>). Second, SIVVA accounts for SLR in a more explicit way than existing assessments. Third, because SIVVA is partitioned into four modules, users can treat each module independently or combine them in various ways to examine correlations between, for example, vulnerability and conservation value, and can include values other than extinction risk in species priority-setting (Marsh et al. 2007; Joseph et al. 2008). Users can also visualize the effects of different weighting schemes on species ranking (Table 5, Figure 3). Pie charts (Figure 3) make visually explicit the relative contributions of different modules or criteria to an index's total score (Andreasen et al. 2001). Fourth, while many assessments focus primarily on vulnerability (e.g., CCVI), others reflect more social or political values (e.g., ESA), and still others emphasize rarity or population trend (IUCN, CSA). SIVVA contains all of these elements and the framework for additional factors, while maintaining transparency in the prioritization process. This is a step forward in the seemingly endless trend of new assessment and prioritization methods because it represents an open-source and flexible framework for combining different types of information according to user needs and judgments. Leinster and Cobbold (2012) followed a similar approach to combine and compare different diversity indices along a standardized scale. Fifth, by quantifying uncertainty in how scores are attributed, the amount of information available, and in how criteria are weighted, SIVVA provides results that are fully transparent. Thus, users are able to assess the effects of uncertainty on priority-setting and avoid the criticism that their particular weighting scheme or uncertainty analysis strongly influenced their results.

We provide an example configuration of SIVVA that includes the vast majority of criteria used by other prioritization and vulnerability assessments, but that also includes criteria particularly relevant to low-lying coastal regions. A Microsoft Excel version of SIVVA and accompanying documentation can be found at http://noss.cos.ucf.edu/publications/sivva; we encourage interested parties to contact the authors for input on adapting these tools for their own needs. Although we designed SIVVA to absorb information from existing VAs through translation tools (see Appendix A2) (Appendix A2 posted on BioOne website: <http://www.bioone.org/>), some users may find that SIVVA does not include criteria specific to the threats facing their species assemblage or geographic area. For such cases, we suggest that users modify the criteria to reflect their specific circumstances (e.g., adding criteria such as depth of snow pack or duration of permafrost), but maintain the structure of SIVVA, because it provides a transparent format for evaluating species irrespective of the criteria applied.

SIVVA results for 40 Florida species

We evaluated 40 species in Florida for their vulnerability to SLR and land-use and climate change, and their adaptive capacity, conservation value, and information availability. Mammals showed higher conservation value scores than other taxonomic groups, which may reflect the greater attention to mammals in the published literature (Luck 2007). The species with the highest vulnerabilities were taxonomically diverse, but tended to be distributed in South Florida, especially the Florida Keys. This is consistent with previously published data identifying species and natural communities restricted to the Florida Keys as among the most vulnerable to SLR (Ross et al. 2009; Maschinski et al. 2011) and land-use change. The species with the lowest adaptive capacities were equally diverse, but tended to have long generation times, low reproductive capacity, or low dispersal capabilities.

We emphasize a stepwise approach because this best reflects current practice, where conservation planners assign priority to species of greatest conservation value, including narrow endemics, phylogenetically distinct taxa, and those at greatest risk of extinction/extirpation. This approach identified the mangrove terrapin (*Malaclemys terrapin rhizophorarum* Fowler), Key deer

(*Odocoileus virginianus clavium* Barbour and G.M. Allen), Lower Keys ribbon snake, Lower Keys marsh rabbit (*Sylvilagus palustris hefneri* J.D. Lazell), the Florida distribution of the Mangrove Cuckoo (*Coccyzus minor* Gmelin), and the Florida panther (*Puma concolor coryi* Bangs) as the six most vulnerable and valuable species. The amount of information available tended to be lower for invertebrates, but the impact of this lack of information varies depending on how that factor is weighted (i.e., we considered information availability a positive factor for effective conservation). For example, *Eburia stroheckeri* (J.N. Knull) ranges from the 7th to the 25th most highly ranked species depending on how the different types of vulnerabilities and values are weighted (Figure 3), whereas species with high information availability scores show relatively consistent rankings across variable weighting schemes. All of the most highly-scored species exhibit high vulnerabilities to sea-level rise and habitat loss due to changes in projected land-use and climate change, but each also has unique qualities that place it at high priority for conservation. These unique qualities include the high conservation value of the apex predator Florida panther, the social importance of the endemic and federally listed Key deer, and the small range and high vulnerability of *Malaclemys terrapin rhizohorarum* and *Thamnophis sauritus sackenii*. Our approach is innovative in identifying, explicitly and graphically, which factors contribute to each species' priority for conservation.

Our survey highlighted the types of information that are consistently missing across species. Genetic data were the most common type of missing information and were lacking for 63% of species surveyed. Consistent with this pattern, Pearse and Crandall (2004) and Fallon (2007) suggested that genetic data are often lacking or ignored in conservation planning. The second most common type of missing information was data on threats due to biotic interactions (missing for 40% of species surveyed). Urban et al. (2012) noted that lack of attention to biotic interactions in projected species distribution models likely causes dramatic underestimates of extinction. Information on the probability of conservation success or cost was the third most common type of missing information, lacking for 30% of species surveyed. While difficult to estimate, this type of information is critical to the efficient allocation of resources for conservation (Marsh et al. 2007; Joseph et al. 2008; Arponen 2012). Using SIVVA to assist priority-setting at the species level can help users make these decisions and direct future research to fill knowledge gaps efficiently by identifying the types of information that are consistently missing across taxa, guilds, or geographic regions. An additional application of SIVVA to 300 species of conservation concern in Florida can be found in Reece et al. (2013).

SIVVA and adaptation to sea-level rise

Climate change and SLR are increasingly politicized and controversial, yet adaptation strategies are usually less so, and there is a growing acknowledgement that in addition to projecting future climate and SLR scenarios, urgent attention should be paid to how those scenarios affect biodiversity and what might be done to ease the impacts. At the global scale, in 2011 the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) was formed as a counterpart to the Intergovernmental Panel on Climate Change (IPCC) to assess the biological impacts of IPCC projections and to provide guidelines for adaptation (Perrings et al. 2011). At the local scale, some coastal communities now recognize the need to include SLR projections in their future growth plans (Johnson 2000; California State Lands Commission 2009; Parkinson and McCue 2011). Likewise, conservation efforts in coastal areas must account for projected SLR, particularly combined with threats from climate and land-use changes. A meta-analysis of threats to biodiversity from climate change (Bellard et al. 2012) suggested that previous studies focused too much on a single threat (climate change), and discounted the importance of synergistic threats such as "sea-level rise….fragmentation, pollution, overexploitation and biological invasions" (all of which are accounted for in SIVVA). SIVVA and similar approaches should play an integral role in adaptation planning by helping to prioritize species for conservation attention and, for species listed under the ESA, for critical habitat designation, habitat conservation plans, and recovery plans.

One of the most powerful features in SIVVA relevant to adaptation planning is the ability to assess how different priority-setting schemes affect the relative rankings of species. In our case study of 40 species in Florida, we contrast a stepwise prioritization approach (other examples include Andelman et al. 2001; Possingham et al. 2001; Regan et al. 2008) with four other approaches that differentially emphasize different types of vulnerabilities and values. This type of transparency in the conservation planning and prioritization process is extremely powerful for identifying adaptation strategies that are robust to uncertainties in the data, and are thus more defensible.

NOTE:

Appendices A1 and A2, along with all Supplemental Figures, are posted, and accessible, on the BioOne website: <http://www.bioone.org/>).

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