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# Assessing the Effectiveness of Reserve Acquisition Programs in Protecting Rare and Threatened Species

WILL R. TURNER,\*§ DAVID S. WILCOVE,\*† AND HILARY M. SWAIN‡

\*Princeton Environmental Institute and Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08544, U.S.A.

†Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544, U.S.A.

‡Archbold Biological Station, PO Box 2057, Lake Placid, FL 33862, U.S.A.

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**Abstract:** *Measuring the effectiveness of reserve networks is essential to ensure that conservation objectives such as species persistence are being met. We devised a new approach for measuring the effectiveness of land conservation in protecting rare and threatened species and applied it to an ecosystem of global significance. We compiled detailed global distributional data for 36 rare and threatened plants and animals found in the Lake Wales Ridge ecosystem in central Florida (U.S.A.). For each species, we developed a set of protection indices based in part on criteria used to categorize species for the World Conservation Union's Red List. We calculated protection indexes under three different conservation scenarios: a past scenario, which assumed recent, major land-acquisition efforts never occurred; a current scenario, which assumed no additional areas are saved beyond what is currently protected; and a targeted scenario, which assumed all of the remaining areas targeted for protection are eventually acquired. This approach enabled us to quantify the progress, in terms of reduced risk of extinction, that conservationists have made in protecting target species. It also revealed the limited success these land-acquisition efforts have had in reducing those extinction risks associated with loss of habitat or small geographic ranges. Many species of the Lake Wales Ridge will remain at high risk of extinction even if planned land-acquisition efforts are completely successful. By calculating protection indexes with and without each site for all imperiled species, we also quantified the contribution of each protected area to the conservation of each species, enabling local conservation decisions to be made in the context of a larger (global) perspective. The protection index approach can be adapted readily to other ecosystems with multiple rare and threatened species.*

**Keywords:** endangered species, IUCN Red List, Lake Wales Ridge (Florida), protection index, sandhill, scrub

Evaluación de la Efectividad de los Programas de Adquisición de Reservas en la Protección de Especies Raras y Amenazadas

**Resumen:** *La cuantificación de la efectividad de las redes de reservas es esencial para asegurar que objetivos, como la persistencia de especies, se cumplan. Diseñamos un nuevo método para medir la efectividad de la conservación de tierras en la protección de especies raras y amenazadas y lo aplicamos a un ecosistema de importancia global. Compilamos datos detallados de la distribución global de 36 especies raras y amenazadas de plantas y animales que se encuentran en el ecosistema de la Lake Wales Ridge en el centro de Florida (E.U.A.). Para cada especie desarrollamos un conjunto de índices de protección basado parcialmente en criterios utilizados para clasificar especies para la Lista Roja de la Unión Mundial para la Naturaleza. Calculamos los índices de protección bajo tres escenarios de conservación distintos: un escenario pasado, que asumía que los esfuerzos recientes de adquisición de tierras nunca ocurrieron; un escenario actual, que asumía que*

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§Current address: Center for Applied Biodiversity Science, 1919 M St. NW Suite 600, Washington, D.C. 20036, U.S.A., email [w.turner@conservation.org](mailto:w.turner@conservation.org)

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*no se protegen áreas adicionales a las ya conservadas; y un escenario deseado, que asumía que todas las áreas consideradas para ser protegidas son adquiridas eventualmente. Este método nos permitió cuantificar el progreso, en términos de la reducción del riesgo de extinción, en la protección de las especies obtenido por conservacionistas. También reveló el éxito limitado de los esfuerzos de adquisición de tierras en la disminución de los riesgos de extinción asociados con la pérdida de hábitat o con rangos geográficos pequeños. Se pronosticó que muchas especies de la Lake Wales Ridge permanecerán en alto riesgo aun si los esfuerzos de adquisición de tierra planificados son completamente exitosos. Al calcular los índices de protección con y sin cada sitio para todas las especies en peligro, también cuantificamos la contribución de cada área protegida a la conservación de cada especie, lo que permite que las decisiones de conservación se tomen en el contexto de una perspectiva mayor (global). El método del índice de protección se puede adaptar fácilmente a otros ecosistemas con múltiples especies raras y amenazadas.*

**Palabras Clave:** Lake Wales Ridge (Florida), especies en peligro, índice de protección, Lista Roja IUCN, matorral

## Introduction

Given the limited resources available for conservation and the rapid rate at which habitats are being lost, accountability is critical for conservation planning (Margules & Pressey 2000; Saterson et al. 2004). The creation of reserves is an integral component of efforts to conserve biodiversity, yet protected areas are often established and managed with only limited analysis of their contribution toward regional or global priorities for species conservation. Measuring the effectiveness of protected areas is essential to ensure that key objectives, such as species persistence, are being met. Likewise, applying appropriate measures of conservation effectiveness to alternative future actions can improve planning and lead to a more efficient allocation of resources.

A number of approaches for measuring conservation effectiveness have been developed (Stem et al. 2005), including some specifically targeted at measuring the effectiveness of reserve networks (e.g., Scott et al. 1993; Pressey & Taffs 2001; Gutierrez 2005). The simplest metrics for characterizing reserve networks include the number or total area of reserves and the total amount of money spent for their acquisition. Nevertheless, these metrics make no connection between reserve acquisition and the protection of biodiversity and are therefore of limited value (Rodrigues et al. 1999; Pressey et al. 2002).

More sophisticated effectiveness metrics measure how well a reserve network represents the conservation elements it is intended to protect. These “representativeness” measures (Pressey & Taffs 2001; often called simply “effectiveness,” e.g., Rodrigues et al. 1999) assess the proportion of predetermined protection targets met by a given reserve network. Such metrics are widely used and are an essential part of broader frameworks such as gap analysis (Scott et al. 1993; Fearnside & Ferraz 1995; Rodrigues et al. 2004) and systematic conservation planning (Margules & Pressey 2000). But representativeness measures have their limitations too. The targets used are

often arbitrary (e.g., ensure that each species is protected in at least two sites; protect 10% of each habitat) and may not reflect even estimated probabilities of species persistence (Pressey et al. 2003). Moreover, targets specified in terms of protected habitats or natural community types carry no assurance that species in general (Pressey & Taffs 2001) and rare species in particular (Dickman et al. 1993) are being protected. Furthermore, if meeting targets for the least-imperiled species is relatively easy, then substantial representativeness scores can be obtained without helping the species most in need of conservation attention. Incorporating a separate measure of vulnerability (Pressey & Taffs 2001; Pressey et al. 2002; Rodrigues et al. 2004) partially addresses this shortcoming. These methods, however, neither adjust for decreases in vulnerability that result from increased protection within the growing reserve network nor consider explicitly the extent to which species depend on the particular reserve network for their global persistence.

We developed a measure of effectiveness—the protection index (PI)—that uses global conservation status criteria to assess the degree to which a particular reserve network contributes to the estimated global or regional persistence of species. Although population viability analysis (PVA) can be a useful method for estimating species persistence (Brook et al. 2000), the data and methods necessary to construct robust PVAs are seldom available for more than a few species in a given system. Although less precise than a PVA, the PI we developed relies on data that are more readily obtainable.

We linked the PI to the criteria used to categorize species for the World Conservation Union (IUCN) Red List (IUCN 2001). Although our approach can be applied to other species-ranking schemes, the IUCN Red List is a good starting point because it is based on precise thresholds—refined by extensive consultation, discussion, and validation—to ensure repeatability over time, consistency among users, and applicability to different geographic regions (Rodrigues et al. 2006). Moreover, IUCN

Red List rankings are positively correlated with other ranking systems and with extinction risk predicted by more detailed PVAs (O'Grady et al. 2004).

The PI differs from typical application of red-list criteria in two important ways. First, rather than use the criteria to place species into discrete categories such as "critically endangered" or "vulnerable," we mapped each criterion onto a continuous index from 0 (species with no protected populations) to 4 (species sufficiently protected so as to fall within the red-list "least concern" category). Doing so allowed us to measure all changes in protection status, not just those large enough to move a species into a new red-list category. Second, whereas red-list assessments are typically based on both protected and unprotected populations, we calculated PI values based solely on those populations that are protected in a given conservation scenario, thereby assuming that unprotected populations do not contribute to species persistence indefinitely.

These two modifications mean our results are not directly transferable to red-list assessments of species, and we did not intend them for this use. Nevertheless, these modifications create a useful and versatile effectiveness measure. Because the criteria are nonlinear, the PI assigns greater weight to actions benefiting the more seriously threatened species. The PI can be used to assess the effectiveness of land conservation programs in the past or present or to estimate the effectiveness of alternative future actions. It can also be used to assess the specific contribution of each protected area to broader-scale (regional to global) conservation objectives. We applied the PI to the Lake Wales Ridge, an ecosystem of global significance in Florida (U.S.A.).

## Methods

### Study Area

The Lake Wales Ridge (LWR) is a discrete, fire-adapted, scrub and sandhill ecosystem covering approximately 2400 km<sup>2</sup> (White 1970; Fig. 1) in central Florida. By virtue of its age (>1 million years) and isolation, it harbors numerous endemic species and subspecies (Muller et al. 1988). (Hereafter we use the term *species* to include both species and subspecies, except where the distinction is relevant.) In recent decades, urbanization and the conversion of natural habitats to citrus groves have resulted in the destruction of approximately 85% of the LWR's native vegetation (Friedman et al. 1993; Figs. 2a-b), leaving a much-reduced and highly fragmented ecosystem. As a result, the LWR now harbors 29 species classified by the U.S. Fish and Wildlife Service (1999) as either endangered or threatened, among the highest concentrations of federally listed species in the continental United States (Dobson et al. 1997; Chaplin et al. 2000).

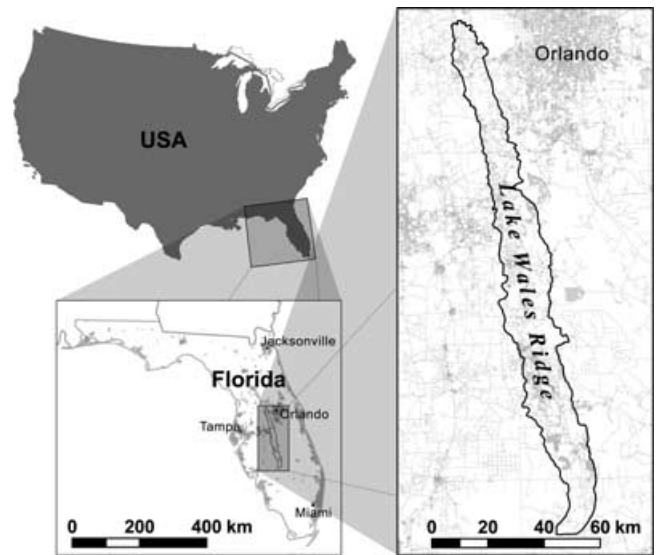


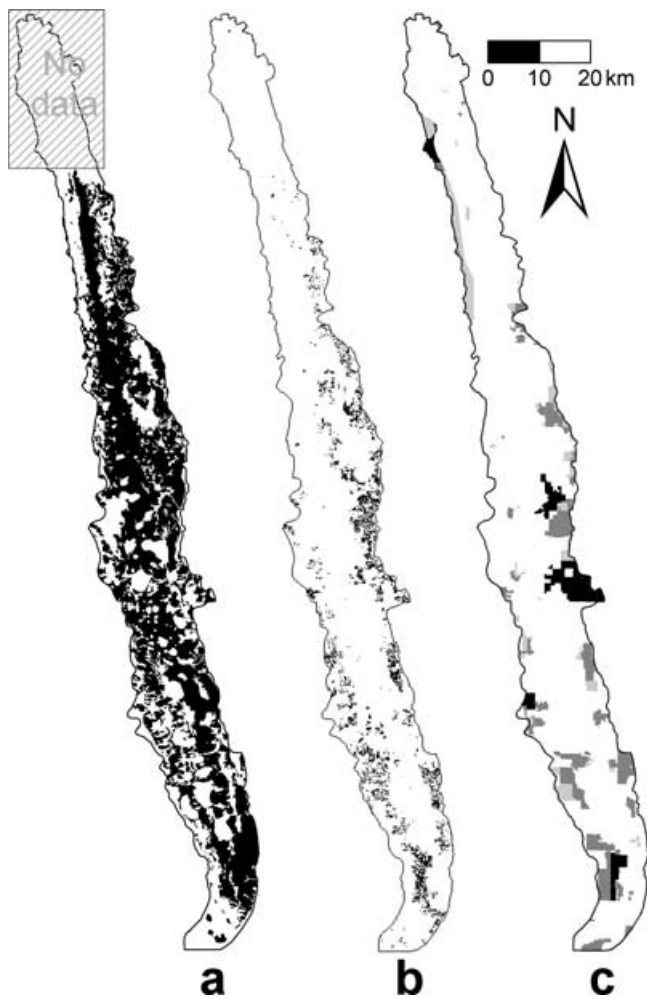
Figure 1. Location of the Lake Wales Ridge in central Florida (U.S.A.). Florida map (lower left) shows urban areas (gray) and major urban centers (population > 1 million, black dots). Enlarged Lake Wales Ridge map (right) shows roads (gray lines).

The destruction of LWR habitats and the resulting endangerment of numerous species have spurred a vigorous land-acquisition effort by governmental and private entities. The goal of these conservation initiatives has been to ensure the persistence of LWR species and the preservation of their original geographic extent (Archbold Biological Station 1989). Since 1992 the state of Florida has spent over \$68 million to acquire nearly 100 km<sup>2</sup> of land within the LWR, with plans to acquire an additional 10,000 ha (Florida Department Environmental Protection 2005). The federal government complemented these efforts by creating the first national wildlife refuge designated primarily for plants, the LWR National Wildlife Refuge (U.S. Fish and Wildlife Service 1993). To date, a total of 282 km<sup>2</sup> of land within the LWR has been protected (Fig. 2c).

The small size and discrete boundaries of the LWR, the presence of numerous rare and threatened species, the near-exhaustive survey data on species occurrences, and the well-documented efforts to conserve many of the remaining natural areas create an ideal situation for examining the effectiveness of land-conservation initiatives aimed at protecting species.

### Database

We assembled a global distribution database for 36 rare or threatened plants and animals that are either LWR endemics or require scrub or sandhill habitats for their survival, including 33 species and 3 subspecies. Eight are strict LWR endemics, whereas the remainder occur



**Figure 2.** Habitat loss and protected areas on the Lake Wales Ridge, Florida: (a) estimated presettlement (prior to approximately 1900) distribution of scrub and sandhill habitats (Friedman et al. 1993); (b) distribution of scrub and sandhill habitats in 2003 (Florida Fish & Wildlife Conservation Commission 2004; white areas include lakes [10.4%], other natural habitats [27.0%], and agriculture and development [62.6%]); (c) protected areas as of 1988 (black), additional areas protected through 2004 (dark gray), and unacquired areas targeted for conservation acquisition (light gray).

to varying degrees outside of the LWR. For example, only 16% of known occurrences of the Florida mouse (*Peromyscus floridanus*), one of our focal species, fall within the LWR.

Our species-occurrence data came in two forms: spatial records and supplemental presence-absence records. Most records (93.3% of 1468) were spatial, containing details on the locations of populations and other data. These records were obtained from the Florida Natural Areas In-

ventory (FNAI), which maintains a statewide geographic information system (GIS) that tracks occurrences of rare or imperiled plants and animals based on NatureServe's element occurrence data standard (NatureServe 2002). We worked with FNAI to add hundreds of additional spatial records for this study. We included only records from 1985 or later. We chose this date so as to minimize the inclusion of recently extirpated populations yet include the results of multiple systematic surveys of LWR habitat remnants (e.g., Christman 1988; Mushinsky & McCoy 1991; Weekley et al. 2001; K. Delaney, unpublished data).

We supplemented these detailed spatial records, as necessary, with credible presence-absence records, which simply record whether or not a given species occurred in a particular managed area or other bounded land unit (6.7% of all records). Presence-absence records lack precise spatial information and only allow the identification of one record per protected area. They are nevertheless valuable in cases where more detailed spatial records do not exist. We compiled presence-absence records for individual sites based on published and unpublished survey lists and site management plans and then consulted >30 local biologists and land managers for additional records and error checking. We excluded presence-absence records from 1995 or later to minimize inclusion of recently extirpated populations. Our combined database of spatial and presence-absence records is nearly exhaustive in scope because it is based on repeated and targeted surveys to collect data over all extant LWR habitat.

In addition to our species database, we constructed a sites database that contained the boundaries and ownership status of all protected areas in Florida ( $n = 1408$ ; Florida Natural Areas Inventory 2004). For the LWR the sites database included 50 currently protected (or partially protected) areas (282 km<sup>2</sup> total) under the management of 11 different organizations (one federal, three state, five local, two nonprofit, each managing between 1 and 17 sites). The database included an additional 27 LWR parcels (130 km<sup>2</sup> total) that are currently unprotected but targeted for acquisition (based on Florida Natural Areas Inventory 2003).

Our analysis also required data on the amount of habitat available to each species within each site at which it occurs. Methods of statistical habitat modeling are often used to identify species-specific habitat requirements. Nevertheless, the spatial accuracy of our species occurrence data is limited. The accuracy is sufficient to assign occurrences to particular sites, but not sufficient for assessing habitat preferences within sites. Instead, for plants we drew on the habitat associations determined by E. Menges et al. (unpublished). These were based on intensive field measurements of species occurrences and absences in relation to soil type and habitat type, with high spatial accuracy (error generally much below 10 m) at spatial scales relevant to patchy LWR habitats.

For animals, we consulted biologists with extensive field experience at finer spatial scales with each species to determine habitat associations. Based on this information, we used soils maps and a 2003 Landsat-derived habitat map (Florida Fish & Wildlife Conservation Commission 2004) to compute the area of potential habitat for each species available at each site. Because of the potential for error in these habitat associations, we examined the sensitivity of our results by repeating analyses under a relaxed assumption that all scrub and sandhill habitats were suitable for all species.

### Calculating the Protection Index

The protection index was based on three distributional factors associated with extinction risk (IUCN 2001): number of locations, extent of occurrence, and area of occupancy. Number of locations is the number of geographically or ecologically distinct areas in which a species occurs within a given set of protected sites (i.e., a conservation scenario, described below). The IUCN Red List criteria define a location as the area over which the most likely threatening event can affect all individuals of the taxon present (IUCN 2001). The greatest threat to LWR species is development. Although development projects in central Florida vary in size, they are typically in the range of 0.5–5 km<sup>2</sup>. The FNAI's existing database protocols (NatureServe 2002) aggregate multiple records into single locations if separated by 0.5–3.5 km, depending on the species. Thus, we were able to define locations in a manner consistent with both data standards. A given species could occur at multiple locations within a single, large protected area if the spatial records exceeded the minimum separation distance (i.e., provided only one of the locations could be affected by a typical threatening event).

Extent of occurrence is the total geographic area of a species' range (Gaston 1991; IUCN 2001). We computed extent of occurrence with the  $\alpha$ -hull method, a generalization of minimum convex polygons recommended by Burgman and Fox (2003) and current IUCN Red List guidelines (IUCN 2005). Our calculations based on the original algorithm (Burgman & Fox 2003) frequently resulted in

undesirable behavior, including estimated range area actually decreasing as new sites were added to a species' range (this occurred for at least 13 of 36 species for  $\alpha = 3$ ). Thus, we modified the  $\alpha$ -hull algorithm so that it used a fixed threshold of 70 km, just small enough to exclude the large gaps of unsuitable habitat between the LWR and the suitable xeric upland habitats of Florida's coasts. This modification produced patterns of extent of occurrence over time closer to what one might expect as sites were added or removed.

Area of occupancy is the area within a species' extent of occurrence that is actually occupied by the species (i.e., it excludes unsuitable and unoccupied habitats; Gaston 1991; IUCN 2001). We computed the area of suitable habitat for each species at each site and then computed area of occupancy by summing suitable habitat across all sites at which the species occurs in a given conservation scenario.

In order of decreasing endangerment, the IUCN Red List categories are extinct in the wild, critically endangered, endangered, vulnerable, near threatened, and least concern. Each category (except near threatened and least concern) is defined in part by specific values for the distributional criteria (Table 1; IUCN 2001). By assigning integer values to the cutoffs between categories (Table 1) and then interpolating linearly to compute intermediate values, we derived a continuous, quantitative PI for each of the three distributional criteria ( $PI_{locs}$ ,  $PI_{ao}$ , and  $PI_{ext}$  for number of locations, area of occupancy, and extent of occurrence, respectively). For example, a species at six locations would fall within the locations range for vulnerable ( $5 < locations \leq 10$ ), which has a corresponding PI range of  $2.0 < PI_{locs} \leq 3.0$  (Table 1). We computed the final value by interpolating linearly within this range:  $PI_{locs} = 2.0 + (6 - 5)/(10 - 5) = 2.2$ . Figure 3 shows a full mapped example. Because the IUCN Red List does not specify quantitative cutoffs between near threatened and least concern, we set these cutoffs at five times the values of cutoffs between vulnerable and near threatened (Table 1).

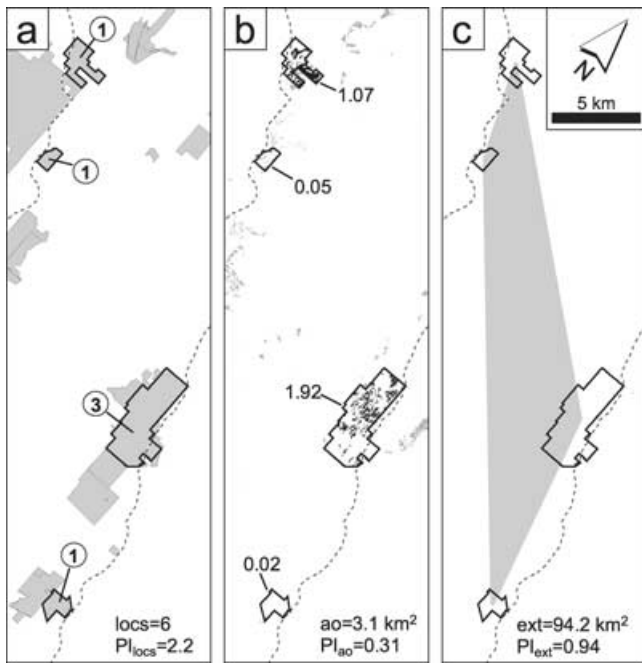
We also constructed an overall PI ( $PI_{tot}$ ) that reflects the protection status of a species when all three criteria are considered together. In doing so, we could either

**Table 1.** Derivation of quantitative protection index (PI) values<sup>a</sup> from discrete cutoffs between categories of the IUCN Red List.

Protection index (PI)	Criterion			Equivalent IUCN Red List category
	no. of locations	extent of occurrence (km <sup>2</sup> )	area of occupancy (km <sup>2</sup> )	
0	0	0	0	extinct in the wild
0 < PI ≤ 1	≤1	≤100	≤10	critically endangered
1 < PI ≤ 2	≤5	≤5000	≤500	endangered
2 < PI ≤ 3	≤10	≤20,000	≤2000	vulnerable
3 < PI ≤ 4	≤50 <sup>b</sup>	≤100,000 <sup>b</sup>	≤10,000 <sup>b</sup>	near threatened

<sup>a</sup>A separate PI is derived for each criterion by assigning integer PI values to the specified cutoffs and interpolating linearly between cutoffs.

<sup>b</sup>Because the IUCN Red List does not specify cutoffs for near threatened, we set these cutoffs at five times those of vulnerable.



**Figure 3.** Example of calculation of protection index (PI) values for a hypothetical species under the targeted scenario (see text): (a) number of locations (*locs*; numbers, number of distinct locations with the species in each protected area; shading, all land protected under the targeted scenario); (b) area of occupancy (*ao*; shading, all habitat suitable for the hypothetical species; numbers, area [ $\text{km}^2$ ] of suitable habitat available at each of the four protected areas where the species occurs); (c) extent of occurrence (*ext*; shading, extent for this species under the targeted scenario). All maps have the same scale and orientation and show the four protected areas (solid lines) that contain the species. Dotted lines show approximate Lake Wales Ridge boundary.

choose the minimum (i.e., worst) PI among the three criteria (this is the quantitative analog of the IUCN Red List approach, in which, in most cases, a species receives the most severe category for which it fulfills any of the criteria) or the average across all three criteria. The average allows each criterion to influence overall status (in contrast with the minimum approach, which effectively allows only the worst criterion to determine overall status). These and other approaches have merit under different circumstances; moreover, they produced different results in our preliminary analyses. We used the average PI for descriptive purposes ( $PI_{\text{tot}} = [PI_{\text{locs}} + PI_{\text{ao}} + PI_{\text{ext}}]/3$ ), although a more extensive exploration of aggregate indexes is warranted in the future (e.g., for use as an objective function in optimal site-selection algorithms).

In all of our analyses, we counted only those species occurrences that fell within the boundaries of actual or

potential protected areas. Thus, we computed extent of occurrence based only on species locations protected under a given conservation scenario (scenarios described below). Similarly, we measured area of occupancy for a given species as the amount of that species' habitat present on protected areas where the species occurs. We restricted our focus to protected populations because our goal was to measure the effect of land acquisition on imperiled species. The scrub and sandhill habitats that harbor virtually all our focal species are subject to high development pressure; few unprotected parcels are likely to persist for more than a few years. Moreover, these habitats are regenerated by periodic fire, which due to development has all but disappeared from the LWR as a natural phenomenon. Because there is little chance of prescribed fire being instituted to maintain habitat suitability in unprotected fragments, imperiled species on unprotected sites will almost certainly disappear over time even if the sites themselves remain undeveloped.

### Conservation Scenarios

To evaluate conservation progress within the LWR, we considered three conservation scenarios (past, current, and targeted; Fig. 2c). Each assumes a static picture of conservation efforts outside LWR boundaries. That is, we take all protected populations outside the LWR into account in our analyses, but we assumed that no additional sites outside the LWR will be protected beyond those currently protected. Thus, the PI measures only the contribution of land-protection efforts within the study area (LWR) to changes in the global status of the focal species.

Significant efforts to acquire and protect important habitats of the LWR did not begin until the late 1980s. In the past scenario, we assumed this push to conserve land did not occur, that the only LWR protected areas were those created prior to 1988, and that all unprotected parcels within the LWR were either developed or allowed to degrade, resulting in a total loss of the species within them. Total LWR scrub and sandhill habitat protected under this scenario was  $28.0 \text{ km}^2$  (2.0% of the estimated presettlement total).

In the current scenario we assumed that all areas currently protected (as of December 2004) within and outside the LWR persisted but all unprotected fragments either were degraded or disappeared. Under this scenario,  $87.4 \text{ km}^2$  of LWR habitat was protected (6.3% of presettlement total).

In the targeted scenario, we assumed that all currently protected areas within and outside the LWR persisted and that conservationists succeeded in protecting all the unprotected fragments within the LWR that were targeted for acquisition under current conservation initiatives. Under this scenario,  $103.8 \text{ km}^2$  of LWR scrub and sandhill habitat was protected (7.5% of presettlement total).

By comparing PIs under these three scenarios, we addressed the following questions: What would the protection status of these species be had conservation efforts within the LWR ended 2 decades ago? What if those efforts stopped now, leaving only the currently protected areas for posterity? and What if conservationists are successful in acquiring all of the LWR sites that are currently targeted for acquisition?

A special case arose with respect to certain sites that have been only partially acquired. These seven “megaparcels” total approximately 52 km<sup>2</sup> and consist of largely undeveloped scrub and sandhill. They were finely subdivided (into mostly 0.1- to 0.4-ha lots) and sold to thousands of investors in previous decades. Various government agencies and conservation organizations have been contacting the owners and acquiring these sites, but the process has proved difficult and slow. We included megaparcels sites in the current scenario but penalized each according to the percentage of area within it that has been acquired. Although any scheme for penalization is arbitrary to some degree, we attempted to roughly account for the limitations fragmented ownership places on biological processes and essential management activities (e.g., prescribed fire). Specifically, in computing the number of locations at which a given species occurs (for  $PI_{locs}$ ) in the current scenario, we scored each location within the megaparcels sites as 0 locations if the site was  $\leq 50\%$  acquired, 0.25 if  $> 50\%$  but  $\leq 75\%$  acquired, 0.75 if  $> 75\%$  but  $\leq 90\%$  acquired, and 1.0 if  $\geq 90\%$  acquired. In computing area of occupancy (for  $PI_{ao}$ ), habitat area acquired in the current scenario for each site was multiplied by the percentage acquired for that site. Computation of extent of occurrence (for  $PI_{ext}$ ) was not changed for megaparcels sites. In the targeted scenario, all megaparcels sites were assumed to be acquired completely and thus incurred no penalty.

## Site Evaluation

We measured the contribution of each protected area to the conservation of each species by calculating PI values with and without a given site. For a given site the difference, or  $\Delta PI$ , between PI values with and without the site indicated the contribution of that site to the overall protection of species. For current sites  $\Delta PI$  values thus represented the overall decrease in PI that would result if that site ceased to be protected or lost species due to lack of sufficient management activities. This  $\Delta PI$  calculation required as a baseline the set of additional sites assumed protected while the focal site is added or removed. In practice the most broadly useful baseline may be the set of currently protected sites—which we used here—although other questions potentially could be addressed by choosing a baseline in the past or future.

## Results

Land acquisition since 1988 altered dramatically the distribution of PIs for imperiled LWR species (Fig. 4). Median  $PI_{tot}$  across species increased from 1.36 in the past scenario to 1.92 in the current scenario and climbed to a projected value of 2.02 when all currently targeted but unprotected sites were acquired (targeted scenario). Given the nonlinear nature of the cutoffs between IUCN Red List categories (Table 1), larger absolute gains in PIs were associated with early land-acquisition efforts, whereas expected gains when all targeted areas were acquired were smaller.

When PIs for the three criteria were considered separately, a more nuanced picture of conservation efforts emerged. The value of  $PI_{locs}$  jumped substantially from the pre-1988 situation (past scenario, median  $PI_{locs} = 2.60$ ) to the present (current scenario, median  $PI_{locs} = 3.37$ ). It increased again from the current scenario to the targeted scenario (median  $PI_{locs} = 3.49$ ), reflecting the gains that could be achieved by acquiring the still-unprotected sites (Fig. 4a). In contrast, median values for  $PI_{ao}$  and  $PI_{ext}$  changed little from the current scenario to the targeted scenario (Figs. 4b-c), largely because the LWR is a relatively small ecosystem that has already lost most of its natural habitat.

Some species made significant gains in  $PI_{locs}$  from past to current scenarios (Fig. 5), for example, the plants *Crotalaria avonensis* ( $PI_{locs}$  increased from 0 to 1.38) and *Hypericum edisonianum* (1.00 to 3.08). (Table 2 provides a complete list of the 36 focal species, including taxonomic authorities.) Only five species had current  $PI_{locs} < 2.0$ , and only three species would remain so if all targeted sites were acquired. Two species, however, that were widely assumed to be well represented in the reserve network—the plant *Centrosema arenicola* and the lizard *Eumeces egregius lividus*—in fact appeared to be poorly represented (current  $PI_{locs} = 2.00$  and 3.06, respectively; Fig. 5).

In terms of area of occupancy and geographic extent, nine plant species (*C. arenicola*, *Conradina brevifolia*, *C. avonensis*, *Dicerandra christmanii*, *Dicerandra frutescens*, *Eryngium cuneifolium*, *H. cumulicola*, *Warea amplexifolia*, *Ziziphus celata*) and one animal (*Citindela scabrosa*) exhibited one or more PIs  $< 1.0$  even under the (optimistic) targeted scenario because of some combination of small area of occupancy or limited extent of occurrence (Fig. 5). Even under the targeted scenario, which was premised on acquisition of all of the remaining, unprotected priority sites, 26 of 36 species had  $PI_{ao}$  below 2.0, and 33 had  $PI_{ext}$  below 2.0.

To illustrate how our methodology enabled us to measure the role a given site plays in the global conservation effort for each imperiled species, consider two LWR protected areas, the Archbold Biological Station (a nonprofit

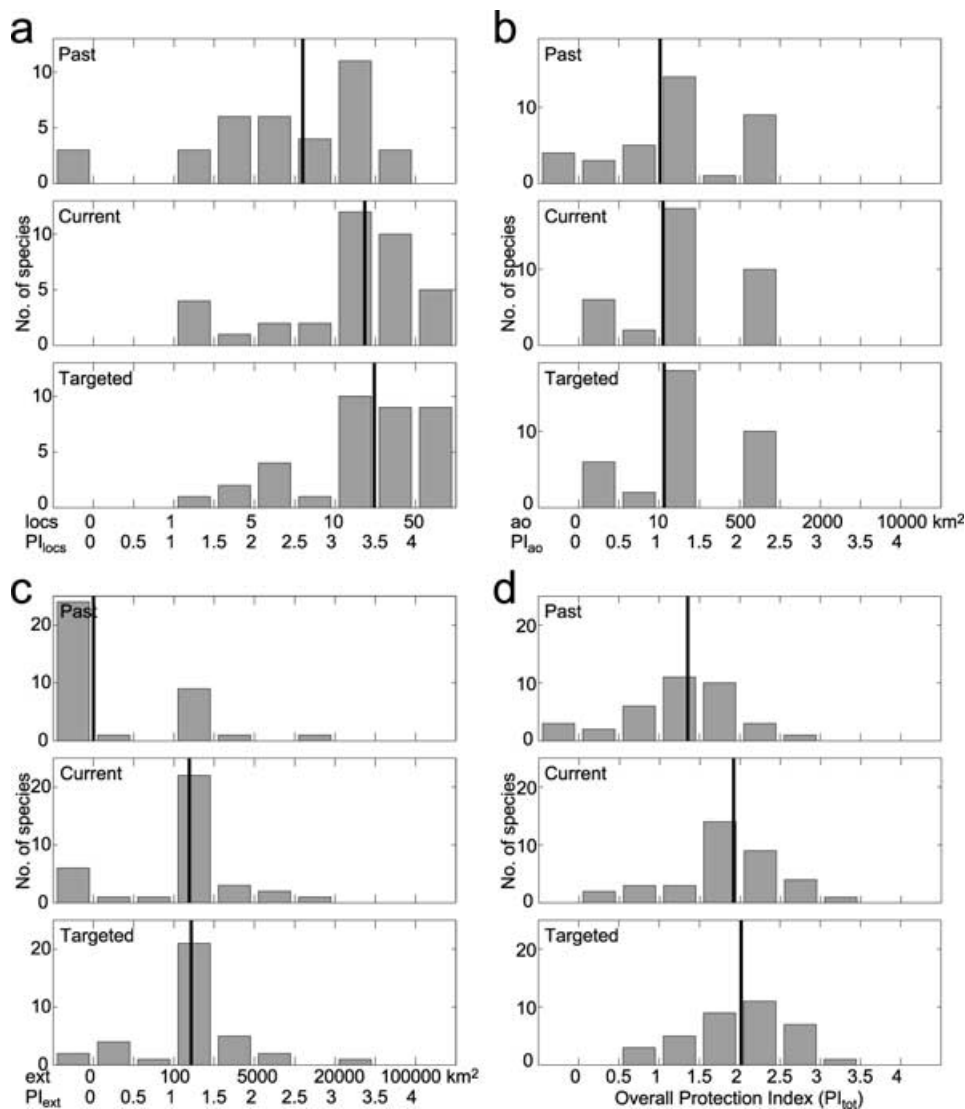


Figure 4. Change in protection indexes (PIs) between past, current, and targeted scenarios (see text for explanation of scenarios) for the Lake Wales Ridge reserve network: PI based on (a) number of locations ( $PI_{locs}$ ); (b) area of occupancy ( $PI_{ao}$ ); and (c) extent of occurrence ( $PI_{ext}$ ). Overall PI ( $PI_{tot}$ ) is shown in (d). Each histogram shows the number of species in various PI intervals, with zero indicating no protection and higher PI values indicating increased protection. Black vertical lines are median values across all 36 species.

research institution) and Flat Lake (owned by the State of Florida). Based on  $\Delta PI$  values, Archbold stood out as being vital to the conservation of many imperiled LWR species (e.g., 16 have one or more  $\Delta PI$  values  $\geq 0.05$ ; Table 2). Flat Lake was important to the conservation of several species, including *W. amplexifolia* ( $\Delta PI_{locs}$ ), *Clitoria fragrans* ( $\Delta PI_{ext}$ ), and *Stylisma abdita* ( $\Delta PI_{ext}$ ). The  $\Delta PI$  values measured the component of the overall protection of each species that each site represented, or, viewed differently, the reduction in overall protection that would occur if a particular site were lost or ceased to be managed appropriately for a species. To aid acquisition and management personnel in the LWR ecosystem, we conducted similar analyses for all existing LWR reserves and unprotected areas targeted for acquisition (Turner et al. 2006).

Our results were computed using the habitat associations developed by E. Menges et al. (unpublished) and other experts to define species habitat preferences. When

we repeated analyses assuming coarser habitat tolerances (specifically that all scrub and sandhill habitats are suitable for all species), our results differed only slightly. For example, under the coarse habitat model, median  $PI_{tot}$  for the current scenario was 1.965 (2.3% more than the 1.92 obtained with the more detailed habitat associations). The small changes observed in our results despite a known misspecification of habitat preferences (most focal species have much narrower preferences than the coarse habitat model) suggest that the more-modest errors possibly inherent in the habitat associations did not substantially influence our results.

## Discussion

A quantitative protection index, based on three variables important to species conservation (number of locations, area of occurrence, extent of occurrence), benefits

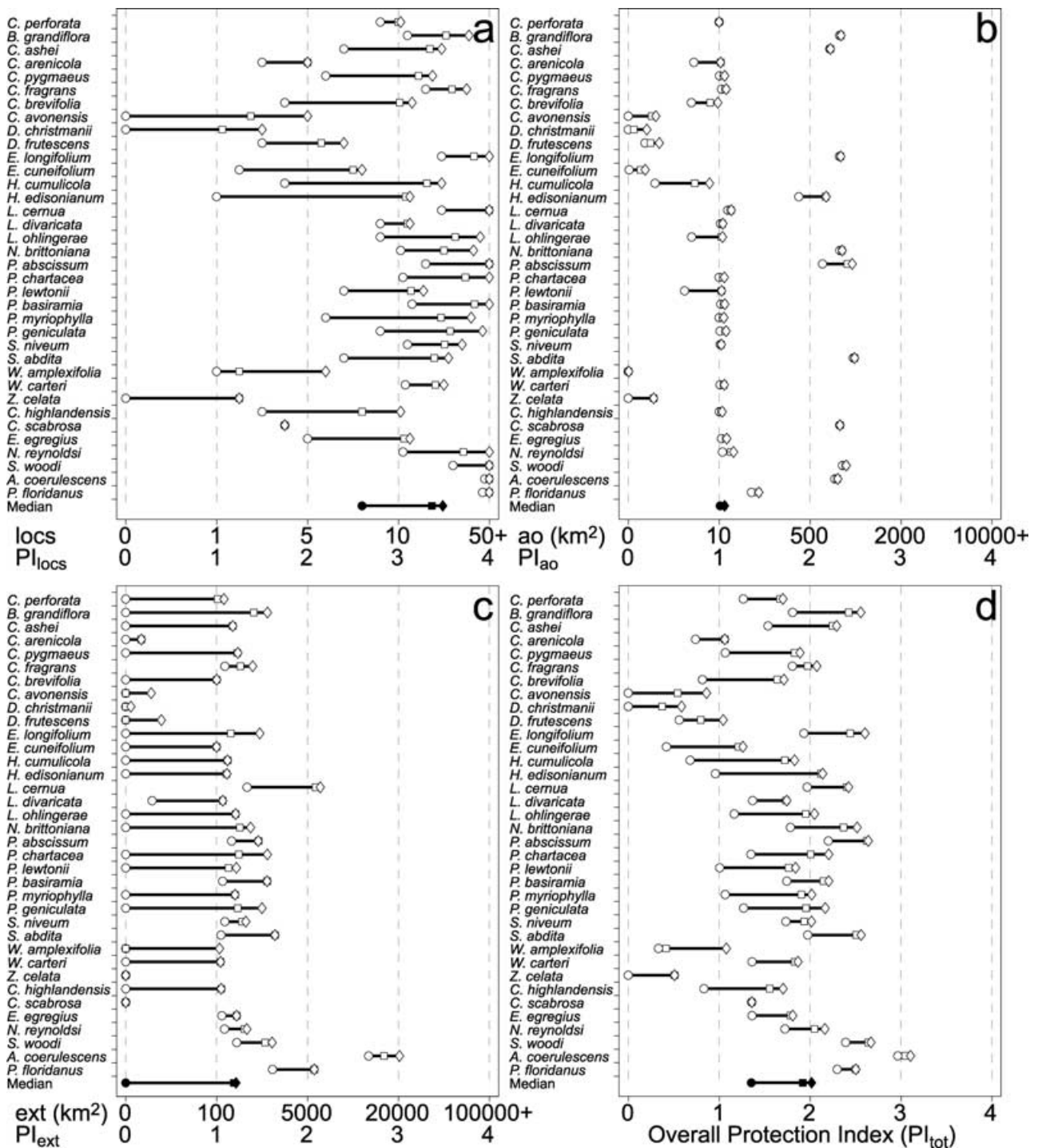


Figure 5. Changes in protection index (PI) values across three conservation scenarios (past, circles; current, squares; targeted, diamonds; see text for explanation of scenarios) for 36 focal species on the Lake Wales Ridge: PI based on (a) number of locations ( $PI_{locs}$ ); (b) area of occupancy ( $PI_{ao}$ ); and (c) extent of occurrence ( $PI_{ext}$ ). Overall PI ( $PI_{tot}$ ) is shown in (d). Open shapes are species-specific values; closed shapes are median values across all species. See text and Fig. 4 legend for explanation of PI index values, and see Table 2 for full names of species.

ongoing conservation efforts in several ways. First, the PI approach measures overall progress in protecting the imperiled flora and fauna of a given ecosystem through land acquisition or some other form of protection. In the

case of the LWR, our analysis showed that land acquisition programs launched in the late 1980s have resulted in substantial improvements in the protection status of many plants and animals.

**Table 2.** Use of protection index (PI) values to measure the importance of each reserve (here, Archbold Biological Station and Flat Lake) to overall protection of individual imperiled species<sup>a</sup>.

Site <sup>b</sup>	Species	$\Delta PI_{locs}$	$\Delta PI_{ao}$	$\Delta PI_{ext}$	$\Delta PI_{tot}$
Archbold Biological Station					
	<i>Cladonia perforata</i>	0.6	0 <sup>+</sup>	1.01	0.65
	<i>Dicerandra frutescens</i> Shinners subsp. <i>frutescens</i>	0.96	0.23	-	0.3
	<i>Centrosema arenicola</i> (Small) E.J. Herm	0.25	0.01	0.87	0.49
	<i>Eryngium cuneifolium</i> Small	0.4	0.01	0.08	0.13
	<i>Cicindela scabrosa</i>	0.25	0 <sup>+</sup>	-	0.06
	<i>Warea carteri</i> Small	0.13	0.01	0 <sup>+</sup>	0.04
	<i>Hypericum cumulicola</i> (Small) W.P. Adams	0.1	0.01	0 <sup>+</sup>	0.03
	<i>Paronychia chartacea</i> Fernald subsp. <i>chartacea</i>	0.1	0.01	0 <sup>+</sup>	0.03
	<i>Eriogonum longifolium</i> Nutt. var. <i>gnaphalifolium</i> Gand.	0.1	0 <sup>+</sup>	0.03	0.04
	<i>Nolina brittoniana</i> Nash	0.08	0 <sup>+</sup>	0 <sup>+</sup>	0.02
	<i>Liatris oblongerae</i> (S.F. Blake) B.L. Rob.	0.08	0 <sup>+</sup>	-	0.02
	<i>Schizachyrium niveum</i> (Swallen) Gould	0.05	0 <sup>+</sup>	0 <sup>+</sup>	0.01
	<i>Prunus geniculata</i> R.M. Harper	0.05	0.01	0 <sup>+</sup>	0.02
	<i>Polygonella basiramia</i> (Small) G.L. Nesom & V.M. Bates	0.05	0 <sup>+</sup>	0 <sup>+</sup>	0.02
	<i>Hypericum edisonianum</i> (Small) W.P. Adams and N. Robson	0.05	0.02	-	0.02
	<i>Clitoria fragrans</i> Small	0.05	0 <sup>+</sup>	0 <sup>+</sup>	0.02
	<i>Eumeces egregius lividus</i>	0.03	0.03	0.04	0.03
	<i>Podomys floridanus</i>	-	0.03	0 <sup>+</sup>	0.01
	<i>Neoseps reynoldsi</i>	0.03	0.03	-	0.02
	<i>Polygonella myriophylla</i> (Small) Horton	0.03	0.01	0 <sup>+</sup>	0.01
	<i>Lecbea divaricata</i> Shuttlew. ex Britton	0.03	0.01	0.02	0.02
	<i>Calamintha asbei</i> (Weath.) Shinners	0.03	0 <sup>+</sup>	0 <sup>+</sup>	0 <sup>+</sup>
	<i>Panicum abscissum</i> Swallen	0 <sup>+</sup>	0.02	-	0 <sup>+</sup>
	<i>Abelocoma coerulea</i>	-	0 <sup>+</sup>	-	0 <sup>+</sup>
	<i>Sceloporus woodi</i>	-	0 <sup>+</sup>	0 <sup>+</sup>	0 <sup>+</sup>
	<i>Lecbea cernua</i> Small	-	0 <sup>+</sup>	0 <sup>+</sup>	0 <sup>+</sup>
Flat Lake					
	<i>Warea amplexifolia</i> (Nutt.) Nutt.	0.25	0 <sup>+</sup>	-	0.06
	<i>Stylisma abdita</i> Myint	0.03	0 <sup>+</sup>	0.19	0.1
	<i>C. fragrans</i>	0.03	0 <sup>+</sup>	0.1	0.03
	<i>Polygala lewtonii</i> Small	0.03	0 <sup>+</sup>	0 <sup>+</sup>	0 <sup>+</sup>
	<i>N. reynoldsi</i>	0.03	0 <sup>+</sup>	-	0 <sup>+</sup>
	<i>P. geniculata</i>	0.03	0 <sup>+</sup>	0 <sup>+</sup>	0 <sup>+</sup>
	<i>E. longifolium</i>	0.03	0 <sup>+</sup>	0.01	0.01
	<i>Bonamia grandiflora</i> (A. Gray) Hallier f.	0.03	0 <sup>+</sup>	-	0 <sup>+</sup>
	<i>P. floridanus</i>	-	0 <sup>+</sup>	-	0 <sup>+</sup>

<sup>a</sup>Key:  $\Delta PI_x$ , decrease in PI based on criterion *x* that would occur if a particular protected area were lost from the "current" scenario. Criteria include number of locations (locs), area of occupancy (ao), extent of occurrence (ext), and overall (tot). All focal species at each protected area shown sorted in order of descending  $\Delta PI_{tot}$ . See text for details. The  $\Delta PI$  values of 0<sup>+</sup> indicate  $0 < \Delta PI < 0.01$ , whereas dashes indicates  $\Delta PI_x = 0$ .

<sup>b</sup>These two sites include 30 of this study's 36 focal species. The remaining six include five plants (*Chionanthus pygmaeus* Small, *Conradina brevifolia* Shinners, *Crotalaria avonensis* DeLaney & Wunderlin, *Dicerandra christmanii* Huck & Judd, *Ziziphus celata* Judd & D.W. Hall) and the beetle *Cicindela highlandensis*.

Second, the PI approach provides useful insights into some of the challenges conservationists may face in protecting imperiled species in a given ecosystem. For example, the small extent of the LWR ecosystem combined with the limited amount of remaining habitat will likely continue to threaten the survival of the ecosystem's rare species, even if land acquisition efforts are maximally successful (Fig. 4b-c). This suggests that LWR conservationists must not only protect remaining habitat, but they must also make certain that protected habitat is maintained in suitable conditions for threatened species.

Third, the PI approach identifies species likely to be of particularly high conservation concern now and in

the future. Those species with the lowest PIs under current and targeted scenarios will likely require even more intensive management, including propagation, translocation, and reintroduction to potentially suitable habitat, to survive. Conservation actions beyond basic habitat management are underway for only two of our focal species, *Z. celata* and *W. amplexifolia* (U.S. Fish and Wildlife Service 1999). Thus, other species with low PIs should be reviewed for more direct management action, beginning with the other eight species with one or more PIs < 1.0.

Fourth, the PI approach, by systematically gathering and tabulating the data on which species occur within which protected areas, uncovered two species (the plant

*C. arenicola* and the skink *E. egregius lividus*) whose lack of protection in the current network seems to have been overlooked. Discoveries of this sort are not a virtue of the PI per se, but they are a benefit of carefully reviewing the protection status of all imperiled species within the ecosystem. More intensive surveys for such species should be conducted within existing reserves, and if they prove to be genuinely underrepresented, action should be taken to increase their representation in the network.

Finally, the PI approach enables conservationists to quantify the contribution of each protected area (or potential protected area) to regional or global efforts to conserve particular species. Used in this way, the PI facilitates coherence between multiple scales of management, enabling local conservation decisions to be made in the context of broader-scale conservation strategies. With this information, conservationists can coordinate global status assessments, land acquisition programs, recovery plans, and other large-scale plans with site-specific management activities. Managers of the LWR are already using the results of our analysis to determine priorities for local management actions.

Although a species' PI value is not a direct reflection of its red-list status, given the rapid pace of land development within the LWR and the need to actively manage scrub and sandhill fragments to maintain their constituent species, few if any unprotected populations within the LWR are likely to survive more than a decade. Thus, our results may be useful predictors of each species' best-case red-list status in the near future. If all targeted acquisitions are made (targeted scenario), our analysis predicted 10 critically endangered, 25 endangered, and 1 vulnerable species (with none near threatened or least concern) among our 36 focal species. These status ranks resulted largely from IUCN Red List criteria B1 (restricted extent of occurrence) and/or B2 (restricted area of occupancy; IUCN 2001). Were more detailed information available (e.g., population size, trend, and viability), some LWR species would likely be assigned even more severe categories and/or qualify for the IUCN Red List based on more criteria.

Although we used  $PI_{tot}$  to examine the overall protected status of each species, we also considered separately the contribution of each criterion ( $PI_{locs}$ ,  $PI_{ao}$ ,  $PI_{ext}$ ) to this index. A single, overall index such as  $PI_{tot}$  is a useful way to summarize information for decision makers and planners, but such an index, if used alone, could mask important conservation problems and opportunities. Thus, we advocate an approach that uses both aggregate indexes (e.g.,  $PI_{tot}$ ) and their constituent components ( $PI_{locs}$ ,  $PI_{ao}$ ,  $PI_{ext}$ ) to assist conservation decision making.

We envision several extensions of the PI approach that would enhance its utility in conservation. For example, because it links readily available data to stated conservation goals and can be computed for different reserve

network scenarios, the PI is a useful tool for evaluating alternative future additions to existing reserve networks. To date we have examined only one potential future scenario (the targeted scenario). We are currently integrating PIs into a more comprehensive planning framework by altering existing site-selection algorithms so that they maximize PIs across species given practical constraints such as limited budgets for land acquisition (Turner et al. 2006).

Our analyses considered species occurrences in actual or potential protected areas only. In ecosystems where species are more likely to persist in unprotected sites, the PI could be modified to consider all occurrence records, including those not on protected areas. In such cases calculation of habitat area (for  $PI_{ao}$ ) could consider additional habitat types (e.g., human-modified habitats on which species might persist). With this extension to include unprotected sites, one could then use PIs to assess the outcomes not only of alternative scenarios of habitat protection, but also alternative scenarios of development or other habitat loss. One potential challenge is acquiring species data from unprotected areas, where access restrictions frequently make data difficult to obtain.

Given that the LWR harbors so many endemic or near-endemic species, one might reasonably ask whether the PI approach is useful in ecosystems with few endemic species. Our approach is applicable to any conservation situation involving species considered threatened according to IUCN Red List distributional criteria, provided actual or estimated global distributional data are available (or, if the persistence of an isolated population is of interest, distributional data over the range of that population). Distributional data, however, may be more readily available for narrowly distributed species. This was the case in Florida, where limited resources for inventory and monitoring are allocated preferentially to species likely to be threatened.

A weakness of the protection index approach is that it does not explicitly account for the viability of individual populations or the dynamics of interacting populations. By failing to do so, the various PIs may paint an incomplete picture of the status of certain species. For example, PIs for all criteria for the Florida Scrub-Jay (*Aphelocoma coerulescens*) are higher than comparable values for most other LWR species, suggesting that this species is more secure than the others (although the best-case PI values for the jay were nonetheless below 3.0, placing it equivalent to vulnerable on the IUCN Red List). The relatively high values for the jay stem from the fact that there are numerous small populations of jays both within and outside the LWR. The  $PI_{locs}$  values consider only the number of locations (i.e., populations), not their relative size, viability, or proximity to other populations. Yet censuses and PVAs indicate that numbers of jays within these populations have been declining for many years (U.S. Fish and Wildlife Service 2003; R. Bowman, personal communication). Thus,

whenever more detailed data and analyses are available, they should be considered in addition to indexes like the PI. They can even be integrated into the PI. For example, one straightforward extension of the PI approach would be to weight each location according to a species' viability there. Alternatively, one could add PI components according to additional red-list criteria (e.g., population size or trend) and estimate changes in those quantities due to past or anticipated conservation actions. Unfortunately, detailed demographic data and PVAs are rarely available for most species. Even in the well-studied LWR, the jay is one of only a few species for which abundance and population estimates exist.

In a world where resources for conservation are limited and many urgent needs go unaddressed, conservation biologists and decision makers must be able to measure their progress toward achieving tangible goals, and they must be able to demonstrate that they are deploying their limited resources in an efficient and effective manner. Moreover, although most conservation actions necessarily take place at a local scale, there is a pressing need to maintain a broader perspective, as embodied in the hackneyed yet truthful maxim, "think globally, act locally." The approach presented here permits those engaged in species conservation to do just that.

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## Literature Cited

- Archbold Biological Station. 1989. Biological priorities for a network of scrub preserves on the Lake Wales Ridge. Archbold Biological Station, Lake Placid, Florida.
- Brook, B. W., J. J. O'Grady, A. P. Chapman, M. A. Burgman, H. R. Akcakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. *Nature* **404**:385-387.
- Burgman, M. A., and J. C. Fox. 2003. Bias in species range estimates from minimum convex polygons: implications for conservation and options for improved planning. *Animal Conservation* **6**:19-28.
- Chaplin, S. J., R. A. Gerrard, H. M. Watson, L. L. Master, and S. R. Flack. 2000. The geography of imperilment: targeting conservation toward critical biodiversity areas. Pages 159-200 in B. A. Stein, L. S. Kutner, and J. S. Adams, editors. *Precious heritage: the status of biodiversity in the United States*. Oxford University Press, New York.
- Christman, S. P. 1988. Endemism and Florida's interior sand pine scrub. Florida Game and Fresh Water Fish Commission, Nongame Wildlife Section, Tallahassee, Florida.
- Dickman, C. R., R. L. Pressey, L. Lim, and H. E. Parnaby. 1993. Mammals of particular conservation concern in the Western Division of New South Wales. *Biological Conservation* **65**:219-248.
- Dobson, A. P., J. P. Rodriguez, W. M. Roberts, and D. S. Wilcove. 1997. Geographic distribution of endangered species in the United States. *Science* **275**:550-553.
- Fearnside, P. M., and J. Ferraz. 1995. A conservation gap analysis of Brazil's Amazonian vegetation. *Conservation Biology* **9**:1134-1147.
- Florida Department Environmental Protection. 2005. Florida forever status report—February. Florida Department Environmental Protection, Tallahassee, Florida.
- Florida Fish & Wildlife Conservation Commission. 2004. Florida 2003 landcover classification. Florida Fish & Wildlife Conservation Commission, Tallahassee, Florida.
- Florida Natural Areas Inventory. 2003. Florida Forever/Board of Trustees Environmental Land Acquisition Projects shapefile (FF-BOT). November version. Florida Natural Areas Inventory, Tallahassee, Florida.
- Florida Natural Areas Inventory. 2004. Florida managed areas shapefile (FLMA). March version. Florida Natural Areas Inventory, Tallahassee, Florida.
- Friedman, S., B. M. Stith, and J. W. Fitzpatrick. 1993. Lake Wales Ridge (a map). Page 36 in F. E. Lohrer and D. Cummings, editors. *Archbold Biological Station 50th anniversary biennial report, 1991-1992*. Archbold Biological Station, Lake Placid, Florida.
- Gaston, K. J. 1991. How large is a species' geographic range? *Oikos* **61**:434-438.
- Gutierrez, D. 2005. Effectiveness of existing reserves in the long-term protection of a regionally rare butterfly. *Conservation Biology* **19**:1586-1597.
- IUCN (World Conservation Union). 2001. IUCN Red List categories and criteria. Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland, and Cambridge, United Kingdom.
- IUCN (World Conservation Union). 2005. Guidelines for using the IUCN Red List categories and criteria. IUCN, Gland, Switzerland.
- Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. *Nature* **405**:243-253.
- Muller, J. W., E. D. Hardin, D. R. Jackson, S. E. Gatewood, and N. Caire. 1988. Summary report on the vascular plants, animals, and plant communities endemic to Florida. Technical report 7. Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program, Tallahassee, Florida.
- Mushinsky, H. R., and E. D. McCoy. 1991. Vertebrate species composition of selected scrub islands on the Lake Wales Ridge of central Florida. Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program, Tallahassee, Florida.
- NatureServe. 2002. Element occurrence data standard (February 6). NatureServe, Arlington, Virginia.
- O'Grady, J. J., M. A. Burgman, D. A. Keith, L. L. Master, S. J. Andelman, B. W. Brook, G. A. Hammerson, T. Regan, and R. Frankham. 2004. Correlations among extinction risks assessed by different systems of threatened species categorization. *Conservation Biology* **18**:1624-1635.
- Pressey, R. L., and K. H. Taffs. 2001. Sampling of land types by protected areas: three measures of effectiveness applied to western New South Wales. *Biological Conservation* **101**:105-117.
- Pressey, R. L., R. M. Cowling, and M. Rouget. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. *Biological Conservation* **112**:99-127.

- Pressey, R. L., G. L. Whish, T. W. Barrett, and M. E. Watts. 2002. Effectiveness of protected areas in northeastern New South Wales: recent trends in six measures. *Biological Conservation* **106**:57–69.
- Rodrigues, A. S., R. Tratt, B. D. Wheeler, and K. J. Gaston. 1999. The performance of existing networks of conservation areas in representing biodiversity. *Proceedings of the Royal Society London B* **266**:1453–1460.
- Rodrigues, A. S. L., et al. 2004. Global gap analysis: priority regions for expanding the global protected-area network. *BioScience* **54**:1092–1100.
- Rodrigues, A. S. L., J. D. Pilgrim, J. F. Lamoreux, M. Hoffman, and T. M. Brooks. 2006. The value of the IUCN Red List for conservation. *Trends in Ecology & Evolution* **21**:71–76.
- Saterson, K. A., N. L. Christensen, R. B. Jackson, R. A. Kramer, S. L. Pimm, M. D. Smith, and J. B. Wiener. 2004. Disconnects in evaluating the relative effectiveness of conservation strategies. *Conservation Biology* **18**:597–599.
- Scott, J. M. et al. 1993. Gap analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs* **123**.
- Stem, C., R. Margoluis, N. Salafsky, and M. Brown. 2005. Monitoring and evaluation in conservation: a review of trends and approaches. *Conservation Biology* **19**:295–309.
- Turner, W.R., D.S. Wilcove, and H.M. Swain. 2006. State of the Scrub: conservation progress, management responsibilities, and land acquisition priorities for imperiled species of Florida's Lake Wales Ridge. Archbold Biological Station, Lake Placid, Florida.
- U.S. Fish and Wildlife Service. 1993. Proposed establishment of Lake Wales Ridge National Wildlife Refuge. U.S. Fish and Wildlife Service, Atlanta.
- U.S. Fish and Wildlife Service. 1999. South Florida multi-species recovery plan. U.S. Fish and Wildlife Service, Atlanta.
- U.S. Fish and Wildlife Service. 2003. Draft revised recovery plan for the Florida Scrub-Jay. U.S. Fish and Wildlife Service, Atlanta.
- Weekley, C. W., S. I. Hamzé, R. L. Pickert, and E. S. Menges. 2001. GPS/GIS mapping of federally-listed scrub plants of the Lake Wales Ridge in Highlands County, Florida. Final report to US Fish and Wildlife Service. Archbold Biological Station, Lake Placid, Florida.
- White, W. A. 1970. The geomorphology of the Florida peninsula. Bureau of Geology, Florida Department of Natural Resources, Tallahassee, Florida.

