Assessment of South Atlantic Landscape Conservation Cooperative Terrestrial Indicators

Final Report
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Prepared for the South Atlantic Landscape Conservation Cooperative by:

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Introduction

The South Atlantic Landscape Conservation Cooperative (SALCC) is leading a conservation design initiative that incorporates expert knowledge and a synthesis of data resources to develop a Conservation Blueprint. The Blueprint is intended to highlight opportunities for members to achieve conservation objectives. Diverse data resources exist to map patterns of species distribution, resource availability, ecological function, and other information about landscape gradients that are also associated with cultural and natural resource value. With this project, we evaluated such data resources to support SALCC's development of landscape indicators for the Conservation Blueprint. We delivered to SALCC data visualizations of positive or negative spatial associations to inform indicator evaluation (i.e., not to reach conclusions regarding ecological drivers and relationships). The assumption is that the indicators are all aimed at a singular ecological integrity, therefore they should be positively associated. As indicator development was (and is) an ongoing, adaptive learning process, all the results referenced in this report have already been received by SALCC, reviewed by the technical committees, and applied to indicator development. Thus, the primary purpose of this report is to compile the delivered graphs and tables into a single document as a permanent record of the comparisons considered.

At the initiation of this project, SALCC provided two lists. The first list identified a set of candidate indicators (hereafter, primary indicators). These indicators were the terrestrial data products expected to best guide landscape-scale, long-term natural resource conservation planning and to monitor the success of the plan as it is implemented. Selected through regional workshops and expert elicitation, SALCC hypothesized these indicators would broadly represent the critical ecosystem processes and components necessary to ensure the ecological integrity of the natural resources. The second list identified a variety of additional data resources (hereafter, second tier indicators) that had been 1) proposed by workshop participants but not selected as candidate indicators for this stage of the Blueprint development and/or 2) were deemed to be important enough stand-alone conservation elements that they could serve as a valuable tool to test out the validity of the first tier indicators. SALCC desired to know whether the candidate primary indicators adequately represented the information expressed by the secondary, non-candidate data resources.

SALCC sought a rapid assessment of proposed indicators to facilitate discussions and decisions regarding effective versus ineffective indicators. SALCC defined effective primary indicators as those that spatially represent the majority of known ecosystem components (e.g., species) and/or processes as portrayed by the second tier indicators. We visually examined patterns of spatial overlap among data layers proposed to serve as primary and secondary indicators. Importantly, for this rapid assessment we did not test for correlations (which require more rigorous data modeling procedures) but rather produced exploratory data visualizations of the percent special overlap. High performing primary indicators, those with strong spatial overlap suggestive of positive correlations were identified as potentially effective indicators. Once identified, effective indicators could be targeted by SALCC partners for more rigorous data modeling, increased monitoring effort in support of adaptive management, or directed research to better understand mechanisms behind observed patterns. Low performing primary indicators and redundant secondary indicators could be recommended for removal from the Blueprint design. Indictors deemed ineffective via these visual assessments may warrant further scientific investigation.

Methods

For each ecosystem type independently, and for the landscape overall, we compared proposed indicator metrics against a variety of alternative metrics. In each case, SALCC provided a prioritized list of requested comparisons and in all cases we completed their full list. Comparison results provided insight into whether selected primary indicator metrics effectively captured (overlapped) sites identified as important by the secondary metrics. In cases of strong overlap, SALCC interpreted the indicator as a strong surrogate for the excluded metric. In cases of weak or zero overlap, we explored whether the differences resulted from the two metrics presenting distinct ecological information, using distinct mathematical or statistical models, or using distinct geographic data sets (different time periods, spatial scales, etc.). Most of these discussions were informal and exploratory among SALCC, NatureServe, and NCSU staff with hypotheses, conclusions, and recommendations passed on to the SALCC indicator team for consideration. In many cases, review of these indicator test data resulted in revision of the primary indicator set, as noted below.

This final report (1) documents the metrics and their associated data sources, (2) presents the comparison figures used in our discussions, and (3) summarizes observed comparative relationships. Definitions for several metrics are provided (Table 1) and a full list of secondary indicators considered for this project is available in Appendix 1. We do not offer conclusions or recommendations regarding the selection of specific metrics as indicators because these discussions were internal to SALCC and applications will be described in the forthcoming Conservation Blueprint report. Also, following principles of lean product design, this round of indicator assessment offers graphical and tabular results for visual assessment. Formal statistical analyses are anticipated in later stages, when final targets and metrics have been defined by SALCC partners and when the range of available data resources have been explored sufficiently to prioritize which resources warrant detailed statistical analyses.

Table 1. Definitions of select secondary indicator data resources. All other data layers had intuitive names (e.g., sea turtle nest density) and are defined when introduced through the text.

Indicator	Definition
Carolina Vegetation Survey	One of the most comprehensive plant-based ecosystem surveys in the USA. Composed of data from vegetation plots across North Carolina and South Carolina and compiled by a team of academics and volunteers.
Coefficient of Conservatism	A measure of vegetation that attempts to identify areas containing large numbers of species that require very specific and rare habitat and disturbance regimes.
Element Occurrences	Areas of land and/or water where a species is, or was, present, and which has practical conservation value.
Landscape Condition	An index that attempts to capture the degree of human alteration of the landscape.
Rarity-weighted Richness	A measure that attempts to identify areas of high species rarity and endemism.
Resilient Biodiversity Hotspots	A metric that evaluates landscape diversity and local connectedness to highlight areas where species are more likely to be able to move and adjust to changing conditions.

Results

Landscapes

We evaluated combinations of eight potential indicators (Table 2 & Figures 1-4). The four potential primary indicators (low road density, Resilient Biodiversity Hotspots, National register of Historic Places, and structural connectivity) showed a mixed performance relative to the four secondary indicators (rarity-weighted richness, landscape condition, percent cover of invasive exotics, and the Coefficient of Conservatism). Low road density areas related positively to all the secondary indicators. With one exception, all comparisons with the Resilient Biodiversity Hotspots also showed positive relationships; we observed no relationship between the hotspots and the percent cover of invasive exotics. Not surprisingly, the National Register of Historic Places related negatively (percent invasive exotics, Coefficient of Conservatism) or showed no relationship (rarity-weighted richness, landscape condition) with the four primary indicator metrics. Most historic places are managed for their cultural rather than their natural value and many occur in urbanized settings. Finally, while structural connectivity related positively to rarity-weighted richness and Coefficient of Conservatism, we observed no relationship between this landscape indicator and either landscape condition or percent of invasive exotics.

Table 2. Indicators for the whole landscape analysis.

Primary Indicator	Secondary Indicator	Results
Low road density areas	Rarity-weighted richness	Positive
	Landscape condition	Positive
	Percent cover of invasive exotics	Positive
	Coefficient of conservatism	Positive
Resilient biodiversity hotspots	Rarity-weighted richness	Positive
	Landscape condition	Positive
	Percent cover of invasive exotics	Neutral
	Coefficient of conservatism	Positive
National register of historic places	Rarity-weighted richness	Neutral
	Landscape condition	Neutral
	Percent cover of invasive exotics	Negative
	Coefficient of conservatism	Negative
Structural connectivity	Rarity-weighted richness	Neutral
	Landscape condition	Positive
	Percent cover of invasive exotics	Neutral
	Coefficient of conservatism	Positive

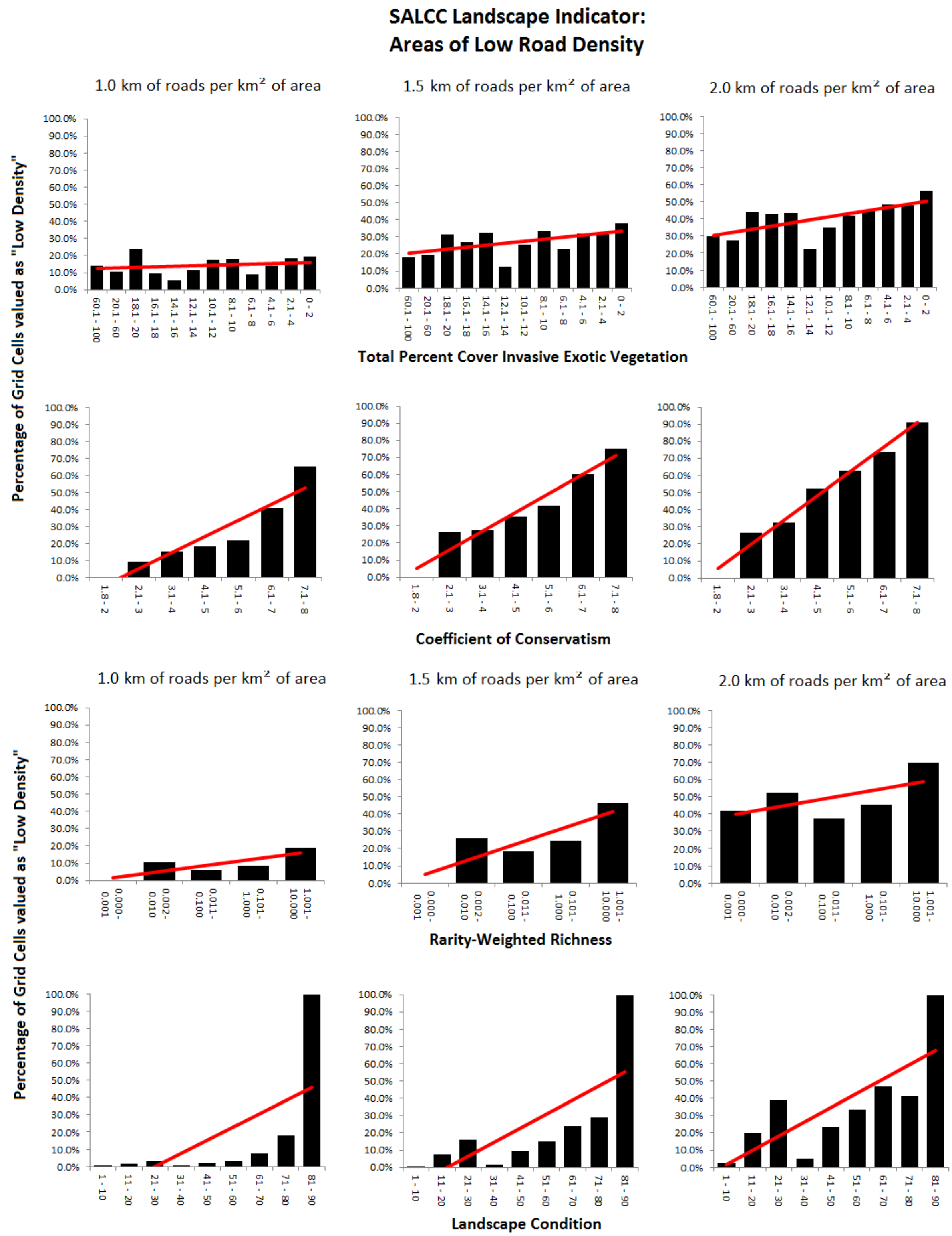

Figure 1. Evaluation of the primary indicator: Low Road Density Areas. Three different road density values were considered as the threshold for low versus high road density.

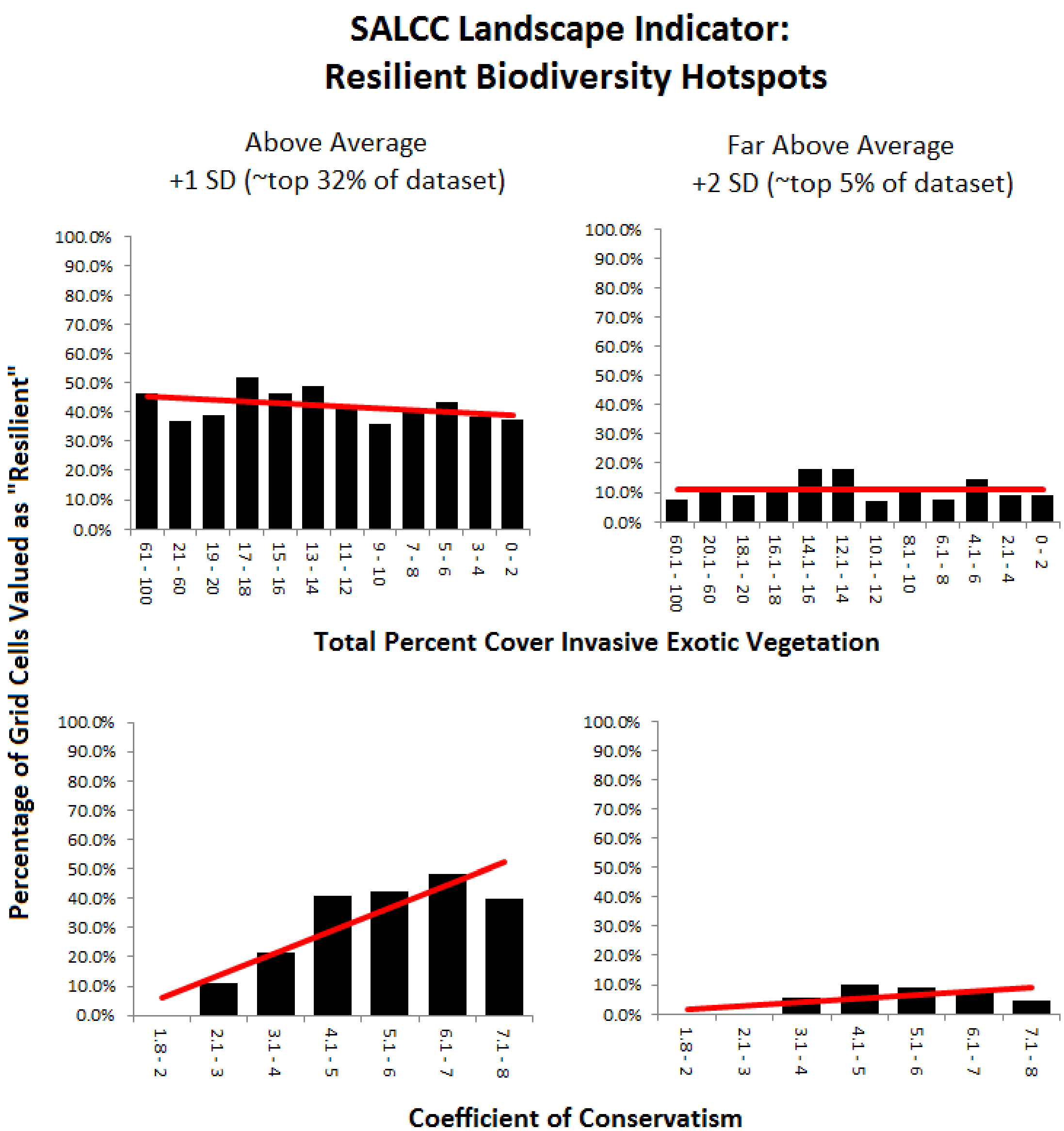

Figure 2A. Evaluation of the primary indicator: Resilient Biodiversity Hotspots. Two different resiliency values were considered as the threshold for low versus high resilience.

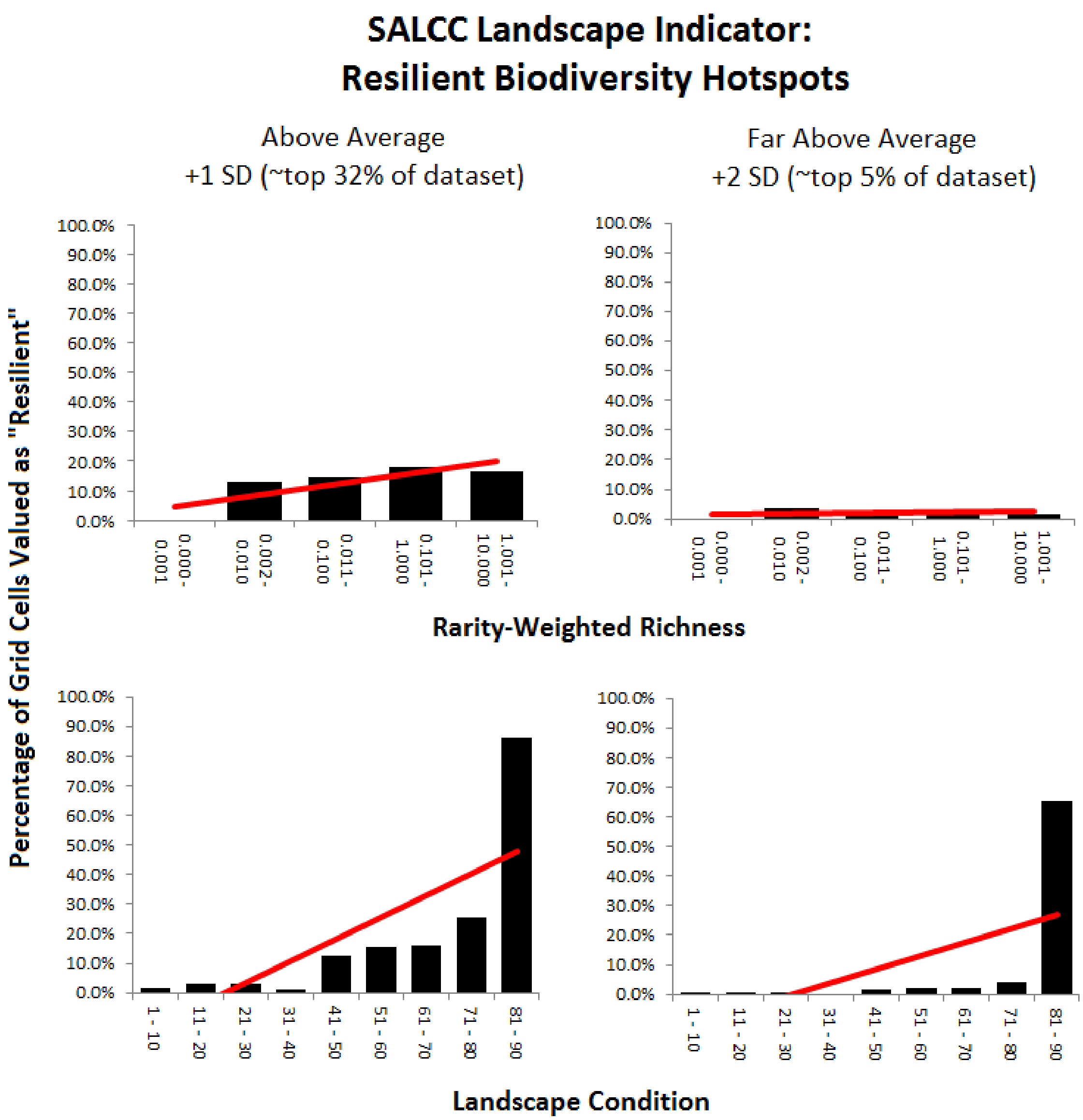

Figure 2B. Continuation of the evaluation of the primary indicator: Biodiversity Resilient Hotspots.

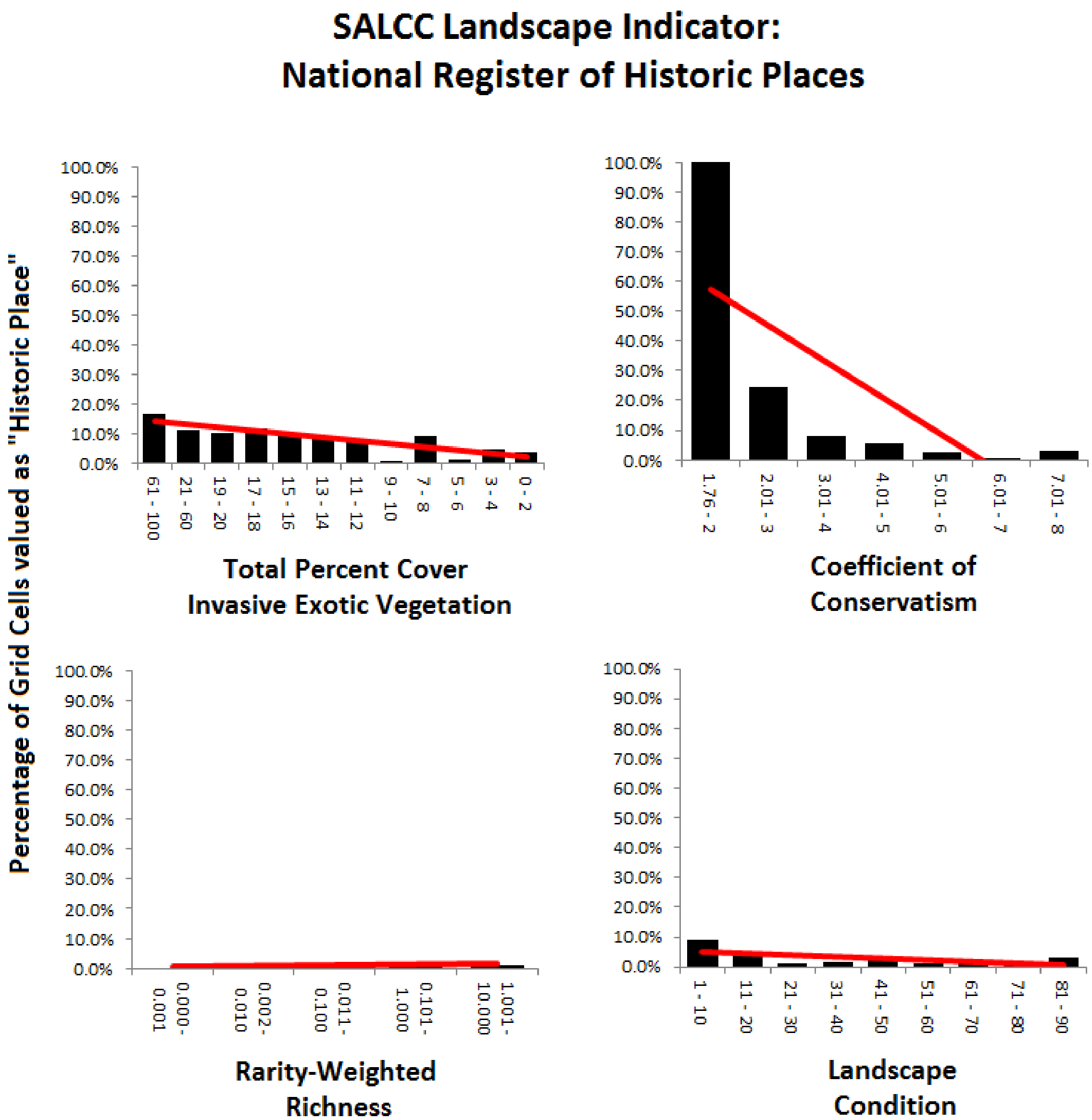

Figure 3. Evaluation of the primary indicator: National Register of Historic Places.

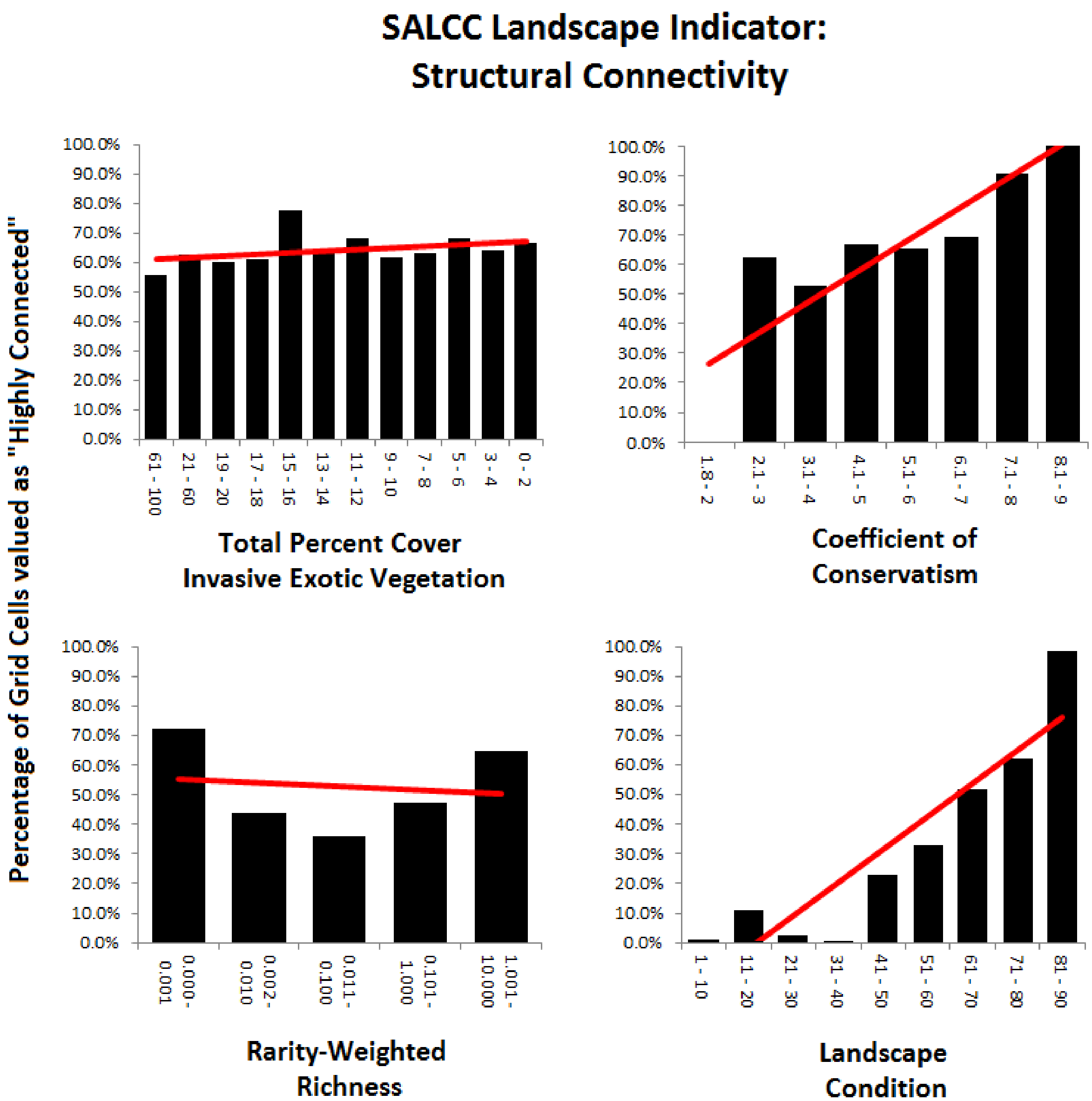

Figure 4. Evaluation of the primary indicator: Structural Connectivity.

Beaches and Dunes

We evaluated combinations of eleven primary and secondary indicators for beach and dune ecosystems (Table 3 & Figures 5-8). The primary indicators for this ecosystem changed on multiple occasions over the course of indicator analysis and Blueprint design. The dynamic, linear nature of this coastal ecosystem, species-specific issues, and the intensive human management of both natural and developed beaches impacted the ability of some potential indicators to distinguish high versus low conservation value lands. The original set of primary indicators were (1) productivity of loggerhead sea turtles (*Caretta caretta*), (2) miles of altered beach, and (3) index of beach birds. Following analyses, proposed primary indicators included (1) beach width and (2) index of beach birds. After external review and further revisions, final indicators for beaches and dunes were (1) miles of altered beach and (2) index of beach birds.

The poor performance of the sea turtle data as an indicator for other natural resources was at first surprising. Sea turtle nesting density was negatively related to the beach bird index, negatively related to beach width, and showed no relationship to sea oat (*Uniola paniculata*) density. Three factors likely contributed to the unexpected negative and neutral relationships with other indicators of habitat quality. First, there is a strong north-south gradient in sea turtle density with higher nesting density in the southern part of the SALCC region. Turtle density performed better as an indicator in the southern half of the region than the northern half. Such strong geographic gradients reduce the value of sea turtle data as regional indicators for SALCC. Second, sea turtles are highly managed by natural resource managers. Common examples include the relocation of nests (by the 1,000's), predator trapping, and the use of predator exclusion devices. Third, several sea turtle biologists noted the species' high site fidelity probably makes them a poor indicator of current conditions of beaches. We concluded that sea turtle nest density failed to adequately account for high ecosystem integrity.

Some important dune and beach plant species have highly variable population abundance and distribution, in part due to patterns of disturbance (e.g., hurricanes) and the species' response to such disturbance (some species need previous catastrophic disturbance, for instance). We examined, but rejected, data for sea beach amaranth (*Amaranthus pumilus*) because it was too coarse and too variable. We were able to examine data for percent cover of beach/dune vegetation as a class and density of sea oats as a species of interest. We found a positive relationship between beach width and sea oat density, but no relationship between beach width and percent cover by beach/dune vegetation. Beach/dune vegetation was also negatively related to beach bird index. None of the beach/dune Carolina Vegetation Survey (CVS) plots fell in the Resilient Biodiversity Hotspot areas for this ecosystem, so no relationship could be determined for this indicator.

Just as the beach width indicator provided a mixed relationship to potential vegetation indicators, we also found mixed relationships with other potential indicators. Beach width was positively related to the beach bird index and the distance to urban land cover. However, the widest beaches also exhibited a higher erosion class, thus resulting in a negative relationship. Overall, the results demonstrate the challenges of selecting indicators in highly dynamic and highly managed systems.

Table 3. Indicators for the beaches and dunes ecosystem analysis.

Primary Indicator	Secondary Indicator	Results
Beach width	Bird index	Positive
	Sea turtle nest density	Negative
	Distance to urban land cover	Positive
	Sea oats density	Positive
	Beach/Dune vegetation cover	Negative
	Erosion class	Negative
Resilient biodiversity hotspots	Beach/Dune vegetation cover	Not Enough Data
Bird index	Sea turtle nest density	Neutral
	Sea oats density	Positive
	Beach Width	Positive
	Beach/Dune vegetation cover	Negative
Piping plover abundance	Oystercatcher occurrence	Neutral
	Wilson's plover occurrence	Positive
Piping plover presence	Oystercatcher occurrence	Negative
	Wilson's plover occurrence	Neutral
Sea turtle nesting	Bird index	Negative
	Sea oats density	Neutral

Scientific names of species: Sea oats, *Uniola paniculata*; Piping plover, *Charadrius melodus*; Oystercatcher, *Haematopus palliates;* Wilson's plover, *Charadrius wilsonia*.

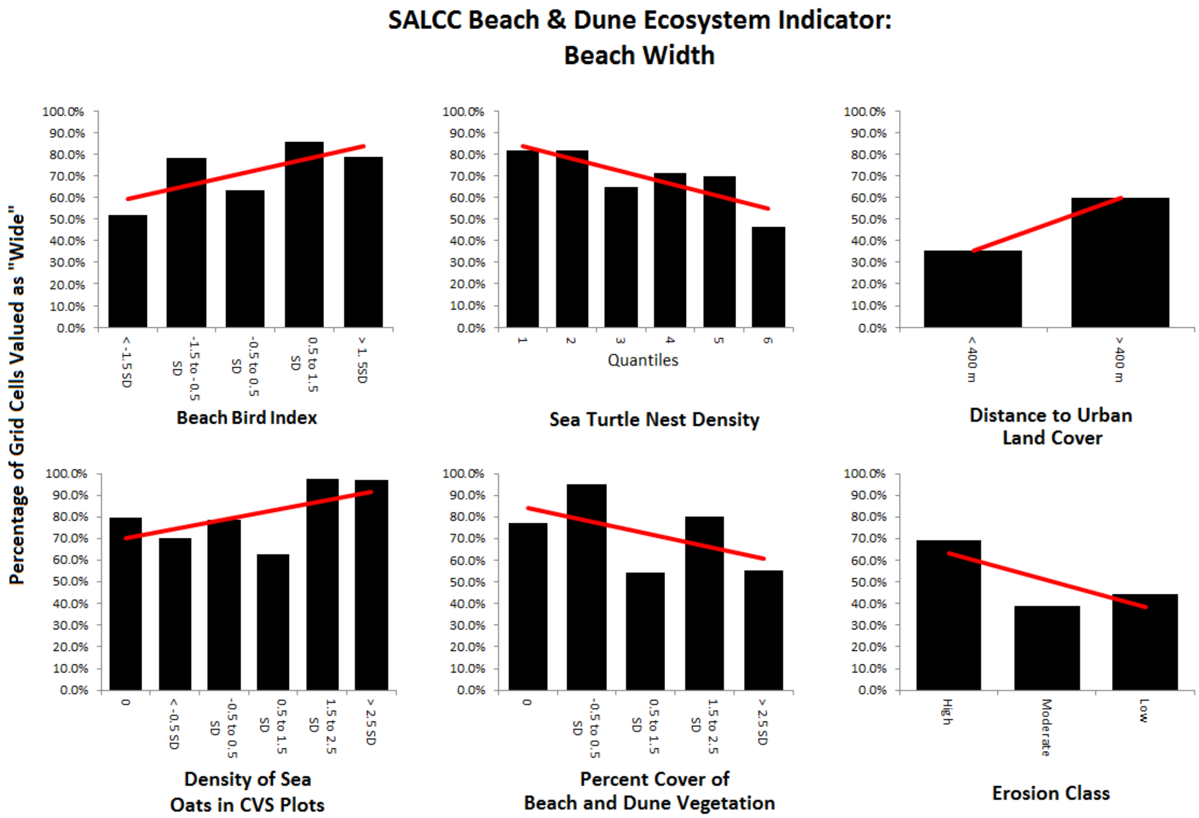

Figure 5. Evaluation of the primary indicator: Beach Width

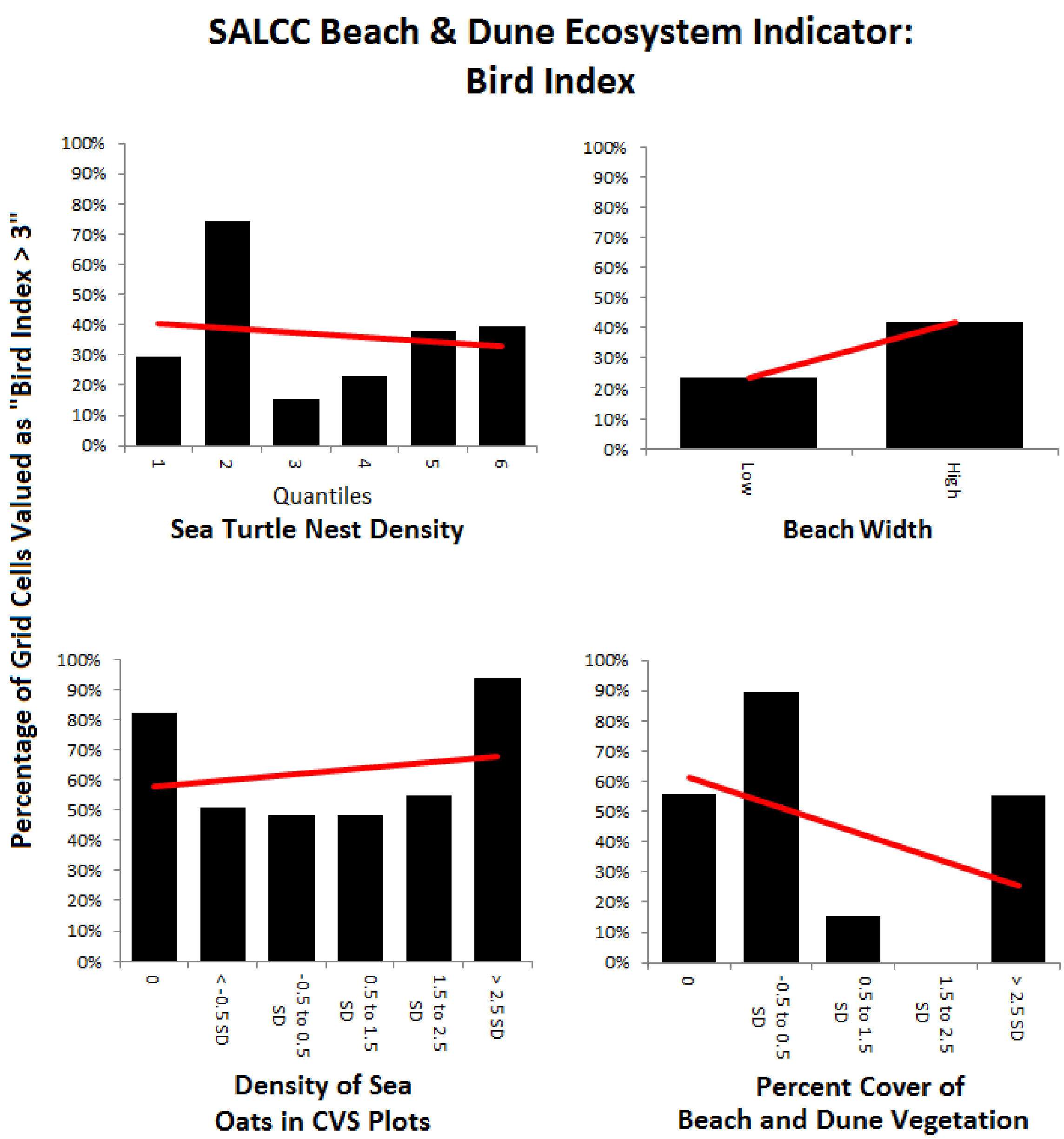

Figure 6. Evaluation of the primary indicator: Beach and Dune Bird Index.

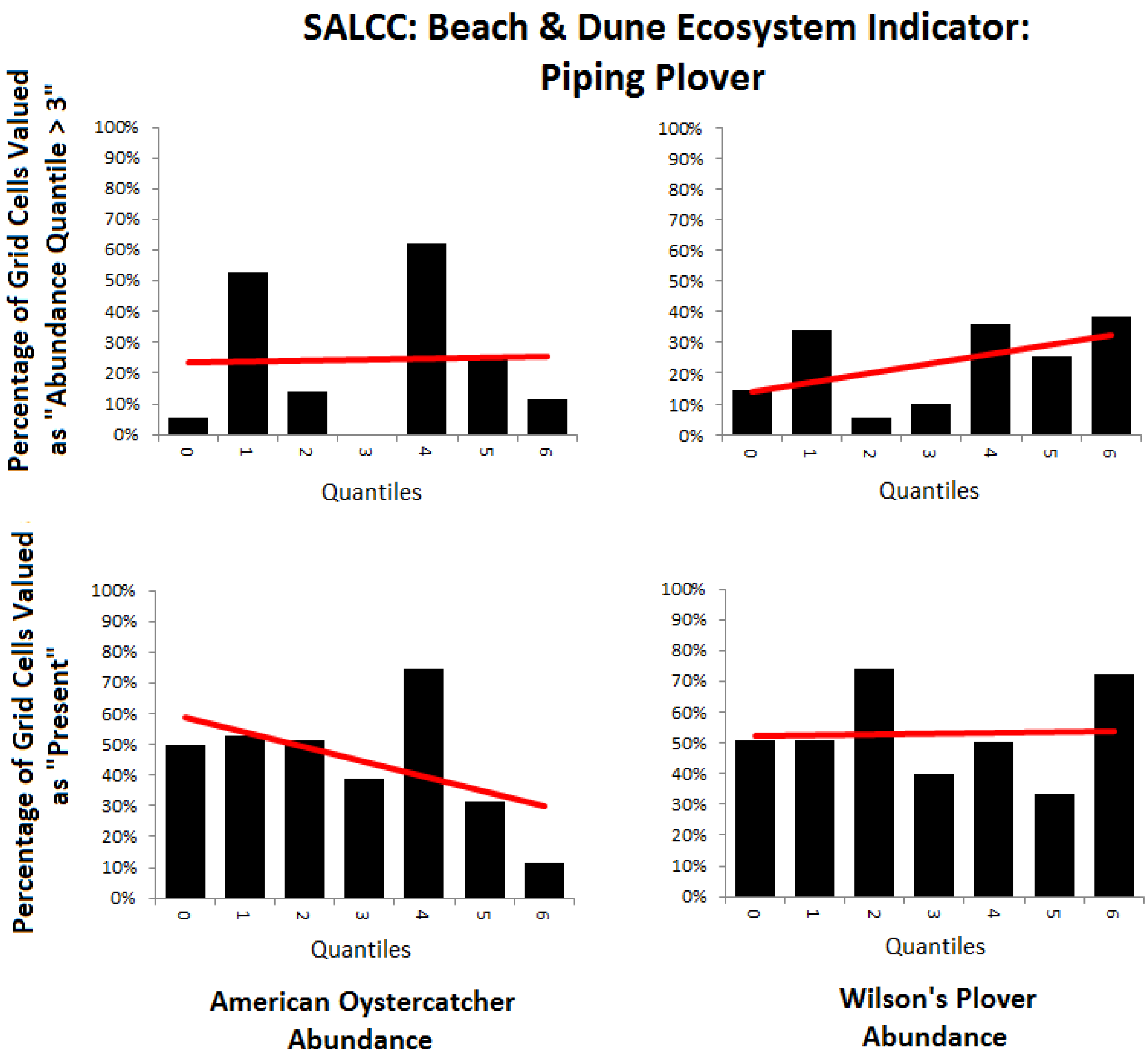

Figure 7. Evaluation of the primary indicators: Piping Plover Presence and Abundance.

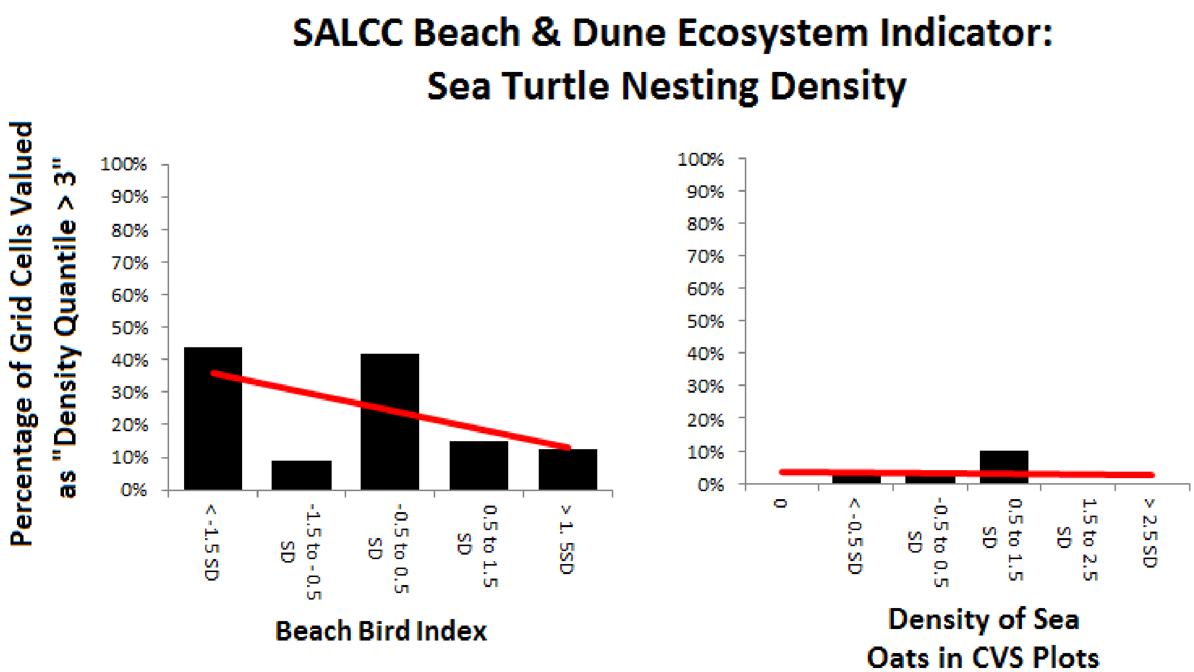

Figure 8. Evaluation of the primary indicator: Sea Turtle Nesting Density.

Maritime Forests

We evaluated combinations of five potential indicators (Table 4 & Figure 9). Maritime forest is a rare ecosystem, and ultimately, acres of maritime forest was selected as the primary indicator. Of the original proposed primary indicators, abundance of painted bunting was not retained and acres in protected status was revised to acres of maritime forest. We observed positive relationships between the maritime forest areas classified as Resilient Biodiversity Hotspots and four secondary indicators: presence of large live oaks (*Quercus virginiana*), circumference of large live oaks, forest areas classified as high quality, and abundance of painted bunting (*Passerina ciris*).

Table 4. Indicators for the maritime forest ecosystem analysis.

Primary Indicator	Secondary Indicator	Results
Resilient biodiversity hotspots	Maritime forest	Positive
	Large live oak circumference	Positive
	Large live oak presence	Positive
	Painted bunting	Positive

Scientific names of species: Live oaks, *Quercus virginiana*; Painted bunting, *Passerina ciris*.

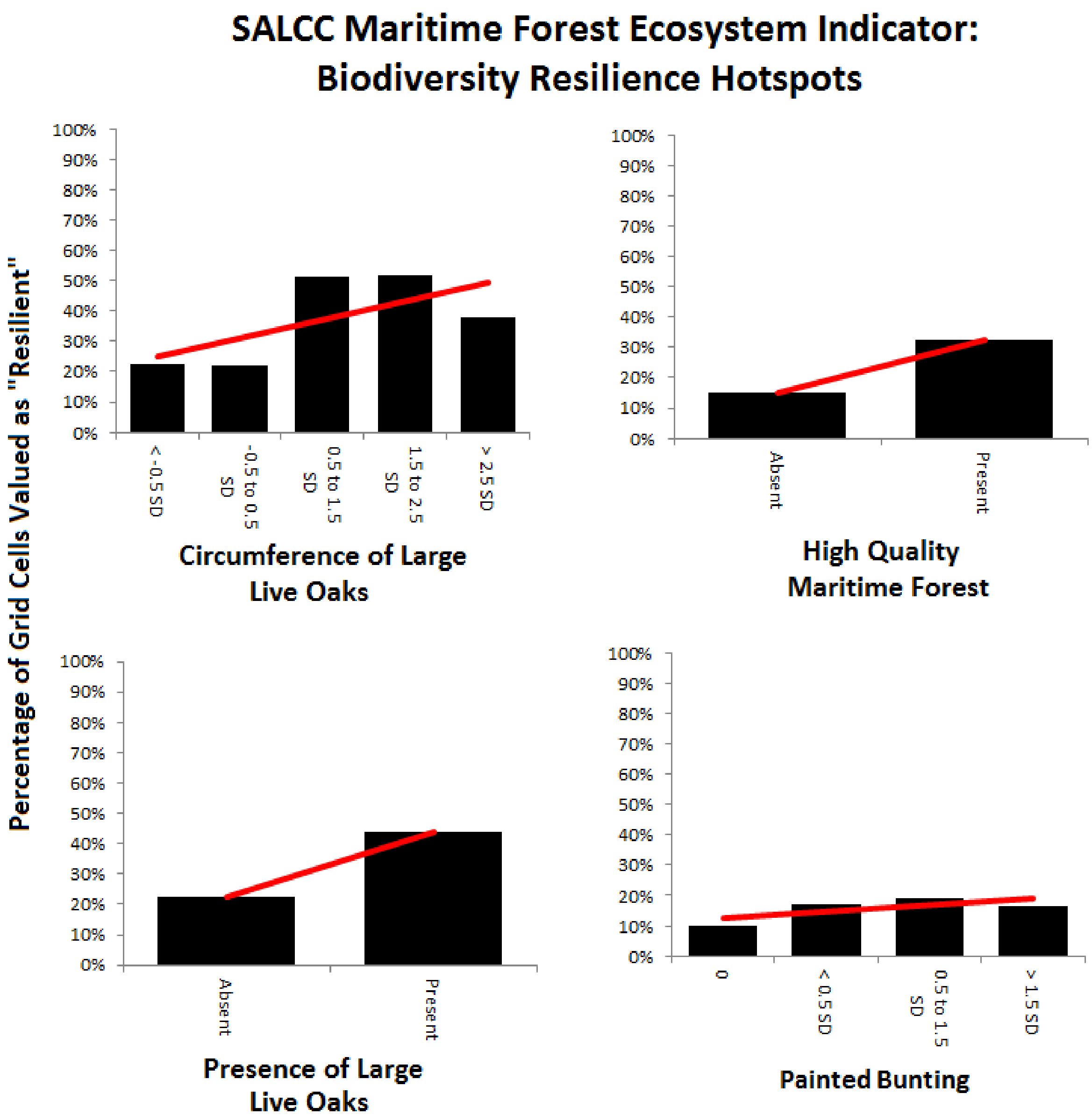

Figure 9. Evaluation of the primary indicator: Resilient Biodiversity Hotspots

Tidal and Non-tidal Freshwater Marshes

We evaluated combinations of four potential indicators (Table 5 & Figure 10). The original proposed set of primary indicators for this ecosystem were: (1) index of marsh birds, (2) acres of marsh, and (3) acres of invasive species. Unfortunately, SALCC and NatureServe determined that the data for invasive species occurrences are not comprehensive enough at this time to serve as a regional indicator. Thus, we only tested the first two primary indicators. Both primary indicators showed a negative relationship with vegetative quality, as measured by the plant guild core area rank from the NC Natural Heritage Program. These same floristic guild data showed a neutral relationship with the Resilient Biodiversity Hotspots.

Table 5. Indicators for the tidal and non-tidal freshwater marsh analysis.

Primary Indicator	Secondary Indicator	Results
Bird index	Plant guild core area rank	Negative
Resilient biodiversity hotspots	Plant guild core area rank	Neutral
Freshwater marsh area	Plant guild core area rank	Negative

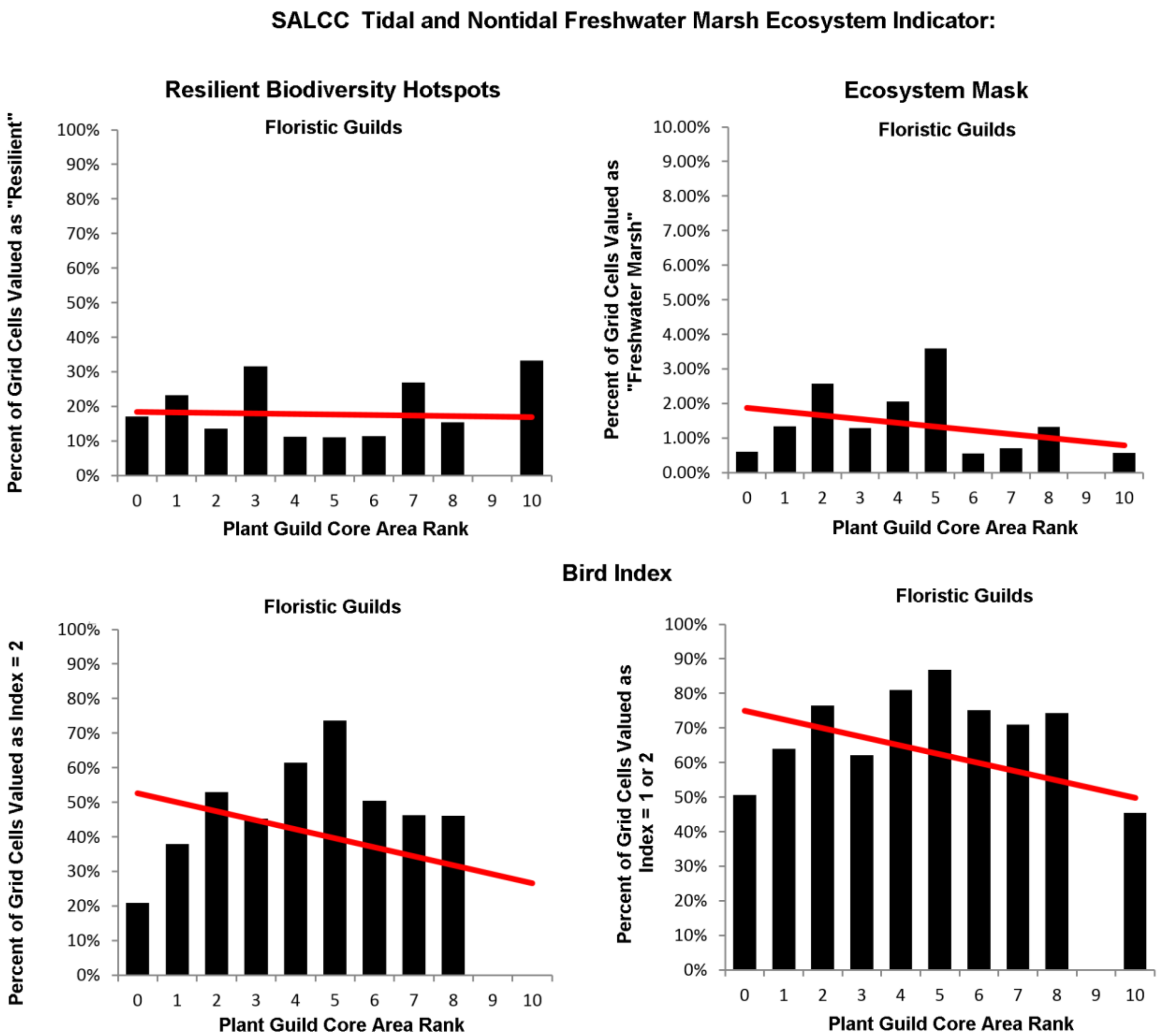

Figure 10. Evaluation of the primary indicators: Resilient Biodiversity Hotspots, Freshwater Marsh Area (Ecosystem Mask), and Marsh Bird Index. The Marsh Bird Index was evaluated for two threshold values.

Forested Wetlands

We evaluated combinations of nine potential indicators (Table 6 & Figures 11-12). The original set of primary indicators were (1) acres of forested wetlands, (2) forested wetland bird index, and (3) acres of natural habitat near isolated wetlands. Through the course of this analysis and other work by SALCC, the first two proposed indicators were retained, but the third was replaced by a forested wetland amphibian index.

The bird index offered mixed results in comparisons with secondary indicators. While we found a positive relationship with largest tree diameter, the relationship with the quadratic mean diameter was neutral. Similarly, the relationship between the bird index and occurrence of Rafinesque big-eared bats (*Corynorhinus rafinesquii*) was inconclusive; a strong positive response for bird index values 0-2 was followed by a strongly negative relationship from bird index values 2-3. Similarly, forested wetlands classified as Resilient Biodiversity Hotspots demonstrated positive relationships with the percent of natural vegetation in Carolina Bays and the Coefficient of Conservatism. Data for individual amphibian species (e.g., tiger salamanders, *Ambystoma tigrinum*) were insufficient to test against the proposed indicators because there were not enough occurrences documented in the natural heritage database.

Table 6. Indicators for the forested wetland analysis.

Primary Indicator	**Secondary Indicator**	**Results**
Bird Index	Rafinesque big-eared bats	Mixed
	Largest diameter tree	Positive
	Quadratic mean diameter of large trees	Neutral
Resilient biodiversity hotspots	Natural Carolina bays	Positive
	Tiger salamanders	Not Enough Data
	Coefficient of Conservatism	Positive
Amphibian Index	Tiger salamanders	Not Enough Data

Scientific names of species: Rafinesque big-eared bats, *Corynorhinus rafinesquii*; Tiger salamanders, *Ambystoma tigrinum*.

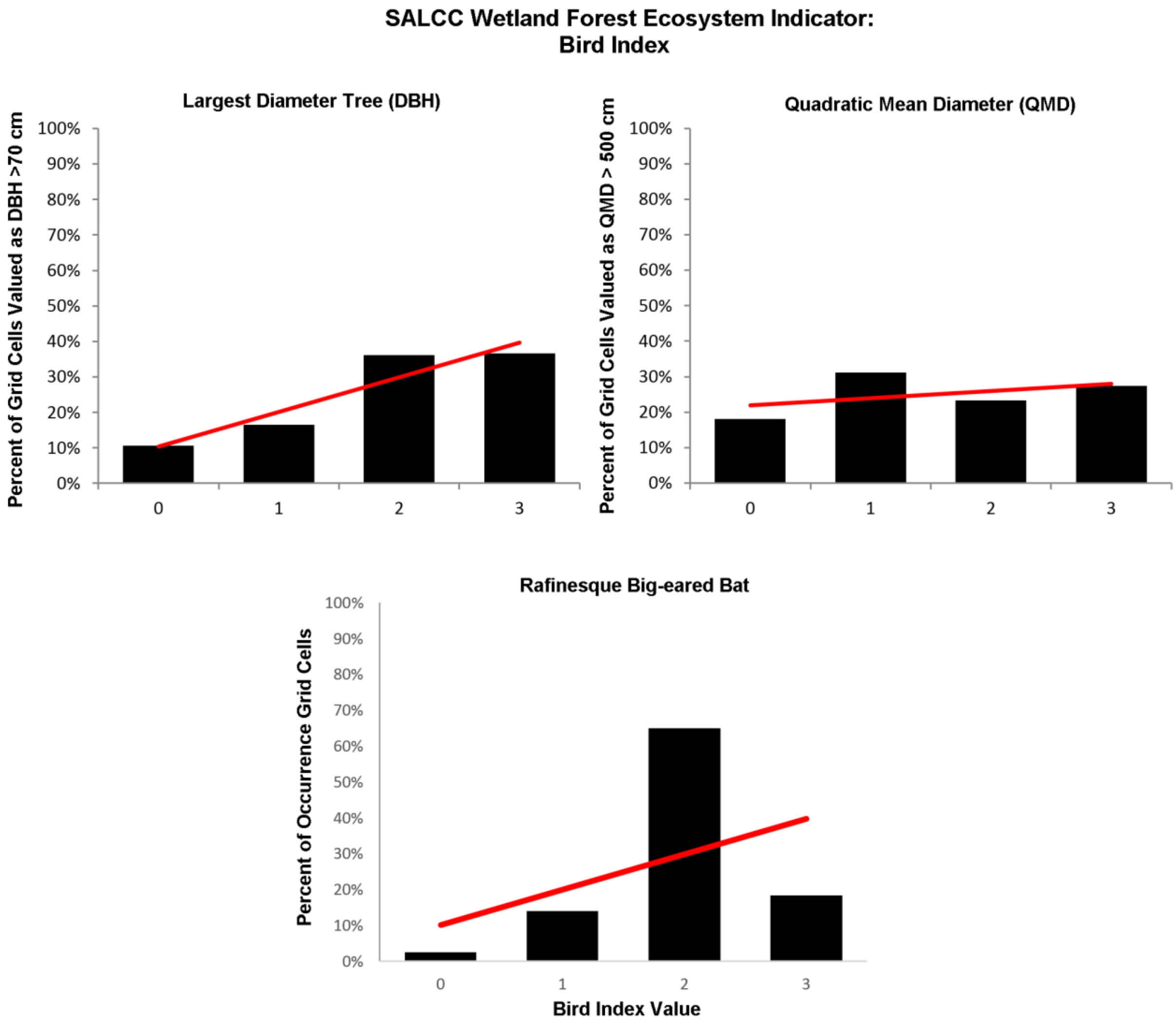

Figure 11. Evaluation of the primary indicator: Forested Wetland Bird Index

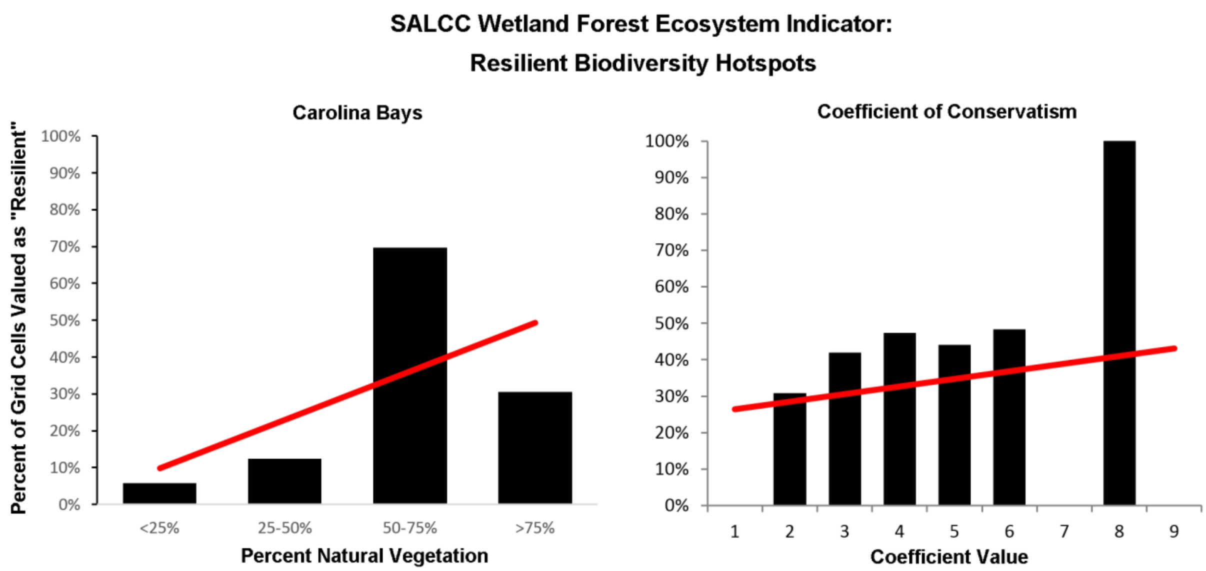

Figure 12. Evaluation of the primary indicator: Resilient Biodiversity Hotspots

Pine woodlands, savannas, and prairies

We evaluated combinations of nine potential indicators (Table 7 & Figure 13-15). The original set of primary indicators were (1) pine bird index, (2) acres of open, regularly burned habitat, and (3) occurrence of flatwoods salamander *(Ambystoma cingulatum*). Data for flatwoods salamander proved insufficient to serve as a regional indicator due to lack of occurrence data, so this indicator was replaced by an amphibian index. SALCC streamlined the bird index for this ecosystem, and the index represented Bachman's Sparrow (*Peucaea aestivalis*), Northern Bobwhite (*Colinus virginianus*), and Red-cockaded Woodpecker (*Leuconotopicus borealis*) (see documentation on SALCC website).

We evaluated four proposed ecosystem indicators (bird index, low density road areas, open and recently burned canopy, and resilient biodiversity hotspots) in relation to Element Occurrence data for five potential species indicators (gopher frog (*Rana capito*), gopher tortoise (*Gopherus polyphemus*), tiger salamander, oak toad (*Anaxyrus quercicus*), and indigo snake (*Drymarchon couperi*). Of these five species, data for tiger salamander and oak toad were too sparse for analysis. Relationships between Element Occurrence data and ecosystem indicators were mixed and complex. The bird index related positively with occurrence of gopher frog, but negatively with occurrence of gopher tortoise and indigo snake. Areas of open canopy and regular burning related positively with both gopher frog and gopher tortoise. However, pine habitat classified as resilient biodiversity hotspots related negatively with gopher frog occurrence. The patterns of positive and negative relationships prompted discussion of the importance of capturing both wet and dry habitats, characteristics of various pine communities (e.g., pine flatwoods, longleaf pine savanna), overall importance of fire and open pine habitat, and interpretation of resilient biodiversity hotspots. These factors should be considered with future testing and revision of the primary indicators.

Table 7. Indicators for the pine woodlands, savannas, and prairies analysis.

Primary Indicator	Secondary Indicator	Results
Bird index	Gopher frog occurrence	Positive
	Gopher tortoise occurrence	Negative
	Indigo snake occurrences	Negative
Low density road areas	Gopher frog, Tiger salamander, and Oak toad occurrence	Not Enough Data
Open canopy & recently burned	Gopher frog occurrence	Positive
	Gopher tortoise occurrence	Positive
Resilient biodiversity hotspots	Gopher frog occurrence	Negative
	Tiger salamander occurrence	Not Enough Data

Scientific names of species: Gopher frog, *Rana capita*; Gopher tortoise, *Gopherus polyphemus*; Tiger salamanders, *Ambystoma tigrinum*; Oak toad, *Anaxyrus quercicus*.

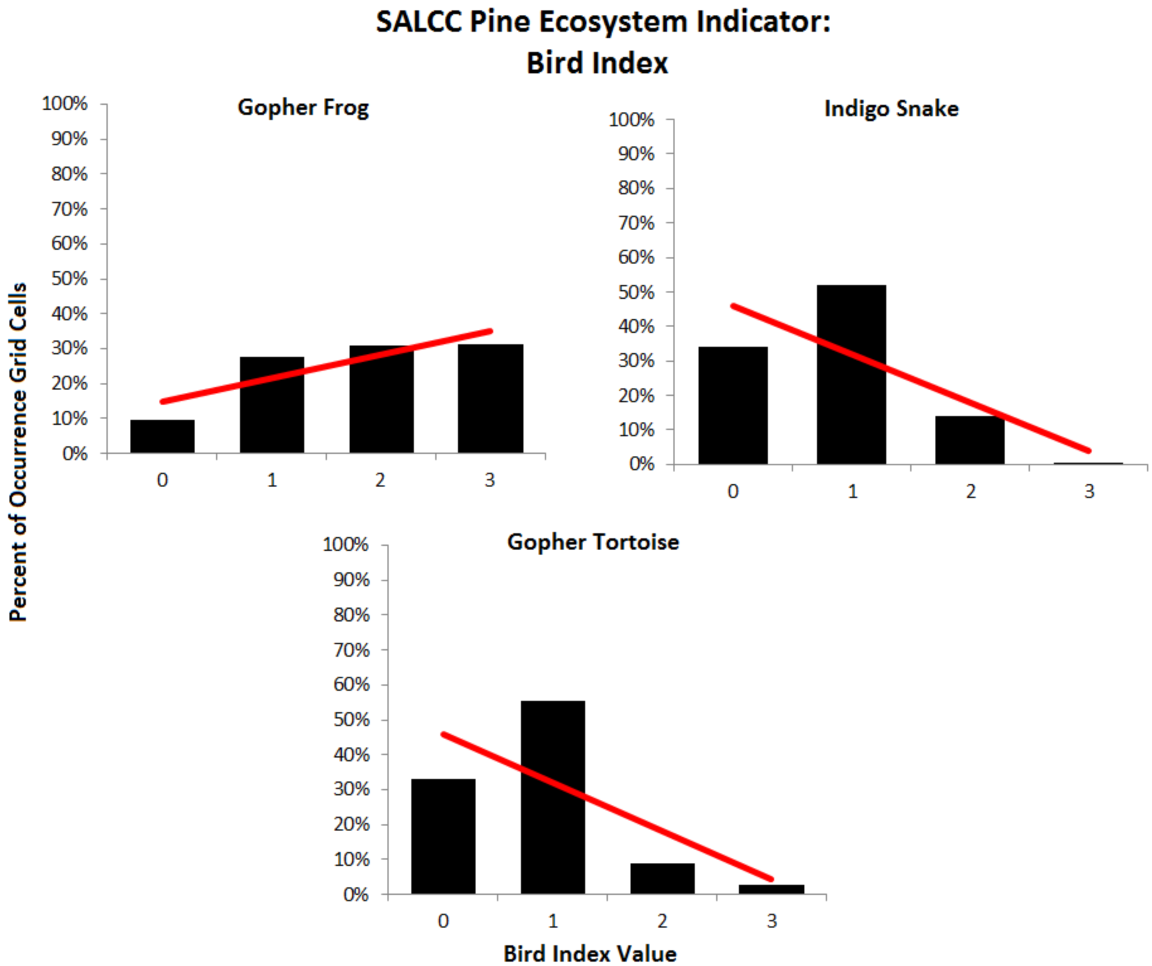

Figure 13. Evaluation of the primary indicator: Pine Bird Index

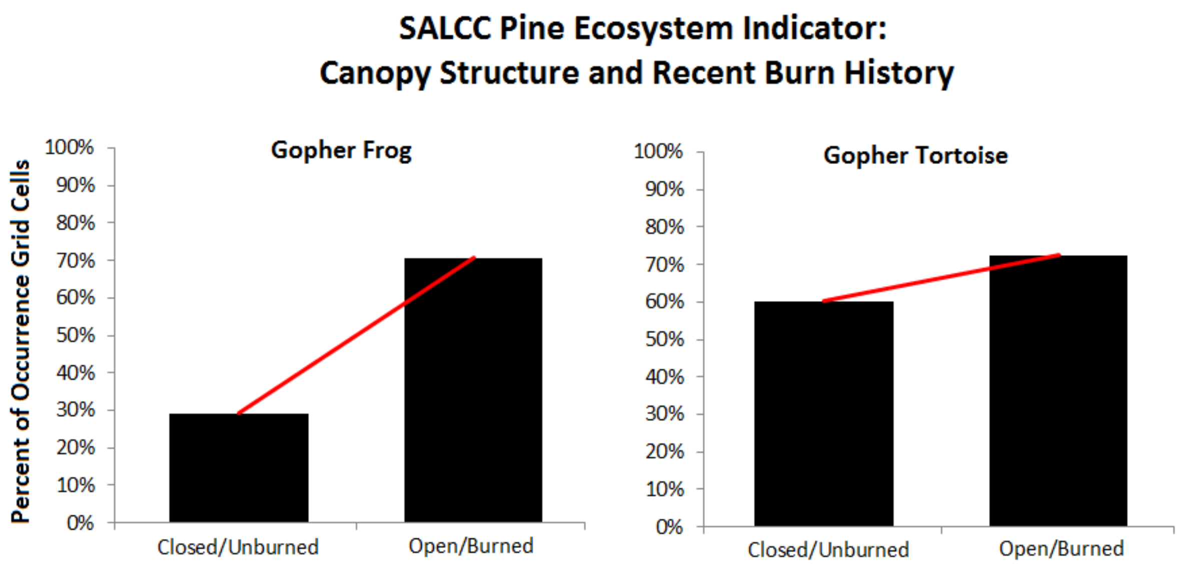

Figure 14. Evaluation of the primary indicator: Canopy Structure and Recent Burn History

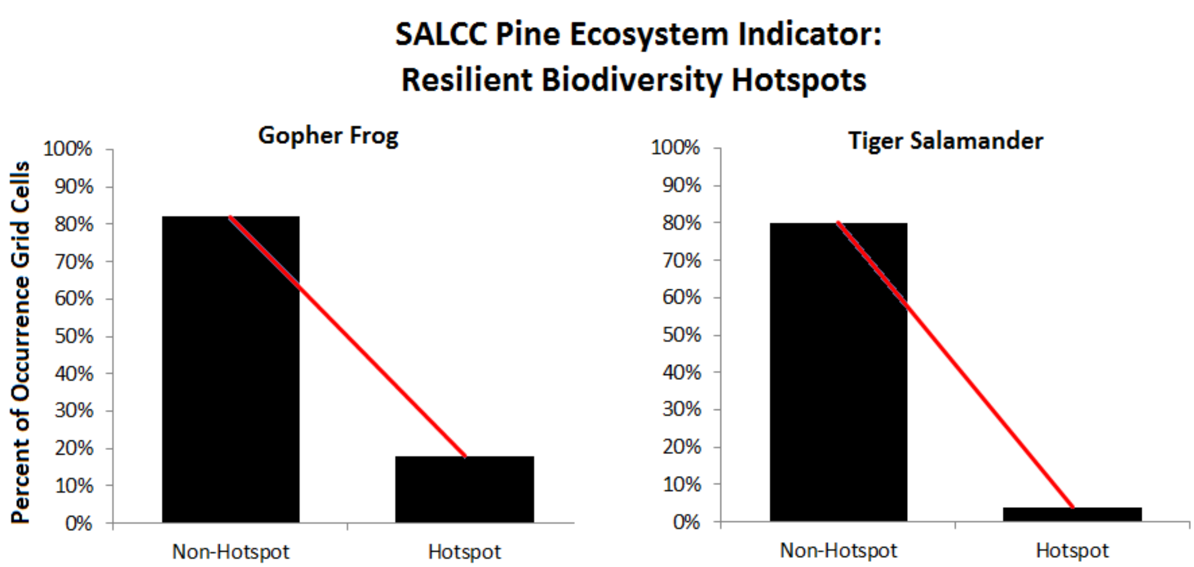

Figure 15. Evaluation of the primary indicator: Resilient Biodiversity Hotspots

Upland hardwood forests

We evaluated combinations of eight potential indicators (Table 8 & Figure 16-18). The primary indicators for this ecosystem changed over the course of indicator analysis and Blueprint design. The original set of primary indicators were (1) acres of biodiversity hotspots in natural condition, (2) abundance of big trees, and (3) upland hardwood bird index. Analysis showed that these indicators missed many of the rare plant occurrences, likely due to the fact that many rare plants in this ecosystem have very specific natural disturbance and light requirements. Natural disturbance (and man-made disturbances that mimic natural disturbance) in this system is limited and often occurs in small areas such as road and power line right-of-ways and that will not qualify as "high quality" under our original primary indicators. The abundance of big trees indicator could not be readily obtained by SALCC given restraints on available spatial data. The final set of primary indicators included the bird index and the biodiversity hotspot indicators, but substituted an urban open space index for the large trees metric. However, as we could not find a way to capture the rare plant species within any of the proposed primary metrics, additional research and development is needed.

The bird index and the largest tree diameter metric were positively associated. Given the restraints on spatial data of large trees for the region, the association may be enough to consider large trees well represented through the use of other indicators. The relationship between the bird index and the quadratic mean diameter (QMD) of forested plots was less clear. The smallest QMD classes showed no relationship to the bird index, the large (300-500 cm) size class showed a slight positive relationship, but the largest (>500 cm) size class showed a slight negative relationship.

The Resilient Biodiversity Hotspot indicator related positively to tree size (both largest tree diameter and quadratic mean diameter) and the Coefficient of Conservatism. However, as mentioned previously, this metric related negatively to the occurrence of rare plants. Rare plant observations occurred with greater frequency in non-hotspot locations. We observed a similar negative relationship between road density and rare plants.

Table 8. Indicators for the upland hardwoods analysis.

Primary Indicator	Secondary Indicator	Results
Bird index	Large diameter trees	Positive
	Quadratic mean diameter	Mixed
Resilient biodiversity hotspots	Coefficient of conservatism	Positive
	Rare plant occurrence	Negative
	Tiger salamander occurrence	Not Enough Data
	Large diameter trees	Positive
	Quadratic mean diameter	Positive
Low road density areas	Rare plant occurrence	Negative

Scientific names of species: Tiger salamander, *Ambystoma tigrinum.*

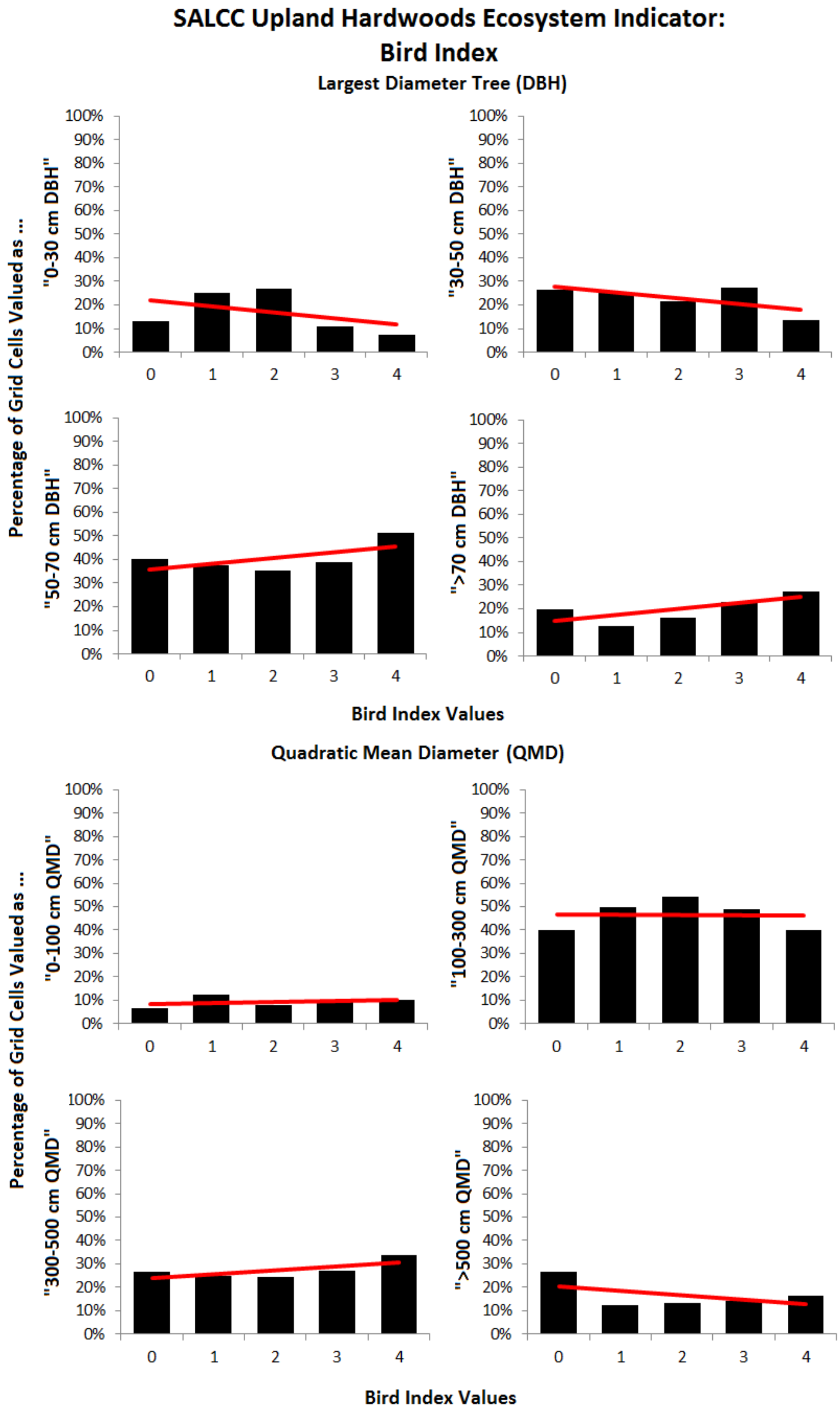

Figure 16. Evaluation of the primary indicator: Upland Hardwood Bird Index.

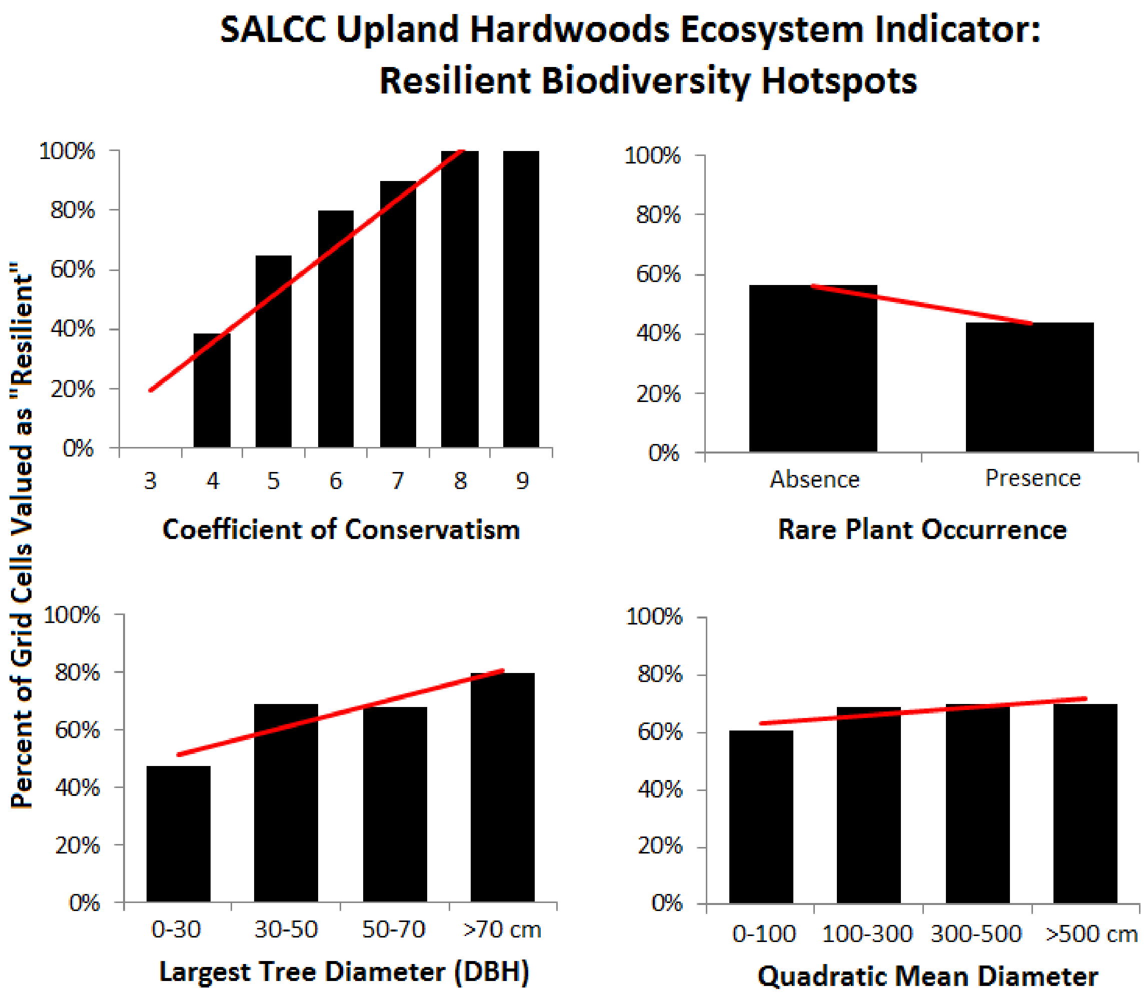

Figure 17. Evaluation of the primary indicator: Resilient Biodiversity Hotspots.

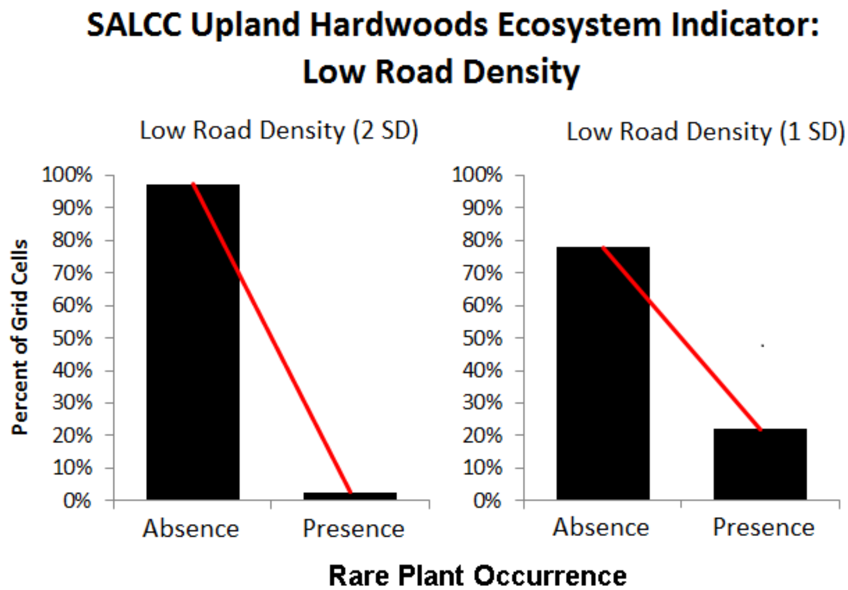

Figure 18. Evaluation of the primary indicator: Low Road Density. Two threshold values for road density were evaluated.

Conclusions

Working one ecosystem type at a time, we provided all of the data outlined above and the associated tables and figures to the SALCC for review and discussion by the technical committees. We made no recommendations regarding data interpretation or indicator value; such conclusions were left solely to the SALCC members. We did provide input in the form of questions about data thresholds, data resolution, and other data quality factors pertinent to the SALCC's interpretation of the results. These data allowed the SALCC to assess performance of the terrestrial indicators for their ability to capture other spatial ecosystem components (species and habitats), processes (fire, freshwater flow), and threats (land use change, climate change, and sea level rise). As highlighted above, these data when combined with other ongoing discussions and data review by SALCC, resulted in multiple updates and improvements to the terrestrial indicators.

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