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Diversity of terrestrial avifauna in response to distance from the shoreline of the Salton Sea

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Abstract

Large aquatic bodies influence surrounding terrestrial ecosystems by providing water and nutrients. In arid landscapes, the increased primary productivity that results may greatly enhance vertebrate biodiversity. The Salton Sea, a large saline lake in the Colorado Desert of southern California, provides nutrients in the form of hundreds of thousands of dead fish carcasses, brine flies, and chemical compounds through windborne salt sea spray. We performed point counts for landbirds and shorebirds monthly or every other month between March 2001 and February 2002 across a sampling grid of 35 points along the west edge of Salton Sea. We found that avian diversity (numbers of species and numbers per species) was dependent on proximity to the Sea. Diversity was at a maximum nearest the shore, and was significantly lower away from the Sea's edge, at all surveyed distances up to 1 km from the shore. Cover by the dominant shrubs on the study site also corresponded to proximity to the water's edge. Whereas one may hypothesize that the avian diversity patterns are caused by these differences in vegetation structure, our data did not support this. Future studies should further investigate this potential correlation between vegetation and bird patterns. Until more is understood about the relationship between elevated avian diversity and the physical environment of the land-shore interface, our results suggest that the Sea's surface be stabilized near its present level. Future management schemes at the Salton Sea that include reductions of water sources should be carefully analyzed, so as to not jeopardize the terrestrial avifauna at this unique ecosystem.

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Keywords: Alkali sink; Allochthonous input; Bottom-up process; Colorado Desert; Land-sea interface; Point count; Vegetation cover

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1. Introduction and literature

Large aquatic bodies influence surrounding terrestrial ecosystems by providing water and nutrients (Polis et al., 1997). In some cases, such as along the Nile, Amazon, and other seasonally flooding rivers, periodic or episodic overflows provide major influxes of organic matter to terrestrial plants. Wind is a major importer of nutrients in some systems (e.g., snow fields, caves, and kipukas; Swan, 1963; Howarth, 1979; Edwards, 1987). Carriage of dead aquatic organisms can be an important source of food for land-based animals, and may influence populations well beyond the immediate shoreline (Polis et al., 2002). In arid landscapes, the increased primary productivity that results from aquatically based allochthonous inputs may greatly enhance vertebrate biodiversity (Bornkamm, 1987). Terrestrial ecosystems can also be affected by windborne contaminants originating in lakes.

The Salton Sea is a large (974 km²), saline lake in the Colorado Desert of southeastern California. Salinity levels in the lake are approaching toxic concentrations for the biologically and economically significant resources of the Sea (Shuford et al., 2002). Management options under investigation by policy-makers and scientists range from reducing the salinity through various means to enhance wildlife, recreational, and economic opportunities to allowing the Sea to dry up completely (Shuford et al., 2002). Proposed management options may directly affect the Sea-land interface; specifically, the flow of energy and biomass from a productive aquatic system to a relatively unproductive terrestrial system (Polis et al., 2002).

In a multi-taxa study, the USGS Biological Resources Discipline investigated the effect natural salt water spray from the Sea has on the adjacent terrestrial ecosystem. Reported herein are the results of an investigation of the possible role allochthonous inputs of the Sea may have on landbird and shorebird diversity (which refers to the number of individuals and species, collectively) and distribution. We investigated these patterns within close proximity of the shoreline, in a terrestrial area and habitat type not yet extensively researched at the Sea. We were particularly interested in whether bottom-up dynamics of nutrients from the Sea might explain patterns in landbird and shorebird distributions.

2. Material and methods

2.1. Site and habitat description

The Salton Sea lies in the counties of Riverside and Imperial, in southeastern California (Fig. 1). Our study site was near the south-western corner of the Sea, almost completely within the US Navy's former Salton Sea Test Base. The US Department of Interior's Bureau of Land Management now manages this land. The geographic position of the center of our study site is 33°11'31" N latitude and 115°50'18" W longitude, or 11S 608304mE and 3673168mN in UTM coordinates (WGS84 datum).

The vegetation on this site of extensive alkali sink constitutes primarily Sonoran desert creosote scrub (Redlands Institute, 2002). This community of evergreen, sclerophyllous shrubs is dominated by creosote bush (*Larrea tridentata*) and its common associates alkali goldenbush (*Isocoma acradenia*), and saltbush species (*Atriplex polycarpa* and *A. canescens*). All plant binomials listed herein are from Hickman (1993). Along the shore

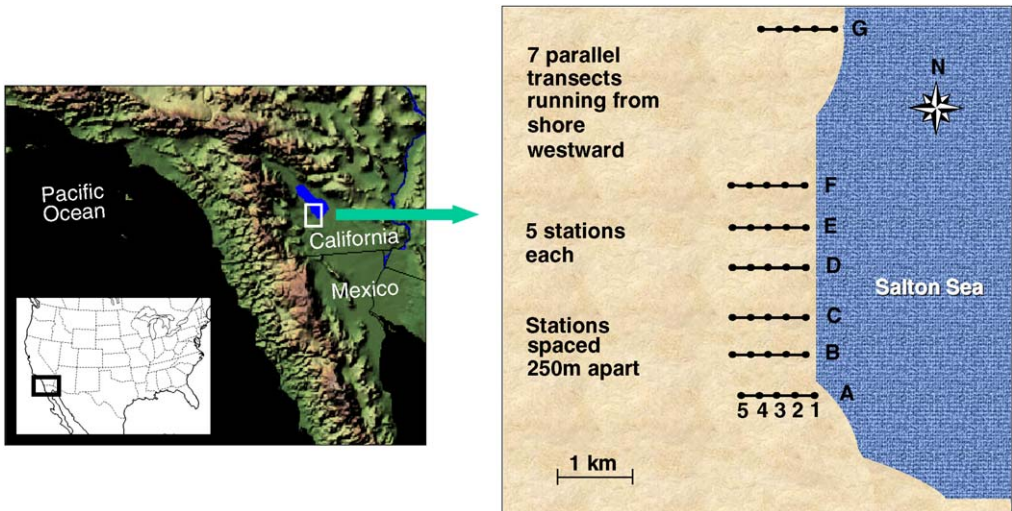


Fig. 1. Study design at site located along the south-western edge of the Salton Sea in southeastern California. Note: transect G is spaced 2 km (vs. 0.8 km distance between other transects) away from the nearest transect because it was intended to serve as a spatial control.

of the study site, greater soil moisture facilitates more lush vegetation than farther away from the water, and for the local dominance of more mesophytic plants, primarily iodine bush (*Allenrolfea occidentalis*) and the introduced salt-cedar, or tamarisk (*Tamarix ramosissima*). The latter species is found as solitary individuals, or quite commonly as well established, long thickets along the shore and washes away from the shore. Honey mesquite (*Prosopis glandulosa*) is a sparsely spaced, but prominent feature mainly in the northern, hardpan region of the site. Common springtime herbs and wildflowers include wild turnip (*Brassica tournefortii*), *Cryptantha* spp., lion-in-a-cage (*Oenothera deltoides*), spanish-needle (*Palafoxia arida*), woolly plantain (*Plantago ovata*), tumbleweed (*Salsola tragus*), and mediterranean grass (*Schismus* spp.). Many of these herbs occur within the site on aeolian sand dunes, which are a significant feature in parts of the study area.

Given that the Navy formerly used the site for support facilities, housing, and live weapons testing, dirt roads traverse the area, and human-made structures (e.g., telephone poles and electrical wiring) and occasional pieces of garbage and shrapnel are present. The Salton Basin receives an average of 63.5 mm (2.5 in) of rain throughout the year, including occasional summer thundershowers. However, rainfall in the basin decreases from the Coachella Valley south to the Imperial Valley, where our study site received a total of 10 mm during the 12 months of this research. Although average temperatures in the winter are quite mild (January low: 3.3 °C, high 21.1 °C), summers bring some of the hottest temperatures in the United States (July low: 23.9 °C, high 41.7 °C) (Redlands Institute, 2002).

2.2. Sampling design

A sampling grid was established along the west edge of the Sea with seven transects running perpendicular to the Sea and five running parallel to it. A grid coverage in

ArcView 3.2 (Environmental Systems Research Institute, 1999), along with USGS digital orthophoto quarter quadrangles for visualization, were used to position sampling points, which were then located in the field, with slight adjustments in a few cases to avoid the risk of the points becoming inundated or mud-covered in the future. The grid was laid out systematically in a block design with distance from the Sea edge being the experimental factor and the lines running perpendicular being the blocking factor to control for spatial variation. The five parallel transects were placed across the gradient of distance from the Sea edge at 250-m intervals beginning approximately 50 m from the water's edge. Six of the perpendicular transects were placed at 800-m intervals from north to south. A seventh was placed approximately 2 km north of the others. Data were collected at each of the 35 sampling points where the transects intersected; each point, or station, was permanently marked by a 26-cm wooden stake with a flag stapled to it. "Distance 1" refers to the seven stations closest (50 m) to the Sea, "Distance 2" the next set of seven stations 250 m farther from the Sea. "Distance 5" refers to the stations farthest (about 1050 m) from the Sea (Fig. 1).

At each of the 35 sampling points, five-minute counts of individuals of each species of landbird or shorebird seen or heard within 100 m of the count station were recorded, following the methods of Ralph et al. (1993). Birds flying overhead ("fly-overs") were noted separately from those on or just above the ground, and were not included in the "total" variables mentioned below. Species that could not be positively identified in the field were recorded to the lowest taxa possible. We did not include as part of these counts waterbirds observed on the immediate shoreline or Sea even if within 100 m of sampling points. The variable, "total individuals," is the number of individuals counted at each sampling point, summed over all visits to that point. "Total species" is the number of unique species observed at each point, summed over all visits to that point.

Counts were performed 15 times at each point count station between March 2001 and February 2002, with a sampling period each month during the spring (March through June) and every other month in other seasons (i.e., August, October, December, and February). During seven sampling periods (all periods excluding the first, March 2001, when just one cycle was completed), we cycled through each of the stations twice. Except for the first two periods (March 2001: 2-day; April 2001: four-day), we counted birds over 5-day sampling periods in the following order: Day 1—Transects A & F; Day 2—C, D & G; Day 3—B & E, F & A; Day 4—G, D & C; and Day 5—E & B. Ordering was arranged giving importance to (1) staying within the recommended daily time period; and (2) pairing transects A–F, B–E, and C–D on the same day. We do not feel that the slight deviation in the order in which transects were visited during March and April 2001, compared to the transect-pairing in visits thereafter, had any impact on the results in this paper. Through the first cycle during each sampling period, points were visited westward along each transect, and eastward for the second cycle. To maximize detection of birds, most counts were conducted during the period between one-half hour before, and 4 hours after sunrise. The mean time of day for all point counts ($n = 525$) was 128.0 ± 87.0 min after sunrise. For each of the five distances from the shoreline ($n = 105$ point counts at each distance), the mean and standard deviation was within 0.6 and 2.5 min, respectively, of the overall mean and standard deviation. To minimize observer bias, only one person, who was experienced in identifying and counting birds, performed all counts.

A variation of a point-intercept vegetation transect (see Elzinga et al., 1998, for examples and further references) was performed at each of the 35 landbird sampling points

to assess cover. A 50-m length of string was centered on the wooden stake at the station being surveyed. Two transects were conducted around each station—one north–south and one east–west. Pre-selected cardinal directions were used to avoid biasing results that may have occurred with measuring vegetation patterns in a non-random fashion. As we walked along each transect, a “hit” was recorded for every time a 1.5-m pole, which was held horizontally and centered over the string, made contact with, crossed directly above, or fell directly underneath vegetation. Each hit was also recorded into one of six species categories (*Larrea tridentata*, *Isocoma acradenia*, *Atriplex* sp., *Allenrolfea occidentalis*, *Tamarix ramosissima*, and “other”) so species-specific cover could be analyzed. The diameter was recorded for all shrub species encountered at that station. To account for natural variation among individual plants, diameter measurements were taken from the three individuals nearest to the stake, for each species. These three diameter readings were then averaged for each species and multiplied by the number of hits for that species. All species-specific products of cover were then summed to yield a measure of overall vegetation cover—the variable “cover index”—at each station. We decided that cover was a descriptive indicator of vegetation structure, since it is frequently correlated with aboveground biomass (Hafner, 1977).

Systat Version 10 (SPSS Inc., 2000) was used for all statistical analyses. The residuals of our bird count and vegetation cover data did not depart significantly from normality (Kolmogorov-Smirnov test), and met constant variance assumptions. Therefore, data were not transformed for analyses except where noted. We performed analysis of variance (ANOVA) tests to detect any differences in the total number of birds and total number of species observed, as well as vegetation cover, with respect to distance from the shoreline. Data from equivalent distances from the shoreline were summed across all visits (just one visit for vegetation cover) and transects were treated as the blocking factor. So, the dependent variables depicted in Fig. 2A–C represent the means across transects. To assess whether vegetation cover played a significant role as a covariate, or interacted with distance from the shore in predicting numbers of total individuals or species, we used an analysis of covariance (ANCOVA). Additionally, we used ANOVA to determine if plant species-specific cover differed with respect to distance from the shore, since this could provide information about any particular bird-plant species associations. Post-hoc Fisher’s least significant difference (LSD) tests and contrast analyses were used to analyze where the differences among distances, if any, lied. Lastly, raw (not averaged) bird point count values were square-root-transformed and plotted against months to display any seasonal trends in diversity, if present.

3. Results

Across the entire study site (land, water, and air), we positively identified 70 species, including data from the point count stations, as well as incidental (observed en route to point count stations) observations. Twenty-four (24; 40%) of these 70 species were observed only as fly-overs above land. Across all visits to all sampling points, 533 individual landbirds and shorebirds of 44 different species were observed (Table 1). We conducted these point counts, which totaled 43.75 h, across an area of close to 5 km². Although counts of avian diversity typically decline further into the morning hours in North American deserts as ambient temperatures quickly rise, the time of day did not have a significant effect on the total number of individuals ($F_{1,23} = 0.69$, $p = 0.414$) or species

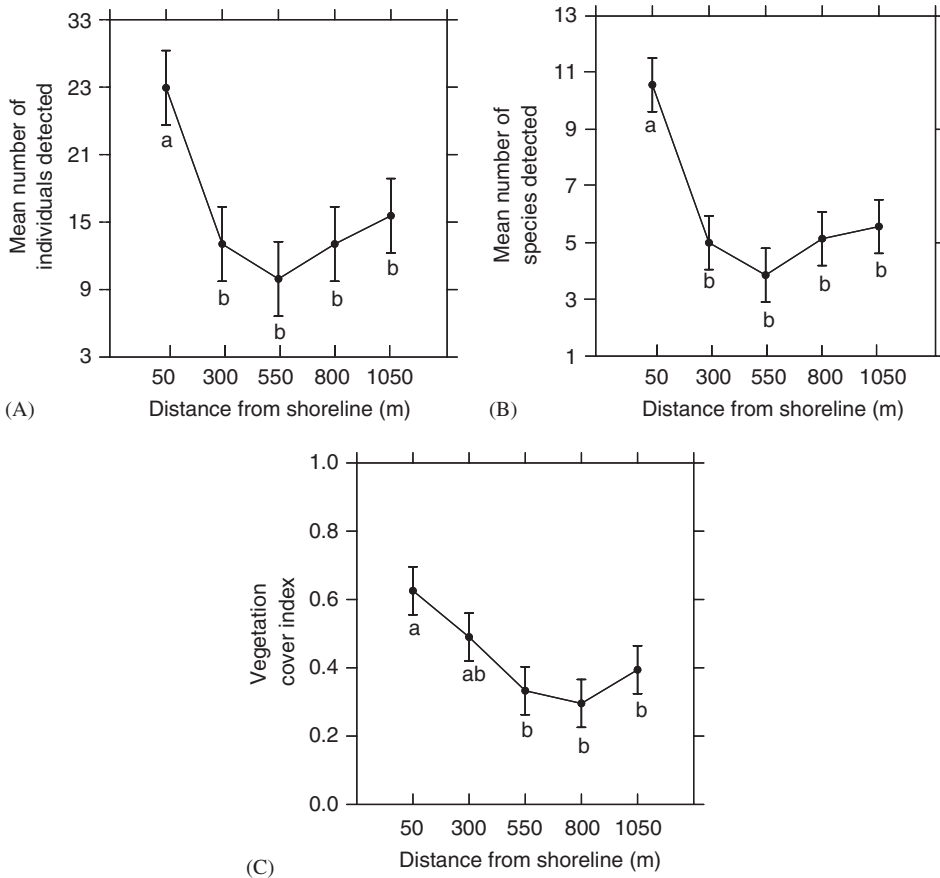


Fig. 2. The number of individuals (A) and species (B) detected differed significantly between Distance 1 (50 m from the shoreline) and all other distances, as shown here with the least squares means (detections were averaged across transects) and standard error bars. Vegetation cover (C) differed significantly between Distance 1 and that at Distances 3, 4 and 5 (550, 800 and 1050 m, respectively, from the shoreline). Cover at Distance 2 (300 m), however, is not different from that at Distances 1, nor 3, 4 and 5. In all panels, group membership from Fisher's LSD signified by the letters "a, b". Note that vertical axes' scales differ among the panels.

($F_{1,23} = 2.92$, $p = 0.101$) in our study, when distance and transect were included in the model.

3.1. Abundance patterns

There was a strong effect of distance from the shoreline on the total number of individuals observed ($F_{4,24} = 3.95$, $p = 0.013$). Distance 1, which included the seven stations closest to the Sea, had a significantly higher number of individual observations (184 birds) than any of the other four distances (Table 1; Fig. 2A). The post-hoc contrast analysis (SS = 1135.14, df = 4) indicated that 90.9% (1031.43, df = 1) of the variance was explained by the differences between the counts at Distance 1 and all others. Number of

Table 1

Totals of each species observed on land during point counts, listed in decreasing order of the number of distances from the shoreline (out of five distances surveyed) at which the species was detected

| Species | | Distance from shoreline (m) | | | | | Total individuals | # Distances observed |
|-----------------------------|--------------------------------|-----------------------------|-----|-----|-----|------|-------------------|----------------------|
| Common name | Scientific name | 50 | 300 | 550 | 800 | 1050 | | |
| Mourning Dove | <i>Zenaida macroura</i> | 8 | 1 | 7 | 4 | 6 | 26 | 5 |
| Say's Phoebe | <i>Sayornis saya</i> | 8 | 7 | 5 | 11 | 6 | 37 | 5 |
| Loggerhead Shrike | <i>Lanius ludovicianus</i> | 13 | 11 | 26 | 5 | 3 | 58 | 5 |
| Verdin | <i>Auriparus flaviceps</i> | 21 | 19 | 8 | 9 | 13 | 70 | 5 |
| Bewick's Wren | <i>Thryomanes bewickii</i> | 4 | 3 | 1 | 1 | 4 | 13 | 5 |
| Sage Sparrow | <i>Amphispiza belli</i> | 7 | 4 | 1 | 2 | 5 | 19 | 5 |
| Lesser Nighthawk | <i>Chordeiles acutipennis</i> | 6 | 10 | 3 | — | 13 | 32 | 4 |
| Northern Flicker | <i>Colaptes auratus</i> | 2 | 1 | — | 1 | 1 | 5 | 4 |
| Blue-gray Gnatcatcher | <i>Polioptila caerulea</i> | 4 | 4 | — | 8 | 15 | 31 | 4 |
| Black-tailed Gnatcatcher | <i>Polioptila melanura</i> | 2 | 1 | — | 2 | 7 | 12 | 4 |
| White-winged Dove | <i>Zenaida asiatica</i> | 1 | 5 | 3 | — | — | 9 | 3 |
| Black Phoebe | <i>Sayornis nigricans</i> | 1 | — | — | 1 | 1 | 3 | 3 |
| Ash-throated Flycatcher | <i>Myiarchus cinerascens</i> | 2 | — | — | 1 | 3 | 6 | 3 |
| Le Conte's Thrasher | <i>Toxostoma lecontei</i> | 3 | 3 | 4 | — | — | 10 | 3 |
| Yellow-rumped Warbler | <i>Dendroica coronata</i> | 14 | — | — | 31 | 11 | 56 | 3 |
| White-crowned Sparrow | <i>Zonotrichia leucophrys</i> | 9 | 2 | — | 1 | — | 12 | 3 |
| Western Meadowlark | <i>Sturnella neglecta</i> | 1 | 11 | 2 | — | — | 14 | 3 |
| Great Blue Heron | <i>Ardea herodias</i> | — | 3 | 1 | — | — | 4 | 2 |
| Rock Pigeon | <i>Columba livia</i> | — | — | — | 7 | 7 | 14 | 2 |
| Western Kingbird | <i>Tyrannus verticalis</i> | 12 | 2 | — | — | — | 14 | 2 |
| Rock Wren | <i>Salpinctes obsoletus</i> | — | — | — | 2 | 1 | 3 | 2 |
| Ruby-crowned Kinglet | <i>Regulus calendula</i> | — | — | — | 1 | 1 | 2 | 2 |
| Black-throated Gray Warbler | <i>Dendroica nigrescens</i> | 2 | — | — | — | 1 | 3 | 2 |
| Wilson's Warbler | <i>Wilsonia pusilla</i> | 3 | — | — | — | 1 | 4 | 2 |
| Northern Harrier | <i>Circus cyaneus</i> | 1 | — | — | — | — | 1 | 1 |
| Snowy Plover | <i>Charadrius alexandrinus</i> | 12 | — | — | — | — | 12 | 1 |
| Killdeer | <i>Charadrius vociferus</i> | 2 | — | — | — | — | 2 | 1 |
| Black-necked Stilt | <i>Himantopus mexicanus</i> | 14 | — | — | — | — | 14 | 1 |

Table 1 (continued)

| Species | | Distance from shoreline (m) | | | | | Total individuals | # Distances observed |
|-------------------------------|-----------------------------------|-----------------------------|-----|-----|-----|------|-------------------|----------------------|
| Common name | Scientific name | 50 | 300 | 550 | 800 | 1050 | | |
| Least Sandpiper | <i>Calidris minutilla</i> | 4 | — | — | — | — | 4 | 1 |
| Greater Roadrunner | <i>Geococcyx californianus</i> | — | — | — | — | 1 | 1 | 1 |
| Short-eared Owl | <i>Asio flammeus</i> | — | — | — | 1 | — | 1 | 1 |
| Common Poorwill | <i>Phalaenoptilus nuttallii</i> | — | — | — | — | 2 | 2 | 1 |
| Common Raven | <i>Corvus corax</i> | — | 1 | — | — | — | 1 | 1 |
| Horned Lark | <i>Eremophila alpestris</i> | — | — | — | — | 2 | 2 | 1 |
| Northern Rough-winged Swallow | <i>Stelgidopteryx serripennis</i> | — | — | 4 | — | — | 4 | 1 |
| Cliff Swallow | <i>Petrochelidon pyrrhonota</i> | — | — | 1 | — | — | 1 | 1 |
| Northern Mockingbird | <i>Mimus polyglottos</i> | — | — | — | — | 1 | 1 | 1 |
| European Starling | <i>Sturnus vulgaris</i> | — | — | — | 1 | — | 1 | 1 |
| Common Yellowthroat | <i>Geothlypis trichas</i> | 11 | — | — | — | — | 11 | 1 |
| Brewer's Sparrow | <i>Spizella breweri</i> | 2 | — | — | — | — | 2 | 1 |
| Savannah Sparrow | <i>Passerculus sandwichensis</i> | — | — | — | — | 1 | 1 | 1 |
| Song Sparrow | <i>Melospiza melodia</i> | 1 | — | — | — | — | 1 | 1 |
| Red-winged Blackbird | <i>Agelaius phoeniceus</i> | 10 | — | — | — | — | 10 | 1 |
| House Finch | <i>Carpodacus mexicanus</i> | 4 | — | — | — | — | 4 | 1 |
| Total individuals | | 184 | 88 | 66 | 89 | 106 | 533 | — |
| Total species | | 30 | 17 | 13 | 18 | 23 | — | — |

Note: Twenty-three (23) other species [ordered phylogenetically: American White Pelican (*Pelecanus erythrorhynchos*), Brown Pelican (*Pelecanus occidentalis*), Double-crested Cormorant (*Phalacrocorax auritus*), Great Egret (*Ardea alba*), Turkey Vulture (*Cathartes aura*), American Kestrel (*Falco sparverius*), Peregrine Falcon (*Falco peregrinus*), American Avocet (*Recurvirostra americana*), Long-billed Curlew (*Numenius americanus*), Western Sandpiper (*Calidris mauri*), Laughing Gull (*Larus atricilla*), Ring-billed Gull (*Larus delawarensis*), California Gull (*Larus californicus*), Herring Gull (*Larus argentatus*), Caspian Tern (*Sterna caspia*), White-throated Swift (*Aeronautes saxatalis*), Purple Martin (*Progne subis*), Tree Swallow (*Tachycineta bicolor*), Barn Swallow (*Hirundo rustica*), Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*), Brewer's Blackbird (*Euphagus cyanocephalus*), Great-tailed Grackle (*Quiscalus mexicanus*), Brown-headed Cowbird (*Molothrus ater*)] were observed only as fly-overs, but observations of these species were made during point counts. Two additional species [Osprey (*Pandion haliaetus*) and Barn Owl (*Tyto alba*)] were observed on land within the study site, and another [Red-tailed Hawk (*Buteo jamaicensis*)] was observed as a fly-over, but these observations were made outside the point counts. All species names (common and scientific) come from American Ornithologists' Union (1998) and Banks et al. (2003).

individuals observed began to rise again at the farthest distance sampled, but the trend was not statistically significant (Fig. 2A).

3.2. Species patterns

There was also a strong effect of distance from the shoreline on the total number of species observed ($F_{4,24} = 7.62$, $p < 0.001$). Distance 1 had a significantly higher number of species observed (30 species total) than any of the other four distances (Table 1; Fig. 2B). The post-hoc contrast analysis (SS = 191.83, df = 4) indicated that 94.1% (180.58, df = 1) of the variance was explained by the differences between Distance 1 and all others. Again, number of species observed at the farthest distance from the shoreline increased from the mid-transect lows, although this also was not a statistically significant trend (Fig. 2B).

Species varied in the breadth of distances from the Sea at which they were found. Of the 44 landbird and shorebird species observed during point counts, six were observed during the counts at all five distances from the shoreline, four species at four of the five distances, seven at three, another seven at two, and 20 species were observed at only one of the five distances (Table 1). Of these latter 20 species, 50% (10 species) were observed at only the stations closest to the shoreline, while 25% (five species) were observed at only the stations farthest from the Sea.

3.3. Vegetation cover patterns

Vegetation cover around each station was sensitive to distance from the shoreline as well ($F_{4,24} = 3.59$, $p = 0.020$). The stations at Distance 1 had significantly more cover than those at Distances 3–5 (Fig. 2C). The post-hoc contrast analysis (SS = 0.494, df = 4) indicated that 69.4% (0.343, df = 1) of the variability among distances was explained by the differences between Distance 1 and all others. The difference between vegetation cover at Distance 1 and that at Distances 2–5 explains less of the overall variability (compared to the patterns seen in total individuals and total species with respect to distance) because cover at Distance 2 is intermediate between Distances 1 and 3–5.

Vegetation cover was not significant as an interaction term with distance with respect to either total individuals or total species ($F_{4,19} = 0.634$, $p = 0.644$; $F_{4,19} = 1.185$, $p = 0.349$, respectively). Neither was vegetation cover significant simply as a covariate with distance with respect to either total individuals or total species ($F_{1,23} = 1.807$, $p = 0.308$; $F_{1,23} = 1.798$, $p = 0.193$, respectively). The only plant species for which cover differed significantly with distance from the shore (when treated as five discrete distances, as in all analyses above) was *Allenrolfea occidentalis* ($F_{4,24} = 2.935$, $p = 0.042$). Fisher's LSD post-hoc analysis revealed that this species had significantly greater cover at Distance 1, compared to both Distances 4 and 5. Cover of *Larrea tridentata* did not vary significantly ($F_{4,24} = 1.970$, $p = 0.131$) across the gradient of distance from the shore, but it appeared to increase sequentially from Distance 1 (median = 0.00) to a maximum at Distance 5 (median = 2.00). If distance from the shore was instead treated as a continuous predictor variable, *Larrea tridentata* cover did indeed vary significantly ($F_{1,27} = 6.589$, $p = 0.016$). However, there was no correlation between vegetation cover and total individuals or total species ($r = 0.104$, $p = 0.552$; $r = 0.015$, $p = 0.934$, respectively).

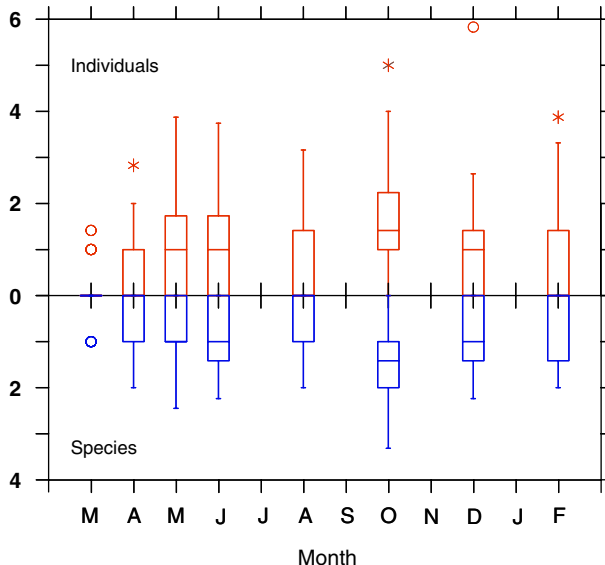


Fig. 3. Despite being low values, the numbers of individuals (top) and species (bottom) observed at a single point count station during any one month followed a very similar pattern, with peaks of median values in late spring and even more so in early fall. In this mirrored box plot, values just outside the interquartile range are plotted with asterisks, whereas values far outside the interquartile range (extreme outliers) are plotted with empty circles. Note that (1) data were square-root-transformed to aid in this visualization, (2) even lower values in March may in part be due to having only one sample period (versus two in other months), and (3) data were not collected during July, September, November, and January.

3.4. Seasonal patterns

Although only 1 year of data was collected, we are presenting the point count data (both variables, total individuals and total species) in terms of seasonal variation. Data were strongly skewed to the right, and extreme outliers were present, so data were square-root-transformed and box plots utilized to show medians, and interquartile and complete ranges within each month. For both variables, we found very similar peaks in early fall and a smaller one in late spring (Fig. 3).

4. Discussion

Spatial patterns in landbird and shorebird diversity—a function of the number of species and number of total individuals—appear to depend on proximity to the shoreline near the south-west edge of the Salton Sea. Patterns of vegetation cover by the dominant plant species at the site are also related to proximity to the Sea's edge. However, our data did not support a correlation between the avian diversity and vegetation cover. Nonetheless, both patterns may be responding to bottom-up causes, if they are sensitive to allochthonous inputs of water and nutrients from the Sea. Water availability is concentrated closest to the shore at our study site. We suspect that this greater soil moisture may allow for elevated levels of primary productivity (particularly in the halophytic *Allenrolfea occidentalis* and

Tamarix ramosissima), and in turn more food—plant stems, leaves, flowers and seeds, as well as insects, and other invertebrates or vertebrates dependent on vegetation cover—and habitat structure for birds. In another study on Sonoran Desert bird communities, water-dependent species increased in areas of greater moisture, such as the human-inhabited areas in and around the city of Tucson, Arizona (Emlen, 1974). Polis et al. (2002, pp. 362–380) also found that vertebrate diversity, including resident and migratory landbirds, was higher closest to the shore along the Sea of Cortés, which begins only 180 km to the south of Salton Sea. They suggested that allochthonous materials, namely organics and nutrients imported into the terrestrial food web by seabirds, increase the abundance of many terrestrial plant and animal species and form the base of a productive food web on coasts and islands.

Intuitively, any reduction of source water to the Salton Sea, which is quite possible with future management schemes (Shuford et al., 2002), will lower the Sea's surface and have potentially serious effects on the distribution and cover of the surrounding vegetation. This speculation of vegetative change has two lines of reasoning. First, greater vegetation cover at the Sea's edge may depend on available ground-water and other edaphic features that are not found farther from the shore. Second, the sea floor that would be exposed if the surface level of the Sea is reduced is saturated with saline sedimentation, likely unsuitable for the propagation of any plant species except for the most extreme halophytes. Therefore, the areas of greatest vegetative cover may be reduced due to loss of water, and may not be soon mitigated in the newly exposed areas immediately next to the water, due to altered substrate conditions.

We are not certain why avian diversity dropped to its lowest values at the intermediate distances from the shoreline, and then began to peak again 1 km from the shore. Since the trend was not statistically significant, these may simply be spurious observations. However, a possible explanation behind the depressed avian diversity at intermediate distances links previous land uses by the Navy to disturbance of the habitat at these distances. Roads long since established for Navy training exercises cross six of our seven transects at points between the shoreline stations and those farthest from the Sea. Our results may be explained similarly to those of Brydolf (1999), who found that increased disturbance caused by years of US Army training at creosote-scrub-dominated Fort Irwin (Mojave Desert, California) was associated with decreased avian species richness. Lovich and Bainbridge (1999) also found evidence of negative impacts of military training operations on plant communities. Their results, covering both the Mojave and Colorado Deserts, showed reduced cover and density of such long-lived, dominant species as *Larrea tridentata* in areas impacted by soil compaction, changes in soil texture, removal of the top layer of soil, and alteration of drainage channel density. Lovich and Bainbridge (1999) further stated that recovery to pre-disturbance plant cover and biomass may take 50–300 years. The Navy's Salton Sea Test Base was operationally closed in 1993.

The temporal peaks in avian diversity that we observed were probably seasonal movements of migrants through the region (Flannery et al., 2004). Vegetation cover changes very little seasonally at this site, because of the dominance of evergreen perennial shrub species.

An important limitation of this study is the brevity of the field work—only 1 year of data collection. There may be year-to-year variation in abundance and diversity of birds using this region that could not be detected in this 1-year study. Additionally, future long-term studies would help to show whether the seasonal patterns we observed repeat themselves.

An extension of the east–west transects farther from the shoreline might also prove to be enlightening, perhaps showing an increase in diversity beyond what was found at 1 km from the shore.

Along those same lines, more sampling effort may be necessary at all five distances to increase sample size. The median number of individuals per 100 acres (40.5 ha) that we observed across all point counts was 0 (range: 0–425; alternatively, mean = 13 ± 30 individuals), assuming similar numbers of individuals existed across the study area outside of the surveyed 100-m radius plots. This extrapolation shows that we recorded considerably fewer birds as compared to the density cited in Emlen (1974) of “about 50 birds per 100 acres in the creosote scrub over much of the Sonoran Desert of southern Arizona and northern Sonora, Mexico.” The distances from the Sea where we observed the lowest diversity on point counts particularly need more effort, to see if the patterns in the numbers of species presented here are just artifacts of the small sample size observed rather than being true differences in total species among distances from the Sea. Bird abundance (sample size) and the number of species recorded are figures that are often highly correlated in analyses of diversity (Nur et al., 1999). Our numbers agree, there was a significant correlation between total individuals and total species ($r = 0.872$, $p < 0.001$). Lastly, we suggest that the avian diversity patterns in this area may be related to insect abundance, and this warrants future study.

4.1. Conservation implications

The Salton Sea has become a critical habitat for aquatic and terrestrial fauna, especially migrating, breeding and wintering birds, perhaps largely because California has lost approximately 90% of its original wetlands (Frayer et al., 1989). More than 400 species and nearly 70 additional subspecies of birds have been recorded at the Salton Sea, of which about 100 species have established breeding populations (Patten et al., 2003). At least 60 of these species are resident or neotropical migrant landbirds (Flannery et al., 2004). This diversity of landbirds, several of which we observed during our study, includes many California Partners In Flight Priority Riparian species. While the importance of the Sea to enormous populations of waterbirds has been shown in a multitude of studies, our research and that of Flannery et al. (2004) provides evidence that the significance of the Sea to avifauna lies in its terrestrial habitats as well.

Avian diversity patterns in the region may be affected at the local, if not landscape (the entire shoreline around the Sea) level if the Sea’s inflow is not maintained at current quantities. For nearly a century, rivers have fed nutrient-filled water into the Salton Sea (Redlands Institute, 2002). Recently, farmers, policy-makers, water district boards, environmental agencies, and many other stakeholders have debated on challenging issues of the use and fate of this resource. Talks of redirecting water from the Colorado River system to coastal southern California for human use are at the forefront. Ecologists and non-scientists alike suggest that this reduction in source water could have direct and far-reaching effects on the Salton Sea ecosystem (Patten et al., 2003), spanning landbirds using the land-shore interface to the millions of waterbirds and other organisms using the region. The threats from a drying Salton Sea extend to humans in surrounding developed areas, who could be exposed to dust storms similar to the ones Owens Valley residents in Central California have experienced since 1913 (Horvitz, 1999).

Therefore, we broaden what Shuford et al. (2002) declared regarding conservation in the region: any proposed projects [which may directly or indirectly modify the Sea] should be carefully evaluated and implemented only if land managers can provide substantial habitat improvements without negatively impacting the suitability of current habitats. It appears in the Salton Basin that as Polis et al. (2002, pp. 362–380) stated, “land and water, although existing separately and readily recognized as distinct biological communities, are very real extensions of each other.”

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