QUANTIFYING BIRD HABITAT AT THE SALTON SEA

INFORMING THE STATE OF CALIFORNIA'S SALTON SEA MANAGEMENT PLAN

Photo by Jennifer Boyer

Technical Report

November 23, 2016

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Audubon California	*Andrea Jones, Katie Krieger*
Point Blue Conservation Science	*Leo Salas, Nathan Elliott*
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EXECUTIVE SUMMARY

The Salton Sea is one of the most critical inland wetland habitats for birds along the Pacific Flyway. It is also one of the most imperiled. For more than a century, the Salton Sea has served as a major nesting, wintering, and stopover site for millions of birds, many of which will be left without adequate habitat as the sea declines in level and increases in salinity.

The State of California is planning for future management of the Salton Sea and is expected to produce a Salton Sea Management Plan by the end of 2016. Here, we provide relevant information by using habitat suitability modeling to quantify the types and extent of bird habitat associated with baseline (1999) and current (2011-2015; henceforth simply "2015") populations of birds at the sea. This report focuses on two objectives:

1. **Describing the preferred habitat features used by bird populations at the Salton Sea**.
2. **Quantifying the extent of preferred habitat used by bird populations at baseline (1999) levels**. (We used 1999 as the baseline because it is the most recent period with sea-wide standardized bird survey data.)

Key conclusions are:

- Birds used approximately 58,000 acres of habitat in both 1999 and 2015.

- Five key habitat types are used by birds at the Salton Sea: playa; mudflats and shallow water; mid-depth water; deep water; and permanent vegetated wetlands.

- The area of each of the five habitat types used by birds was comparable between 1999 and 2015, even though the actual physical locations of those habitats changed as the sea receded.

- Four factors appear to be strong drivers of bird use of Salton Sea habitat: amount of shallow water, sediment composition, amount of open water, and proximity to rivers and river mouths.

- Report results may not provide a good comparison of the *quality* of habitat, or of the size of bird populations, between 1999 and 2015.

- The amount and quality of the data and how they were collected limited the ability to quantify the effects of selenium, salinity, water temperature, water body size, food resources, and flyway impacts. A lack of standardized bird monitoring data and issues around the scale and shelf life of environmental data also presented challenges.

- The recommendations in the Salton Sea Ecosystem Monitoring and Assessment Plan pertaining to developing, maintaining, and disseminating knowledge to management agencies, along with future standardized bird surveys, would enable future updates and improvements to these models.

SUMMARY OF METHODS
We identified five key types of avian habitat at the sea: playa; mudflats and shallow water; mid-depth water; deep water; and permanent vegetated wetlands. We then modified the species-specific statistical models developed in support of the State's 2006 Salton Sea Ecosystem Restoration Program Programmatic Environmental Impact Report (PEIR). In 2006, the goal was to quantify the abundance of focal birds under various future alternatives. Here, we quantify the acreage of what we call preferred habitat (those areas shared by at least half of the indicator species – details on this below). As part of our analysis, we refined the resolution of Geographic Information System (GIS) data layers, such as

water depth, as new information became available. Such improvements allowed us to delineate habitat features in more biologically meaningful ways. We then developed habitat suitability models for 18 indicator bird species that represent these five habitats. We used data from eBird and the Pacific Flyway Shorebird Survey to estimate the probability of presence of the indicator species. We defined thresholds for preferred habitat and summarized the extent of preferred habitat under baseline (1999) and current (2015) conditions to provide essential context for decision-making.

We calculated that the Salton Sea and surrounding wetlands included approximately 58,400 and 57,600 acres (23,633 and 23,310 hectares [ha], respectively) of preferred habitat for birds in 1999 and 2015, respectively. We defined preferred habitat by how many indicator species are predicted to be present. Figure S1 below provides the estimates of area of preferred habitat in 2015. Please note that the aggregate (57,600 acres) is not equal to the sum of the five types of habitat. Rather, it is calculated as the combined footprint of all five habitat types. This is due to the fact that many model grid cells contain more than one type of habitat. To avoid double counting, we have included areas like this in the individual habitat types separately, but have represented them only once in the aggregate total. As an example, if a grid cell contains both mid-depth water and deep water, that area will be included under mid-depth water and under deep water, even though it is only counted once in the aggregate total.
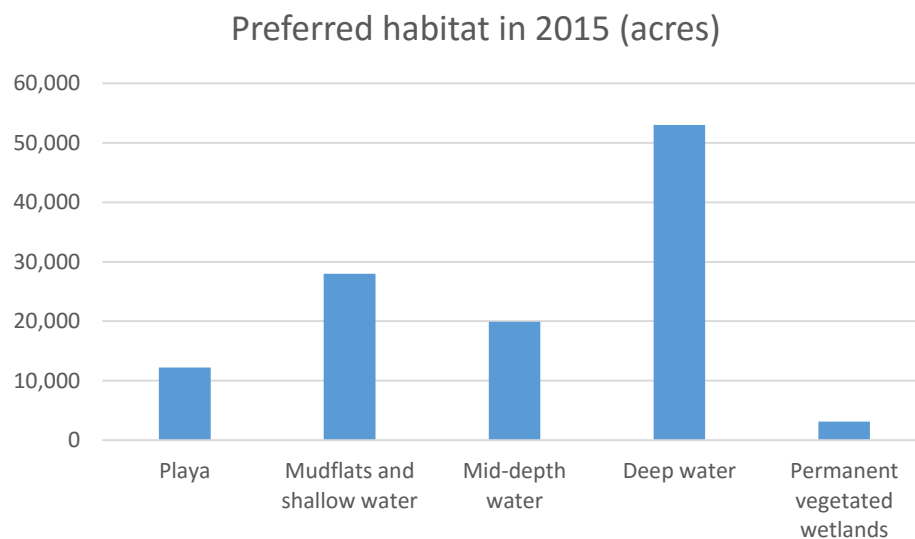

Figure S1. Estimates of amount of preferred habitat per avian habitat category, for the current (2015) period.

We mapped the extent and distribution of preferred habitat areas, which is fundamental to understanding differences in habitat types associated with baseline and current bird populations and which in turn enables a hydrologist to calculate an associated water budget for the modeled area of preferred habitat, as a follow-up to this report.

Models indicate that preferred habitats for the five different groups expanded between 1999 and 2015 while the aggregate area of preferred habitat decreased slightly, presumably reflecting increased overlap of different types of habitat at the scale modeled. Our estimate of 58,000 acres (23,472 ha) of preferred habitat is larger than a commonly cited estimate from the 2006 PEIR of 38,000 acres (15,378 ha), an estimate which is simply equal to the area of the sea within 0.6 miles (roughly 1 kilometer) of the

shoreline. Thus, the geographical extent of the previous study was smaller than ours, which includes adjacent playa and wetlands. For context, the entire Salton Sea was about 240,600 acres in 1999 and 219,700 acres in 2015.

Based on the modeling results and a review of the literature, we identified the top characteristics influencing the suitability of each type of habitat. Our analysis of habitat requirements indicates that several conditions are required to sustain the different avian habitats at a landscape level. These conditions include a sufficient area of the appropriate water type (such as shallow or deep water), availability of prey, appropriate sediment composition, and proximity to a freshwater source. Ultimately, each species and habitat type is affected by a variety of factors at multiple scales. Salinity in particular is a driving factor of habitat quality, affecting both birds and their food resources. Our summaries of the ideal characteristics of each habitat type ("recipe cards") should enable the future creation of new habitat of the highest quality.

The amount and quality of the data available limit the scope and conclusions of the present report. For example, we were limited in our ability to quantify the effects of selenium, salinity, water temperature, water body size, food resources, and flyway impacts. A lack of standardized bird monitoring data and issues around the scale and varying timeframe of collection of covariate data also presented challenges.

This report, together with future refinements and an adaptive management approach, should be an appropriate basis for setting management goals. Ultimately, this project will help the State successfully develop a Salton Sea Management Plan that sustains desired habitat quantity and, hopefully, functionality for avian species as the sea recedes over time.

It is our hope that the material presented here will inform the State as it plans future habitat and dust mitigation over time in the context of reduced water input to the Salton Sea.

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INTRODUCTION

The Salton Sea is one of the most valuable places for birds along the Pacific Flyway, and it is also increasingly one of the most imperiled. For more than a century, the Salton Sea has served as a major nesting, wintering, and stopover site for millions of birds (Patten et al. 2013), many of which may be left without adequate habitat as the sea declines. With over 450 species and subspecies of birds, the Salton Sea supports some of the highest concentrations and most diverse populations of birds in the world (Patten et al. 2003).

The State of California is planning for future management of the Salton Sea, particularly in light of expected reductions in water flows to the sea starting in 2018 due to existing water transfer agreements. The State requested that Audubon California develop habitat suitability models to quantify the types and extent of bird habitat used by bird populations at the Salton Sea. Audubon California developed this model in partnership with Point Blue Conservation Science and Cooper Ecological Monitoring and after peer review and consultation with several scientists familiar with the Salton Sea, including those serving on the Salton Sea Science Advisory Committee.

This technical report focuses on two objectives:

1. **Describing the preferred habitat features used by bird populations at the Salton Sea**. For each habitat type, we selected indicator species, consistent with the U.S. Fish and Wildlife Service (USFWS) Strategic Habitat Conservation approach (USFWS 2016). Using the results of the modeling described here, we developed recommendations for each type of habitat that define ideal habitat parameters, such as salinity ranges, substrate, and water depths.
2. **Quantifying the extent of preferred habitat used by bird populations at baseline (1999) levels**. We selected 1999 as a baseline because it is the most recent period with sea-wide standardized bird survey data. The baseline population numbers provide a starting point for discussions about the amounts of habitat that may be needed to sustain healthy bird populations at the sea.

The following sections provide a context for this work, identify the five habitat types included in the model, describe the methods used in our analysis, present key results, and provide interpretation relative to future avian needs at the Salton Sea. The information provided in this report and subsequent scientific studies on birds' habitat needs and effective wetland restoration design at the Salton Sea will inform the Salton Sea Management Plan (SSMP) and decisions about where and how to spend limited habitat conservation dollars in ways that provide habitat for birds while protecting human health.

HABITATS AND INDICATOR SPECIES

We identified the following five major types of habitat for waterbirds at the Salton Sea, exclusive of any agricultural fields in the Imperial Valley, known to be of relevance to local bird populations (Howell and Shuford 2008):

- Playa
- Mudflats and shallow water
- Mid-depth water
- Deep water
- Permanent vegetated wetlands

We defined the habitat types based on consultation of appropriate literature (mainly accounts from Rodewald (2015)) on indicator species. Each is described in detail below, along with the indicator species that we selected to represent these habitat types.

Playa. This habitat type includes the alkali flats and dry barnacle and sand beaches of the exposed sea bed (playa). Its bird community is represented by the Western Snowy Plover, a cryptic shorebird that exploits alkali flats and sandy areas within 1 km of the water's edge for both breeding and over-wintering habitat. Playa habitat is also used to a lesser extent by nesting American Avocets and Black-necked Stilts, though these species tend to favor small islets and levees within impoundments for nest placement. Important habitat features for nesting Snowy Plovers include not just fine

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sand or alkali, but also driftwood, sparse vegetation and debris that the plovers use for nest concealment and protection from the elements. These shorebirds forage nearshore at very shallow, hyper-saline pools caused by precipitation or wave wash during high winds or storms, out on the playa itself, and presumably at other freshwater sources, such as seeps or water running down from creeks or drains (Patten et al. 2003; W. D. Shuford, pers. comm.).

Mudflats and shallow water (< 15 cm [0.5 ft] in depth). This avian habitat supports high species diversity, and is the primary habitat for shorebirds and small waders that feed on invertebrates, insects, and other arthropods both in exposed and submerged mud and in the water column. This habitat occurs along the immediate edge of the Salton Sea (as well as in off-sea impoundments), often where wind influence forms small waves and small fluctuations in water levels throughout the day.

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The six indicator species are two larger shorebirds, the American Avocet and Marbled Godwit, the medium-sized dowitchers, and three smaller ones, Least and Western sandpipers and Dunlin. Many of the shorebirds species are migratory, stopping at the sea during spring or fall migration, whereas some species, including these indicator species, may spend the entire winter at the sea. Vegetation is typically absent from this habitat, though patches of small reeds and grasses may be found locally where freshwater is present.

Mid-depth water (15-30 cm [0.5-1 ft] deep). This habitat is used by the largest waders (herons and egrets) and certain waterfowl that forage on vegetation, invertebrates, or small fish, and is found just beyond the mudflats and shallowest bands of water and in constructed wetlands. Submerged vegetation is largely absent from this habitat in the Salton Sea itself, but it can be dense and abundant at off-sea impoundments. Indicator species include two locally-common dabbling ducks, the Northern Shoveler and Gadwall, and Snowy Egret. These habitats are critical for a variety of migrant, overwintering, and breeding waterbirds.

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Deep water (> 30 cm [1 ft] in depth). This habitat is the deepest band of water in the Salton Sea (and certain large impoundments), where the larger fish (including adult tilapia) and essential marine invertebrates are found, including pile worms, an important food source for the Eared Grebe at the Salton Sea (Cullen et al. 1999). Indicator species are the fish-eating Double-crested Cormorant and American White Pelican, as well as Eared Grebe and Ruddy Duck, which dive for a variety of invertebrates. Most of the species of this habitat dive for food, either by swim-diving from the water surface (cormorants, grebes and ducks) or plunge-diving from the air (e.g., Brown Pelican and Caspian Tern).

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Permanent vegetated wetlands. These patchy habitats are limited in extent and confined to areas of freshwater input at the edge of the Salton Sea, including agriculture drains and the mouths of the Whitewater, New and Alamo rivers that flow through agricultural areas and into the sea. Certain off-sea impoundments support larger extents of freshwater marsh habitat, such as constructed ponds at state and federal refuges, mitigation wetlands constructed by Imperial Irrigation District (IID) and others, and those maintained by private waterfowl hunting clubs. These areas typically have a blend of open water and emergent vegetation and require a consistent freshwater supply and depth to ensure that this balance is maintained. Bird diversity, particularly nesting waterbird diversity, is high. Indicator species are the Least Bittern, Common Gallinule, Virginia Rail, and Sora. Often dominated by a small number of large reed species (e.g., cattail), the vegetation in these patchy habitats can be very dense.

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PREVIOUS WORK

1999 COMPREHENSIVE BIRD SURVEY

Prior to a 1999 Reconnaissance Survey (Shuford et al. 2000), there were few quantitative data on the abundance, phenology, and distribution of waterbirds at the Salton Sea. In 1999, four comprehensive and standardized surveys, covering the entire sea along 19 shoreline areas and three wetland complexes, were completed during four seasons (mid-winter, spring migration, fall migration, and early winter). In addition, 18 partial surveys were completed throughout the same year covering four shoreline areas and two wetland complexes.

PROGRAMMATIC ENVIRONMENTAL IMPACT REPORT

Using data from the 1999 surveys and other sources, PRBO Conservation Science (now Point Blue Conservation Science) developed habitat-based bird models to evaluate proposed future alternatives in the Salton Sea Ecosystem Restoration Draft Programmatic Environmental Impact Report (PEIR) (CNRA 2006a).

In our analysis, we modified the species-specific statistical models developed in support of the PEIR. We developed current estimates of existing conditions using open access data from 2011 through 2015 in a manner that enables more frequent updating. This approach is not without tradeoffs, which are described more fully in Appendix B. There are other noteworthy differences between this report and the PEIR. For one, the PEIR, by its nature, evaluated specific future alternatives on bird species and habitats. Our goals, however, were to compare baseline (1999) and current (2015) conditions. We also aimed to establish standards against which data gathered during long-term monitoring can be compared in the future.

Separately, the PEIR also included an estimate of the amount habitat used by birds, simply calculated as the area of the sea within 0.6 miles (roughly 1 kilometer) of the shoreline, or 38,000 acres. Our analysis differs in that it explicitly assesses underlying habitat conditions using statistical models across a larger geographical area, including playa and adjacent wetlands.

OWENS LAKE

Recent habitat planning efforts at Owens Lake (Owens Lake Master Planning Committee 2014) strongly influenced our approach. Owens Lake is a saline terminal lake at the edge of the Great Basin below the steep eastern flank of the Sierra Nevada fed by the Owens River and other streams. It historically covered about 110 square miles (285 square km) but was essentially dried by water diversions by 1930. Beginning in the 2001, Los Angeles Department of Water and Power (LADWP) began reapplying water to the dry lake bed to control dust. Today over 40 square miles of playa have been treated to control dust, primarily through water-based methods that have dramatically increased habitat for many waterbirds and shorebirds. More than 90% of the dust that previously became airborne at Owens Lake has been abated.

Beginning in 2010, a collaborative Master Planning process was initiated by LADWP, building from a Conservation Action Plan that Audubon California initiated in 2008. The stakeholders, representing a wide range of interests at the lake, developed a plan to manage the diverse natural resources of the lake, while also controlling dust and conserving water. A Habitat Suitability Model (HSM) was developed

through this process, with the goal of identifying future habitat values at the lake and developing a long-term monitoring and adaptive management program.

The HSM was developed for five target habitat guilds, similar to the habitat guilds we identified for the Salton Sea: breeding and migrating shorebirds, breeding and migrating waterfowl, diving waterbirds, and meadow species. The model developed an understanding of what habitat conditions the guilds of species preferred and quantified the extent of habitat during a baseline year. The calculated habitat-acres were then used to determine how many acres to develop and manage in the future. The model also: 1) provided the ability to track habitat conditions over time; 2) provided guidance on design and management of future construction projects (to make sure they provide necessary conditions to support habitat, such as water depth and salinity); and 3) improved the committee's understanding of habitat preferences of various groups of species using the lake. Lastly, it provided a "balance sheet" by which LADWP can maintain, manage, and rotate various dust control cells that provide habitat to ensure no net loss of habitat-value acres from 2010 levels. LADWP then evaluated the water needs to comply with dust control orders and maintain those habitat value-acres.

While the proposed processes for re-creating lost habitats at Owens Lake and the Salton Sea are different, these two bodies of water are both interior, saline lakes that are essential parts of the interior Pacific Flyway, and support many of the same shorebird and waterbird species during the migration, wintering, and breeding seasons. Both sites support robust saline invertebrate food resources, but the Salton Sea supports more diverse invertebrates, fish, and populations of fish-eating birds, such as terns, cormorants and pelicans. Still, there are many lessons to be learned from Owens Lake, including how to build and maintain habitats in saline environments, and how to adaptively manage habitats under changing conditions.

Our habitat modeling approach at the Salton Sea drew heavily from our experiences at Owens Lake, in that we established a baseline, determined guilds of indicator species, and measured habitat availability based on preferred habitat conditions as identified through the modeling. As a follow-up to this report, we will estimate water amounts needed to establish and manage habitat at the acreages identified for each guild studied in this report. Moving forward, it will be important to understand and reflect on lessons learned at other desert saline lakes in the western United States, and to apply what is being learned at Owens Lake and the Salton Sea to other saline lakes.

METHODS

We used a two-part approach, matching the two related objectives described more fully above:

1. Describing the preferred habitat features used by bird populations at the Salton Sea.
2. Quantifying the extent of preferred habitat used by bird populations at baseline (1999) levels. (We used 1999 as the baseline because it is the most recent period with sea-wide standardized bird survey data.)

Our models are based on use of preferred habitat. We defined preferred habitat by how many indicator species are predicted to be present, and we calculated it using a weighted mean according to how many indicator species are present (see below). We chose not to define population targets for any species or guilds because of the uncertainty inherent in defining population goals, because of variation in local resources and factors operating elsewhere in the flyway at other seasons.

The selection of avian habitats for quantifying their extent at the Salton Sea followed a simple definition based on behavior and resources exploited (Shuford et al. 2000). Following consultation with expert avian biologists, we identified five key avian habitats and selected 1-6 indicator species for each (Table 1, habitat descriptions above). The evaluation of data on indicator species allowed us to determine the likelihood of their being present at different locations in the Salton Sea and thus contributed to the delineation of preferred habitat areas. For each habitat type, we sought the indicator species most commonly seen (i.e., most commonly present in the data after filtering for the most adequate dataset – details below).

Although the Salton Sea is an important breeding area for many species of waterbirds, it is beyond the scope of this report to model the specific habitat components and attributes associated with waterbird breeding success. However, recognizing that the sea is an important breeding area for many species of waterbirds, we use published and unpublished literature to summarize habitat needs for breeding waterbirds at the Salton Sea (see Appendix A).

As noted earlier, we modified the species-specific statistical models developed in support of the PEIR. As part of our analysis, we refined the resolution of Geographic Information Systems (GIS) data layers such as water depth using the best information currently available. Such improvements allowed us to delineate habitat features in more biologically meaningful ways, such as distinguishing shallow water (<15 cm) from mid-depth (15-30 cm) and deep water (> 30 cm), compared to what was possible when the original models were developed for the PEIR (shallow water defined as <1 m).

Below we describe the methodology used to estimate the likelihood of indicator species presence, and how we used the combined information from the presence predictions to estimate the amount of preferred avian habitat for each of the categories defined above. Also, specifics about statistical methods are included in Appendix B, along with model performance information.

STUDY AREA

The study area includes the Salton Sea and the area immediately surrounding it (Figure 1). We used the -69.5 m (-228 ft) contour line as a reference, representing the approximate water level of 1999 (Cohen 2014), and buffered it to 5 km inland to include bird records from the shoreline and adjacent wetlands. We then used any data within the buffer and the sea for our analyses. However, we masked results to include only those inland areas within 1 km of the shoreline (which changes by year), and to exclude

adjacent agricultural lands and other habitats, based on discussions with the State and other stakeholders, though we note that these lands do provide valuable habitat for birds. The mask preserved all inland areas within 1 km of the shoreline and, as one of the avian habitat areas of interest, adjacent wetlands within 5 km of the shoreline.

The center of the sea is > 2.5 m deep. The California Natural Resources Agency (CNRA) states that most birds at the Salton Sea are found within 1 km (0.6 miles) of the shore, which approximates the 2.5-m cut-off depth we selected (CNRA 2006a). Additionally, Detweiler et al. (2002) and Riedel et al. (2002) mention that the most important areas for invertebrates and fish are near-shore shallow waters. Riedel et al. (2002) mentions that most fish are found forming "a dense 'bathtub ring' all along the nearshore" (p. 240). For these reasons, we did not list such areas among our habitat types and masked them out from our models and calculations. Rather than use a fixed distance from shore, we used the more appropriate 2.5-m water depth criterion for the cut-off. Indeed, Detweiler et al. (2002) report a marked decrease in the density of benthic invertebrates (fish prey) at depths beyond 2 m, and related this to changes in the composition of the substrate. The nearshore environments had rocky, heterogeneous substrates where the invertebrates could hide.
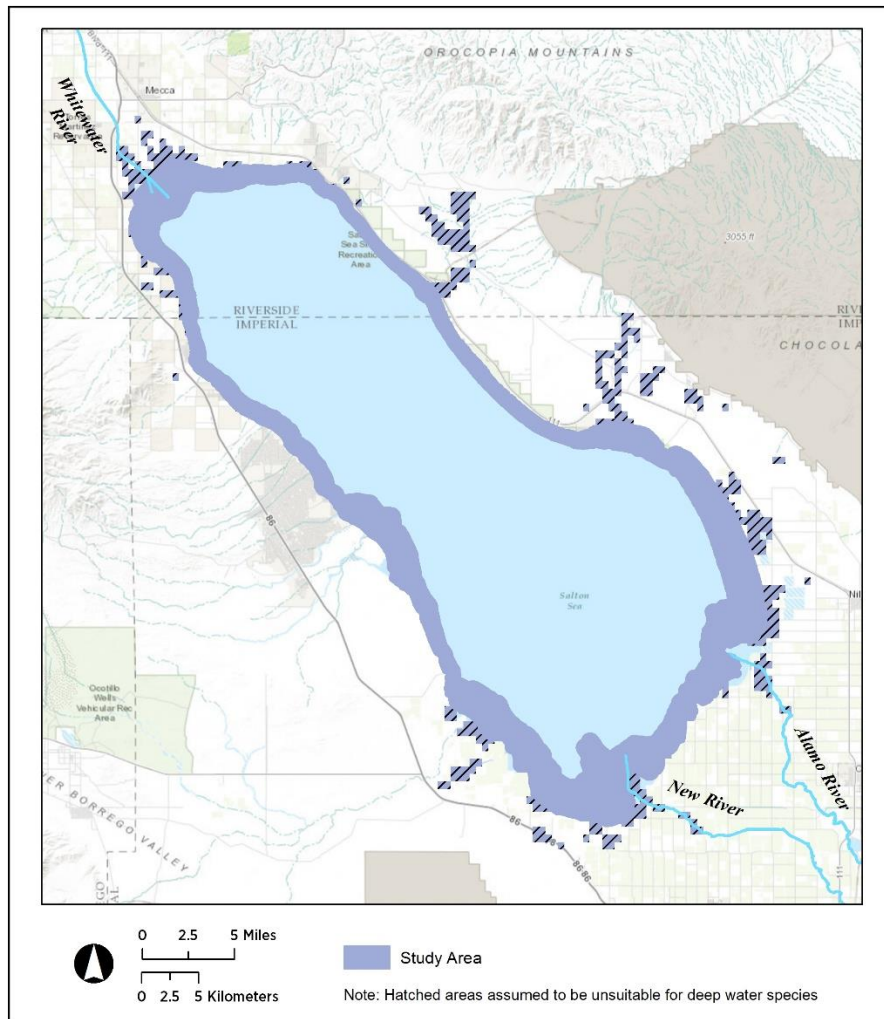

Figure 1. Study area.

BIRD OBSERVATION DATA

We used data from eBird and the Pacific Flyway Shorebird Survey (PFSS) to estimate the probability of the presence of an indicator species. eBird is a database of online birding checklists contributed by birders that provides data on bird abundance and distribution at varying spatial and temporal scales (http://ebird.org/content/ebird/). The PFSS (Reiter 2011) is an early winter survey conducted by expert volunteers following an established protocol (details at www.migratoryshorebirdproject.org/uploads/documents/AreaSearchProtocol_Coast_2012Final_rev101314.pdf

Because these are data gathered by volunteers, it is paramount that they be interpreted and analyzed correctly and with appropriate caution. These data are commonly collected with some spatial bias (e.g., birders mainly go only to areas where birds can be found, and where access is easy, so the sample is not spatially randomized), and error (e.g., birders may record species seen anywhere from a few meters to hundreds of meters away) (see Munson et al. 2010 for more details). On the other hand, systematically collected replicate survey data are expensive to generate and scarce at the Salton Sea. Thus, there is a trade-off in using volunteer science data: the records reflect non-trivial sampling error, but are available in large volume and are repeated every year. Appendix B includes all considerations followed to ensure the data were correctly analyzed, including all the filters applied before any analysis was conducted.

Table 1. List of indicator taxa used, the period-of-presence months for each, and the habitats they represent.

Species	Code	Start month	End month	Habitat
Snowy Plover	SNPL	Jan	Dec	Playa
American Avocet	AMAV	Jul	Apr	
Marbled Godwit	MAGO	Jul	Apr	
Dowitcher spp.	UNDO	Jul	May	
Dunlin	DUNL	Oct	May	Mudflats and shallow water
Western Sandpiper	WESA	Jul	May	
Least Sandpiper	LESA	Jul	Apr	
Snowy Egret	SNEG	Jan	Dec	
Gadwall	GADW	Nov	May	Mid-depth water
Northern Shoveler	NOSH	Jul	Apr	
Eared Grebe	EAGR	Dec	May	
Ruddy Duck	RUDU	Oct	May	
American White Pelican	AWPE	Jul	Apr	Deep water
Double-crested Cormorant	DCCO	Jan	Dec	
Least Bittern	LEBI	Jun	Aug	
Virginia Rail	VIRA	Jan	Dec	
Sora	SORA	Aug	Apr	Permanent vegetated wetlands
Common Gallinule	COGA	Jan	Dec	

For each indicator species we filtered the data to include records only for the months when that species is most common at the Salton Sea (henceforth the "period of species presence") (see Table 1). We used eBird data collected between January 2011 and December 2015 to determine the periods of species presence, along with information in Patten et al. (2003) and seasonal abundance graphs in Shuford et al.

(2000). The determination included correction for differential survey effort (i.e., more surveys in some months, and fewer in others). A full description of the methods used to determine the period of presence are found in Appendix B.

GEOSPATIAL COVARIATE DATA

Our models use data from each pixel in the landscape to predict the species presence at the pixel level. Pixel size was set at 500 m x 500 m. This size was a compromise resulting from several sources of uncertainty. First and foremost, the avian data include uncertainty in the specific location of the bird at the time of the observation. Although each observer reports his or her location, the bird may be located as much as 300 m away (though often within 100 m). Hence, we used this resolution as a way to ensure that the covariate's precision matched that of observational data. If the birder moved around to scan an area (often the case at the Salton Sea), we filtered the data to include records where the distance traveled was < 500 m (with the exception of two species; see Appendix B for details). Though the size of the pixels may seem large for bird species, biological surveys previously conducted in the Salton Sea had coarser spatial resolution. The 500-m pixel size also reduces the error from incorrect determination of the value of the geospatial covariates we used. For example, we are more certain about the estimate of the proportion of shallow water habitat in a 500-m pixel than in a 5-m pixel, because of uncertainty associated with the bathymetry (underwater topography) layer is much higher at smaller resolutions. So, we deem the 500-m pixel size as an adequate compromise between spatial specificity and accuracy in the data.

WATER DEPTH

We sought to use covariates that are related to water level, which were estimated for each pixel from the current water level and the most recent bathymetry layer (USGS, https://www2.usgs.gov/saltonsea/LiDAR.html). The water level data were obtained from the USGS (USGS, Water Gauge #10254005; http://waterdata.usgs.gov/ca/nwis/uv?site_no=10254005). See Appendix B for details.

LAND COVER

We obtained landcover data from the 2011 National Landcover Database (NLCD) (Multi-Resolution Land Characteristics Consortium, http://www.mrlc.gov/nlcd2011.php) and the National Wetlands Inventory (NWI) (USFWS, https://www.fws.gov/wetlands/). These two land cover classification systems have different levels of resolution: one (NWI) is based on aerial photography, the other (NLDC) on satellite data. NWI data are more precise and accurate, but not updated as frequently as the NLDC data. Here we are simply using some information from one, and some from the other, both resampled to our 500-m pixel size. We understand that there will be error from each. Specifically, the two sources of error are how exactly the border is handled (we used center of pixel, so a 30-m pixel was summed if its centroid was within the larger pixel) and the error in NLCD assigning a dominant land cover type at 30m. Of these, the second will be larger than the first, and though the error is not something we can quantify, it will be minimal at the scale of our models.

SEDIMENT

Sediment survey data for the Salton Sea was provided by USGS (Agrarian Research, https://www2.usgs.gov/saltonsea/docs/SSA/Salton%20Sediment%20Report%2020%20Oct%2003.pdf). See reference for discussion of sampling methods. From the sampling locations, we interpolated the

fractions of clay, organic matter, sand, and silt reported by the survey into a raster covering the entire sea using the IDW Interpolation tool in ArcGIS 10.2 (ESRI 2013).

DISTANCE TO GEOGRAPHICAL FEATURES

We calculated covariates of distance to features (shoreline, rivers, river mouths) using the Euclidian Distance tool of ArcGIS 10.2 (ESRI 2013). Slope was calculated using the Slope tool of ArcGIS 10.2 (ESRI 2013). For the calculation of distance to shoreline, we interpolated the shoreline contour from the Digital Elevation Model (DEM) using the Contour tool of ArcGIS 10.2 (ESRI 2013).

We resampled each layer, except for the abovementioned distance-to-feature layers, to resolutions of 500 x 500 m and 5000 x 5000 m, calculating either averages or sums as appropriate, using packages rgdal (Bivand et al. 2015) and raster (Hijmans 2015) in R version 3.2.1 (R Core Team 2015). See Appendix B for a list of landscape covariates, processing information, and original data sources.

For all covariates except those measuring distances to features, we opted to assess their influence on probability of species presence at two different scales: locally (i.e., within the pixel) and at a larger scale. We did so by generating values averaged from radii of 250 m and 2,500 m from the center of each pixel.

SALINITY

Salinity is a desirable covariate to use when modeling suitability. It is likely that there are different degrees of salinity within the sea, depending on proximity to freshwater sources, discharge amounts, and time of year. The effects of salinity are expected to be complex (Anderson et al. 2007, Barnes and Wurtsbaugh 2015). Unfortunately, we were not aware of any consistent, sea-wide salinity data sampled at enough locations to help establish a geospatial layer at the resolution needed for use in our models to help define habitat conditions.

Despite the limited information available, high salinity levels are one of the most pressing issues affecting the avifauna at the sea (Miles et al. 2009, Cohen 2014). We evaluated possible salinity effects by looking at direct measures of bird (guild) abundance versus salinity data from a 12-year series from the San Francisco Bay South Bay Salt Pond (SBSP) project conducted by the USGS (De La Cruz et al. *in review*). Our goal was to determine whether and how to adjust predictions of baseline (1999) habitat suitability according to differences in salinity levels from the period used to build the models (2011-2015). Since we trained our models with data from 2011-2015, predictions for the 1999 baseline may underestimate suitability, as the salinity levels in 1999 were lower than the current 2011-2015 period.

Four considerations supported our decision to make no adjustments for salinity effects to the predictions of suitability for the baseline 1999 estimates. First, the data from SBSP suggest only a minimal change of approximately 0.50 individuals for the mean bird abundance per pond for the approximately 13 parts per thousand (ppt) change in salinity between 1999 (42 ppt) and 2015 (>55 ppt). The USGS study states that optimally most species prefer < 33 ppt but that significant change happens at much higher salinities (> 100 ppt). Second, the approximately 13 ppt difference has an effect on suitability well within the margin of error of the USGS's and our models. Third, it is difficult to untangle ecosystem-specific responses from an absolute effect of salinity. The USGS study showed that the Eared Grebe thrives at much higher salinity (109-124 ppt) than the current value (56+ ppt) for the Salton Sea, as do many other shorebirds and waders, and this is due to the fact that these hypersaline environments are optimal for two invertebrate genera that are prey to Eared Grebe and other waterbirds. These

anthropods are not (yet) present in the Salton Sea. Lastly, Warnock et al. (2002) also analyzed the effect of salinity on bird abundances in the SBSP, reaching similar conclusions to those in the USGS report.

Because of our poor understanding on how salinity may affect the fish and, consequently, piscivorous bird abundance, it is important to stress this ignorance as a caveat of the numbers presented here. It is equally entirely possible that the increase in salinity between 1999 and 2015 had a substantial effect on bird numbers and quality of preferred habitats, as well as no effect. More importantly, because we used data from 2015 to construct the 1999 baseline, the baseline estimate is possibly underestimating the total habitat for this guild of birds.

SELENIUM
High levels of selenium have been repeatedly found in many areas around the Salton Sea, and in sediments in areas of the sea bottom (see comprehensive reviews in Anderson 2008, and Xu et al. 2016). This contaminant should be considered when identifying the areas of suitable avian habitat. The USGS has produced maps of "selenium hotspots", which can be juxtaposed on the projections of preferred habitat.

PREFERRED AVIAN HABITAT MODELING AND ESTIMATION
After attributing the bird data with the biophysical covariates, we fit a data mining model (boosted regression tree, or BRT) with binomial error distribution to detection/non-detection values (i.e., assigning a value of one if the species was detected in the survey in any number and zero otherwise). It automatically handles variable interactions and determines variable relative importance. The BRT method is designed to produce a model that has high predictive accuracy, not to formally test ecological significance of variables (Elith et al. 2008). Nevertheless, it provides valuable insights on the importance of covariates on landscape use by habitat indicator species. See Appendix B for a full description of our methods and details about the BRT.

The preponderance of zeros in the data (i.e., a species not detected in a survey) indicates that the data are zero-inflated (Zuur et al. 2009). Unlike the case of landscape-level models for landbirds (e.g., Veloz et al. 2015) where the inflation was caused by imperfect detection, the datasets from the Salton Sea reflect the highly variable temporal (diel and seasonal) patterns of use by the waterbird indicator species.

Arguably, the preponderance of surveys with 0 detections is a reflection of suitability. For example, two areas where a species was detected may reflect different suitability if one of them is more prone to produce surveys with 0 counts. Hence, we decided not to use zero-hurdled or zero-inflated models to preserve this information in the data. Similarly, the simple use of 1 to indicate species presence may greatly limit the information conveyed by the survey about suitability. For example, two locations where the species has been detected on surveys may differ in suitability if one has counts of no more than 5 individuals of the species and another has counts surpassing 5,000 individuals. We wanted to incorporate the information about suitability from the total counts into our binomial model. We used the log of the total count as the weight for a detection record, so that 1s indicating the presence of a large number of individuals have heavier weight in the model than 1s registering a few individuals. The records with 0 counts were all assigned the same weight of one.

The BRT for each species provided as a result the probability (values between 0-1) that the species would be present in a pixel. We converted the probability into presence absence using the species' prevalence in the landscape (Liu et al. 2005, Lobo et al. 2008). We then overlaid the layers from all

indicator species for each avian habitat to quantify the number of cells where 100% of the species were deemed as present, where all minus 1 were deemed as present, n-2 were deemed present, and so on until half of the indicator species were present. We then calculated the total area of preferred habitat as a weighted average of these estimates:

$$wMPAH = (\sum_{i=n/2}^{n} i * A_i) / \sum_{i=n/2}^{n} i$$

where wMPAH is the (weighted) mean preferred avian habitat area, i are the weights (in this case, the number of indicators species overlapping in presence, for i=n/2 to n), and Ai is the total area of overlap.

We fit the BRT model for each species using the PFSS and eBird data from the period 2011-2015. Once fitted, we predicted the probability of presence for each species in 1999 and calculated the area of preferred avian habitat for that year. We were ultimately interested in calculating estimates of total area of preferred habitat for 1999, our base year. It is also possible to compare these predictions with the prior work of Shuford et al. (2000) regarding the total amount of avian habitat, as well as the location of areas of large patches of preferred habitat.

To predict to 1999, we used the 2001 National Landcover Dataset (instead of the comparable 2011 dataset we used to build our models) and calculated all of our water depth and shoreline variables based on the observed 1999 water level of -69.5 m (-228 ft) National Geodetic Vertical Datum (NGVD) 1929 (USGS Salton Sea water gauge; see methods above for more detail). Lacking data across time, we had to assume that sediment and wetlands as defined by the NWI would remain constant. Differences in distribution between the two years then reflect a combination of landcover (from NLCD), distance to shoreline, amount of exposed beach, average water depth, and area of water in the different depth categories enumerated above.

TOTAL AREA OF PREFERRED AVIAN HABITAT
We estimated the total area of preferred avian habitat as the union of the areas of all preferred avian habitats. Specifically, we used a weighted mean of the estimate of the union if we used the layer of all indicator species present for each habitat type, and the estimate of the union if half of the indicator species for each habitat were present, with the weight equal to the number of species in each estimate being averaged.

UNCERTAINTY ABOUT THE ESTIMATION OF PREFERRED HABITAT
Because it is conditional on the species we chose as indicators, the estimation of the total area of preferred habitat must include some error inherent to the species we chose. One way to provide some estimate of this source of uncertainty is to consider several definitions of "preferred habitat" in terms of the number of indicator species present. For example, at the pixel level, it can be defined as "any one indicator present" or "all indicator species present". As explained above, we used information from all levels of indicator species present through a weighted average. We then calculated uncertainty around the estimate of preferred habitat through two arbitrary choices of level of overlap: where a lower limit of area of preferred habitat as that where all species are present, and an upper limit as where 50% are present.

Similarly, the uncertainty in the total area of avian habitat draws from the uncertainty of a particular habitat type being present in a pixel. Following the same logic explained above, we bounded the mean

estimate by the area of habitat where all habitats are present (lower) or where half of the habitats are present (upper). As explained above, we chose to use information from multiple levels of indicator presence, calculating a weighted average of the area occupied by half or more of the indicator species using the number of species present as the weights.

Like any other statistical model, data mining models include error associated with the data used to train them, how these data were collected, error in the attribution of covariates (as mentioned above, regarding how well the value of the covariate aligns in space and time with the exact location used by the bird), error in the collection or generation of the covariate datasets, etc. To incorporate this prediction uncertainty in our results, we prepared estimates of preferred habitat for each species +/- one standard deviation of the cross-validated model prediction, for both the 2011-2015 period, and for our base year 1999. However, there was relatively large cross-validation error due to the large preponderance of zeros in the data. Specifically, we randomly divided the data into 10 equal-size parts (i.e., cross-validation sub-samples) and used all 10 possible ways to select 9 of them to fit the model. From each of these model fits, we estimated the area of each habitat type, thus obtaining 10 estimates for each. We calculated a standard error from these 10 estimates, with which we constructed confidence intervals around the estimates obtained when using the full dataset. We do not present these results here, but note that they are of similar size as those obtained from altering the definition of preferred habitat. This results strongly suggests that our dataset is limiting, and that additional data may improve the precision and accuracy of our models. We are using as much data as possible, and this type of uncertainty will be inherent to any other modeling approach, including those done in previous analyses.

RECIPE CARDS

We generated a description of each avian habitat in terms of the preferred ranges of covariates. We identified the most important covariates for all indicator species of the habitat and then inspected the value of these covariates in pixels determined to be ideal. In Appendix C we provide graphics depicting how each of the three most important covariates affect the determination of preferred habitat.

We developed "recipe cards" for each habitat type based on the literature for the indicator species and the results of our models, following the example of the Owens Lake report (Owens Lake Master Planning Committee 2014). The recipe cards provide guidelines to be considered during creation and management of preferred habitats for the five habitats we modeled. In our case, the several indicator species for a habitat may have different top predictors, and the relationship between the predictor and habitat selection may also vary among species. Thus, the challenge was to locate these conditions that are simultaneously most preferred for the group of species, and not necessarily those most preferred for one species.

To do this, we constructed the recipe cards by "walking back" our results. We first used our most restrictive estimation of the preferred habitat (where all indicator species for the habitat are present) to obtain the covariate values at these locations for the top 5 covariates. We then plotted these values within the range of observed values of each covariate to identify the "zone of highest joint preference".

MODEL VALIDATION

As noted previously, the most recent detailed survey of avian species and abundances throughout the Salton Sea and at different times of the year occurred in 1999 (Shuford et al. 2000; 2004). In that survey,

surveyors visited the sea four times throughout the year, counting total numbers of waterbirds and other species in 19 shoreline segments and three complexes of freshwater marshes and impoundments. The corresponding report and the data do not include detailed geospatial coordinates, as the spatial attribution is to the abovementioned 22 areas. Therefore, a direct comparison of use vis-à-vis our predictions on the location and amount of preferred habitat is not possible. The corresponding report includes graphics and estimates of abundance by segment, which we used to qualitatively compare the results with our predictions. It also includes descriptions of important bird areas that we used to compare against our results (see p. 18 onward in Shuford et al. 2000).

INDEPENDENT REVIEW

To follow an open, objective, and thoroughly vetted methodology for estimating avian habitat-use areas in the Salton Sea, we sought input from two groups of experts, as well as peer scientists familiar with habitat suitability landscape models using data mining techniques. In Appendix B, we provide a summary of peer review comments and responses.

MODEL METHODS

We shared our draft methods with four experts in the subject of species distribution modeling. Though all reviewers concurred that a data mining approach was sensible, they shared largely the same overarching concerns: how to handle data with so many zeros, bias and error in volunteer science data, and the proper scale of attribution of geospatial covariates. Discussions with and suggestions from these reviewers influenced our use of the weights as described in Methods section above. Based on comments received, we limited eBird data to only surveys where the person gathering the data travelled < 500 m.

SALTON SEA EXPERT REVIEW

We also presented our draft methods to Salton Sea experts at USGS, USFWS, and California Department of Fish and Wildlife, and to the State-led Salton Sea Science Advisory Committee.

A consistent comment concerned the use of sediment data because sediments and the composition of the sea bottom in nearshore habitats may be very important to habitat use. Detweiler et al. (2002) noted how rocky substrates (as opposed to the more silt-laden deeper benthic environments) provided a substrate for invertebrate fauna to hide. Similarly, Riedel et al. (2002) showed that fish, and – we may infer – birds, would be confined to the band where most invertebrates are found, though other factors such as biochemical processes and the presence of algae may also be an important driver of the distribution of fish. These findings point to the important relationship between substrate and availability of avian (and fish) prey. In at least three avian habitat models, sediment composition variables proved to be strong explanatory variables and improved model performance.

RESULTS

DRIVERS OF HABITAT USE

Summaries of the ideal characteristics of each habitat type ("recipe cards", Table 2), based on our models and literature review, should guide the future creation of new habitat of the highest quality (see Appendix C for supporting information).

Four main factors appear to be strong drivers of indicator species' use of habitat at the Salton Sea based on our models:

Amount of shallow water. Proximity to shallow water was an important predictor in many of our models. At the scale of analysis, a minimum amount of shallow water is required for the habitat to be visited by birds (varying from 1 ha to more than 80 ha depending on the surrounding landscape structure and other factors). To be suitable for the indicator species considered here, shallow water habitat also requires suitable sediment composition and the presence of prey. The use of a separate habitat type, playa, also depends on the presence of shallow water nearby.

Sediment composition. Several of our models indicated that percent sand, silt, organic matter, and clay had a strong influence in the selection of areas of suitable habitat.

Amount of open water. Amount of water was an important variable in several models. Large water surface area is a driver for the presence of fish-eating species. Within this open water, depths of 1-4 m are preferred, though it is important to recognize that we did not explicitly model the habitat needs of prey.

Proximity to rivers and river mouths. In almost all models, proximity to a freshwater source had great influence in the determination of preferred habitats.

Table 2. Salton Sea habitat recipe cards.

Descriptions derived from the landscape models	Descriptions derived from a literature review	Data Source
Playa		
Exposed shoreline: a few thousand m² to > 5 ha	*Snowy Plover*	
Shallow water (< 15 cm): < 3 ha (but can be more)	Highly adapted to hypersaline conditions (50-200 ppt)	b, d
Minimally developed/undeveloped land: a matrix of several ha	Breeds on barren to sparsely vegetated ground (0-10% vegetation)	a, d
	Concentrate on sandy beaches and sand or alkali flats	c
	Most feeding is in shallow (1-2 cm) water, wet mud/sand, and playa near seeps and streams	a, d
Mudflats and shallow water		
Shallow water (< 15 cm): ≥ 25% locally and in larger landscape	*American Avocet*	
Exposed shore: some, with > 90% mudlfats, locally and in larger landscape	Highly adapted to hypersaline conditions (50-150 ppt)	b, d
Permanent shoreline: within 1 km	Feeds in shallow water (≤ 15-20 cm) and while swimming (< 25 cm)	d
Rivers/river mouths: within 5 km	Prefers to feed in areas of fine sediments and mud, not sand	a
Submerged sediments: silt (10-45%), sand (15-50%), organic content (< 20%)	Feeds on brine shrimp and brine flies at Owens Lake	d
	Marbled Godwit	
	Tolerates a range of salinities (0-100 ppt)	b
	Feeds in fairly deep to shallow water (13-5 cm)	a
	Feeds primarily by probing substrate	a
	Dowitcher spp.	
	Tolerates a range of salinities (0-100 ppt)	b
	Uses playa lakes at shallow depths (0-16 cm)	a
	Generally feeds in substrates with soft mud bottom	a
	Prefers large mudflats (> 500 m)	a
	Abundance negatively correlated with vegetation height	a
	Dunlin	
	Tolerates a range of salinities (50-200 ppt)	b
	Prefers well- to moderately sorted fine sand for foraging	a
	Usually feeds in water 0-5 cm deep	a
	Western Sandpiper	
	At interior stopover sites, prefers salt lakes and ponds (50-200 ppt)	a, b
	Prefers habitats with high silt content, or mix of silt and sand	a
	Forages mainly on wet mud with thin surface film of water (2-10 cm)	a
	Least Sandpiper	
	Tolerates a range of salinities (50-200 ppt)	b
	Forages in moist or saturated muddy shorelines with shallow water (< 4 cm)	a
	Probes or pecks in damp mud	a
	Uses agricultural fields in the northern Imperial Valley	c

Descriptions derived from the landscape models	Descriptions derived from a literature review	Data Source
Mid-depth water		
Mid-depth water (15-30 cm): a few thousand m^2 to > 2 ha	*Snowy Egret*	
Water depth: < 1.5 m on average in surrounding waters	Generally prefers brackish/marine habitats	a
Shoreline: within 300 m	Prefers shallow water (averaging 3 cm) near dense vegetation	a
Rivers/river mouths: within 6 km	Larger pools (>100 m^2) preferred	a
Exposed shoreline: a few thousand m^2 to several ha	May nest within dense marshes	c
Open water: 5-20 ha	Breeds primarily in snag stands and along channels and islands in Alamo River Delta	c
	Gadwall	
	Highest salinity tolerance of any dabbling duck (0-50 ppt)	b, d
	Prefers shallow to deep wetlands (0-30 cm)	a
	Feeds from water surface over beds of submerged aquatic vegetation	a
	Northern Shoveler	
	Found in both freshwater and saline wetland habitats	a
	Prefers shallow, open lakes with dense growth of aquatic vegetation	a
	Usually forages in open water column, or dabbling through mud on bottom	a
Deep water		
Deep water (> 30 cm): a few thousand m^2 to > 25 ha	*Eared Grebe*	
Water depth: 1-4 m on average in surrounding waters	Prefers saline habitats (50-150 ppt)	a, b, d
Shoreline: within 1.5 km	Uses shallow and deep water, according to prey availability	a
Rivers/river mouths: within 5 km	Mainly occur within 1 km of land, in wide and even distribution	c
Open water: as much as possible (these species like large water bodies)	Diet dominated by invertebrates, including brine shrimp and insects	d
Sediment: silt (10-40%), sand (20-60%), organic content (≥ 2%)	*Ruddy Duck*	
	Most often near brackish river mouths	a
	Forages in relatively shallow water, often with submerged vegetation	a, d
	Mainly occur within 1 km of land	c
	Diet dominated by inverbrates	d
	American White Pelican	
	Prefers lower salinities (0-50 ppt)	b
	Favors shallow water with forage fish	a
	Uses the river mouth and delta areas, roosting at isolated sites	b, c
	Double-crested Cormorant	
	Occupies diverse aquatic habitats (0-100 ppt), aggregating at river deltas	a, b
	Forages in shallow water (< 10 m deep), typically < 2.5 m from shore	a
	Requires exposed sites such as rocks, pilings, trees for resting	a
	New nesting islands should be completely isolated by water, near shoreline	c

Descriptions derived from the landscape models	Descriptions derived from a literature review	Data Source
Permanent vegetated wetlands		
Freshwater wetland: 1 to > 10 ha	***Least Bittern***	
Water depth: < 1 m on average in surrounding waters	Overwintering birds occur mainly in brackish and saline swamps/marshes	a
Exposed shore: ≥ 10 ha	Prefers waters 20-25 cm deep, with most foraging at water's surface	a
Rivers/river mouths: within 10 km	Frequents tall, dense stands of emergent plants along deep, open waters	a
Herbaceous vegetation: a few thousand m^2 to < 10 ha	***Virginia Rail***	
	Occurs in both freshwater and salt marshes	a
	Forages mainly in shallow water or on mudflats	a
	Prefers unstable, moist, silty substrate with high invertebrate abundance	a
	Prefers more open areas with emergent cover	a
	Sora	
	Occurs in both freshwater emergent wetlands and brackish or salt marshes	a
	Prefers shallow and intermediate water depths (0-92 cm, mean 34 cm)	a
	Feeds in 5-46 cm deep water on plant materials and invertebrates	a
	Prefers areas dominated by robust or fine-leaved emergent vegetation (128 cm mean height)	a
	Common Gallinule	
	Doesn't like very saline environments	a
	Prefers half submerged (dense and floating vegetation), half open water (15-120 cm)	a
	Feeds on aquatic and terrestrial plants and aquatic insects	a

Literature review data sources: a - Birds of North America (Cornell Lab of Ornithology - https://birdsna.org/); b - Salton Sea Ecosystem Restoration Program Draft Programmatic Environmental Impact Report, Appendix H-1: Habitat Components of the Salton Sea Ecosystem (California Resources Agency - http://www.water.ca.gov/saltonsea/peir/draft/Appendix_H-1_Habitat_Components.pdf); c - Avifauna of the Salton Sea: abundance, distribution, and annual phenology (PRBO - http://www.spatial.redlands.edu/salton/Downloads/Docs/Biology/finalprboavifauna.pdf); d - Owens Lake Habitat Suitability Models: Validation and Refinements (Point Blue - not available online).

EXTENT OF PREFERRED HABITAT

The amount of Salton Sea habitat used by birds in both 1999 and 2015 was about 58,000 acres (23,472 ha). The area of each of the five habitat types used by birds was comparable between 1999 and 2015, even though the actual physical locations of those habitats changed as the sea receded.

The aggregate (57,600 acres) is not equal to the sum of the five types of habitat. Rather, it is calculated as the combined footprint of all five habitat types. This is due to the fact that many model grid cells contain more than one type of habitat. To avoid double counting, we have included areas like this in the individual habitat types separately, but have represented them only once in the aggregate total. As an example, if a grid cell contains both mid-depth water and deep water, that area will be included under mid-depth water and under deep water, even though it is only counted once in the aggregate total.

Table 3. Preferred habitat available at the Salton Sea, rounded to the nearest 100 acres.

Type of Habitat	Preferred habitat, 1999 (acres)		Preferred habitat, 2015 (acres)	
Playa	10,600		12,200	
Mudflats and shallow water	26,100	(12,000 - 65,100)	28,000	(13,600 - 65,700)
Mid-depth water	18,900	(7,800 – 41,000)	19,900	(8,100 - 43,400)
Deep water	52,400	(46,000 - 61,300)	53,000	(46,500 - 61,700)
Permanent vegetated wetlands	2,500	(500 - 7,800)	3,100	(700 - 8,600)
Aggregate[1]	**58,400**	**(51,000 - 73,200)**	**57,600**	**(50,200 - 72,500)**

1. The aggregate is calculated as the combined footprint of all five types of habitat. Because some habitats overlap at the scale modeled, the aggregate is not equal to the sum of the five types of habitat.

Table 3 and Figure 2 (below) show how the amount of preferred habitat has changed between 1999 and 2015. Although the sea has shrunk in the 15-year interval, the estimates of aggregate habitat between 1999 and 2015 differ by only a relatively small amount.
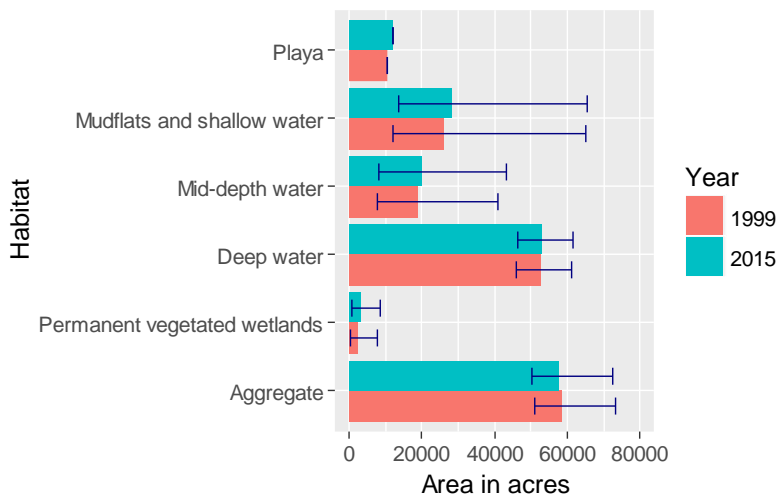

Figure 2. Estimated amounts of preferred avian habitat for each habitat category, and total, in the Salton Sea between 1999 and 2015. Error bars show amount of preferred habitat if all (lower bound) or half (upper bound) of the indicator species are present. For the aggregate estimate, they are the area where all of half of the habitats overlap.

We provide area estimates for the weighted mean of all intersections of indicator species, and for two extremes: all species overlapping (lower estimate) and half of them overlapping (upper estimate). Though these extremes are relatively large, the mean estimates show only a small change in total area by habitat type and in total between 1999 and 2015.
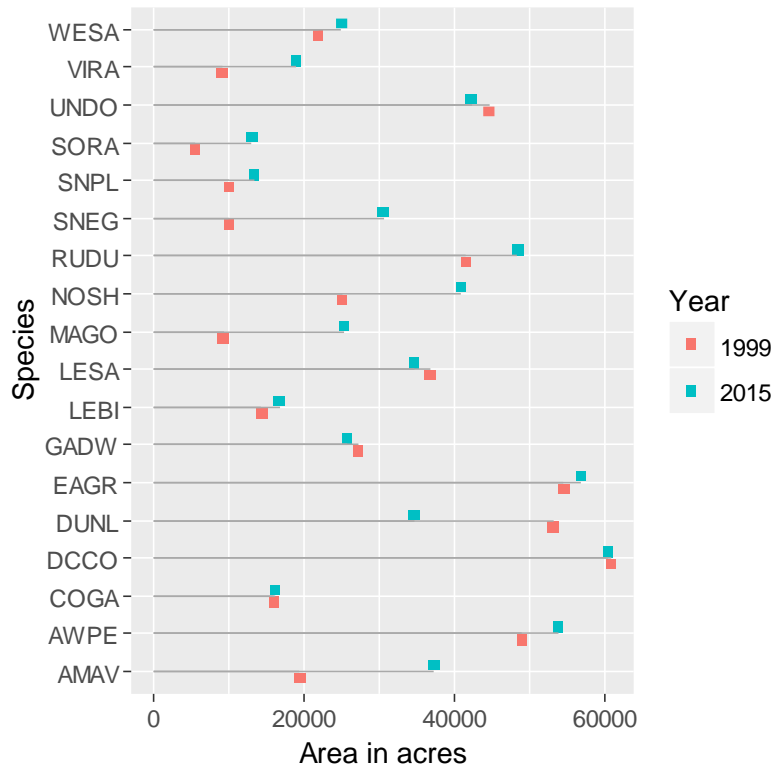

Figure 3. Change in area of preferred habitat by indicator species in the Salton Sea, between 1999 and 2015.

The small change in total avian habitat is also a reflection of the relatively small change in preferred habitat for about two-thirds of the indicator species between 1999 and 2015 (Figure 3). Increases in preferred habitat for wetland species (e.g., Snowy Egret, Virginia Rail) are evidenced by the establishment of new managed wetlands in the period. Notably, for some shorebirds there were notable increases, as well as notable decreases, in preferred habitat area. The American Avocet and Marbled Godwit showed a growth in preferred habitat in the period, whereas the opposite was true for the Dunlin.

Figures showing the extent of preferred habitat for each habitat type are included in Appendix D.

DISCUSSION

DRIVERS OF HABITAT USE

Our findings on four key features that drive habitat use at the Salton Sea are discussed below.

Amount of shallow water. Riedel et al. (2002) noted the importance of shallow water to provide nearshore habitats for many species and estuaries for fish throughout their life cycle. As the shoreline recedes, more shallow water and playa could come into existence. However, in order for receding waters to benefit birds over the longer term, other resources such as appropriate sediments and food must be present in order for playa to be considered suitable habitat.

Sediment composition. Prior studies (Warwick et al. 2002; Detweiler et al. 2002) have noted that the nematode and benthic invertebrate fauna in the sea are restricted to the band of waters < 2.5 m deep, and that this band contains a rocky and complex sediment mix that permits these prey for fish and birds to hide and reproduce. Another important factor is that the deeper water becomes anoxic seasonally and causes die-offs of invertebrates and fish (W. D. Shuford, pers. comm.).

Amount of open water. Species like Eared Grebe likely prefer a minimum area of water to maintain a buffer from disturbance, and there likely is some minimum size that is necessary to enable a pelican to take off. A large body of water like the Salton Sea may provide some beneficial buffering functions, such as temperature regulation, to adjacent shallower water and shoreline-adjacent habitats (D. A. Barnum, pers. comm.). Such functions could be lacking if newly constructed habitats are independent of or separated from a large body of water. On average, larger bodies of water are going to have more food and support more birds.

Proximity to rivers and river mouths. There may be various reasons for this covariate being so important. Perhaps the most likely explanations are sediment composition, amount of organic matter and prey density, and salinity. Salinity is another driver for the presence of fish species, and many birds, especially young birds, cannot handle high salinity levels and need access to freshwater for drinking. As described above, salinity was not included in the model but is presented in the recipe cards.

EXTENT OF PREFERRED HABITAT

The amount of preferred avian habitat that we estimated for both 1999 and 2015 is about 58,000 acres (23,472 ha). In contrast, the PEIR (CNRA 2006b) estimates that "the physical area that supported the majority of the recent level of bird use is roughly 38,000 acres (15,378 ha)," based on the area of the sea within 0.6 miles (roughly 1 kilometer) of the shoreline. Though our approach was quite different, in part because we include other near-sea habitats like playa and permanent vegetated wetlands, the two estimates are the same order of magnitude. Part of the difference may be explained by the PEIR definition of "supporting the majority of the recent level of bird use." With playa supporting mostly Snowy Plovers, their numbers barely register relative to the rest of the species using the sea. Wetlands hold many more species and individuals than does playa, but still the numbers in wetlands may still pale in comparison to the numbers on the sea proper.

Our results show little change in total area of avian habitat, and also of the area of the individual habitat types since 1999. Though our methodology is not intended to determine if the change in the aggregate

of preferred habitat is significant, mirroring the change in the size of the lake, some results are worth noting. First, there has been an increase in playa of about 1,600 acres (648 ha). (Note: the total exposed sea area increase is ten times larger (Cohen 2014), but the preferred habitat is confined to 1 km or less from the shoreline or any wetlands within 5 km of the sea, so we consider a smaller area to be actual playa nesting habitat). Similarly, within the study area there has been an increase in deep water, defined here as 30 cm to 2.5 m (~3,000 acres [~1,214 ha]), due to the bathymetry of the sea. The decrease in mud and mid-depth water areas has been minimal (approximately 7 and 45 acres [3 and 18 ha], respectively), again due to the bathymetry of the sea. In addition, at least 365 acres (148 ha) (IID 2016) of wetlands have been created since 1999 around the sea. So, overall, there has been a net gain of area for each of the five habitat types, which, combined, represent a small decrease in area of preferred habitat in aggregate (measured as the combined footprint, or union, to avoid double counting).

We note that our goal was to obtain estimates for 1999 by modeling the more abundant data from 2011-2015. There are no equivalent, publicly accessible bird survey datasets from 1999 and 2015 that would permit us to perform statistical analyses to establish if changes in preferred habitat areas are statistically significant. Moreover, we did not model the data to establish the likely reasons for change. The results presented here are the predictions of a model for each habitat type, i.e., hypotheses that are assumed to be correct to the degree the models are correct. New datasets would be useful to test the accuracy of the models and the 1999 estimates.

Interestingly, our results suggest that there has been an increased overlap of the five types of preferred habitat as the water level drops. This increase in overlap can mask any reduction of habitat, because our definition of total preferred habitat is measured as all areas where preferred habitat exists for any of the individual habitat groups. Thus, the total area and area by habitat type is a balance between the total area lost for some habitats as water recedes, on the one hand, and the increased overlap of areas of preferred habitat, on the other. The general overlap can be seen in the numbers presented in Table 2 above. Table 2 shows that there has been an increase in the amount of individual avian habitats, in all habitats we considered, between 1999 and 2015, despite a decrease in the aggregate extent of all preferred avian habitat.

However, for the five types of habitat, greater areas of preferred habitat in 2015 versus 1999 are only partially explained by greater areas of use for each indicator species. For example, we calculated that the area used by the indicator species for the mud/shallow water habitat of the Salton Sea increased by some 6,300 acres (2,550 ha), yet acreage of preferred habitat only increased by 2,000 acres (809 ha). Similarly, the area used by indicator species for mid-depth water habitats increased overall by >15,000 acres (6,070 ha), despite an increase of only ~1,000 acres (~405 ha) for preferred habitat.

We present our estimates with a degree of uncertainty and subject to limitations (see Appendix B). The uncertainty reflects the fact that the indicator species we selected within each group are complementary (i.e., not replicates of one another), in that any one species is a poor representative of the habitat selection of the others using the same habitat type. It is perhaps impossible to choose a set of species that will not show similarly large uncertainties, as it is equally difficult to choose a set of species that provide an objective characterization of the avian habitats in the Salton Sea. We intend our findings to be generally applicable, however, by including as indicator species not just those that are typical of each habitat type, but many that are among the most common and numerous in the Salton Sea.

In light of the inherent uncertainty, we compared our results to those in Shuford et al. (2000), which summarized the results of the 1999 survey by 19 shoreline segments (Figure 4).
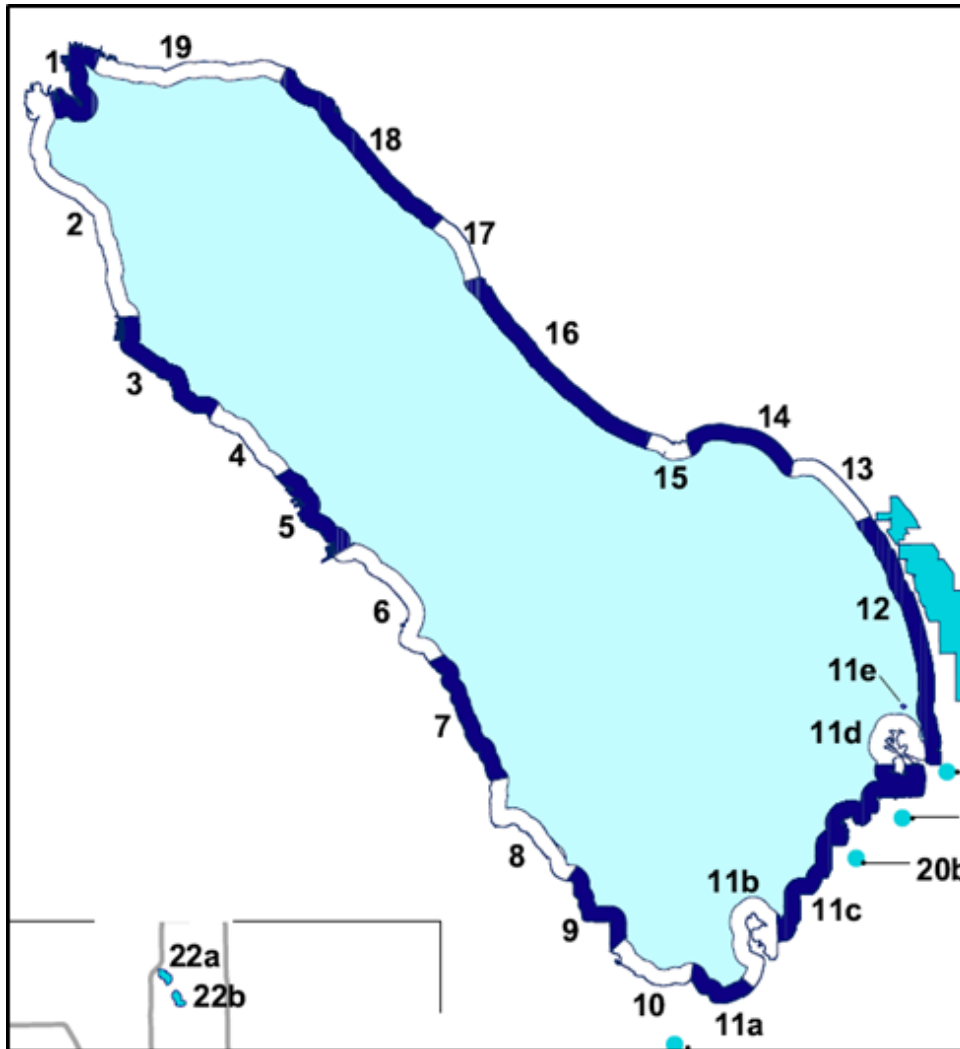

Figure 4. Map excerpted from Shuford et al. 2000, showing 19 survey segments for comparison with the present analysis.

PLAYA

Shuford et al. (2000) described the areas of highest use by Snowy Plover in 1999 as follows:

> Areas of particular importance include the shoreline and expansive alkali flats from Iberia Wash south through the northern portion of the Salton Sea Test Base and San Felipe Creek Delta (Area 6, northern part of 7, and 8) and the shoreline, breached impoundments, and sand spit paralleling Davis Road and the Wister Unit of Imperial WA (Area 12). In 1999, these areas, respectively, held about 44% and 33% of all plovers in January and 55% and 18% in May.

These areas are on the western shore of the sea from the middle portion toward the southern end, and on the southernmost part of the eastern shore. Our results show that exposed playas in specific areas around the sea contain some amount of preferred habitat for this group (Figure D-1). The areas with the

largest amount of contiguous playa habitat are on the southernmost part of the eastern shore (segment 12 of Shuford et al. 2000), but also the southern and southwestern end of the sea (segments 8, 9, 10 and 11 in the 1999 survey). The areas of segments 6 and 7 are also predicted to host large areas of preferred habitat. Our model predicts some patches of preferred habitat on the north end, whereas Shuford et al. (2000) did not report large numbers in this area. Consequently, our results are largely concurrent with the 1999 surveys for playa habitats.

Our model showed an increase in preferred playa habitat from 1999 to 2015 (Figure D-2).

MUDFLATS AND SHALLOW WATER

Shuford et al. (2000) reported the most shorebirds (the closest equivalent to our indicators for this habitat type) occurring in segment 12 (southeastern part of the lake) and segments 1 and 11, and both the north and south ends of the sea, respectively (see their Figure 5 – 4a). Their results are mirrored by ours. The predictions from our model (Figure D-3) are well in agreement with the 1999 survey results. Our 2015 predictions show an increase in the area of this preferred habitat, still confined to the north and south ends (Figure D-4).

MID-DEPTH WATER

Our predictions for 1999 occurrence of the mid-depth avian habitat – the Black Skimmer, Snowy Egret, Northern Shoveler, and Gadwall – show this habitat occurring almost exclusively on the northern and southern ends of the sea (Figure D-5). Shuford et al. (2000; Figure 5-3a) mapped the distribution of wading birds by segments of the Salton Sea, showing a similar concentration of this bird group at the north and south end. Model result predictions show that this habitat changes little from 1999 to 2015 (Figure D-6).

DEEP WATER

Deep-water habitats are found throughout the perimeter of the sea but encompass larger areas toward the north and south ends of the sea (Figure D-7). Results from Shuford et al. (2000, Figure 5-2a) largely concurs with this result. Their plot of total numbers of pelecaniformes (pelicans and cormorants), the closest equivalent to our deep water indicator species, showed these species using all areas around the perimeter, with larger numbers at the north and south ends.

Perhaps the only notable disagreement between our results and the 1999 survey is in what Shuford et al. (2000) referred to as segments 6 and 14 of the shoreline. Shuford et al. 2000 showed that these are areas used by the deep water species – in particular segment 6, and segment 14 compared to adjacent segment 15. Notably, our model results for 1999 predict limited preferred habitat in segment 6 and very little in segment 14 compared to segment 15, the opposite of survey results. Thus we conclude that there is limited agreement between the results of the 1999 survey and our model predictions for this avian habitat. This is probably largely an artifact of the fact that a very high proportion of cormorants and pelicans counted in the 1999 were at roost sites rather than out on the open water. So, the patterns of birds described in Shuford et al. 2000 was largely a reflection of suitable roost sites rather than deep-water foraging habitat.

Our model predicts very small changes between 1999 and 2015 in the distribution of deep water avian habitats (Figure D-8).

PERMANENT VEGETATED WETLANDS

Permanent vegetated wetlands are predicted to occur, based on our model results, along the southern and northern ends, and in discrete locations along the north shore (Figure D-9). Perhaps the only comparable data from the 1999 survey is the map of distribution of Yuma Ridgway Rail (then Yuma Clapper Rail), in Figure 4 – 4 of Shuford et al. 2000. Since these rails are found only in wetlands, it is not surprising that their locations agree with our predictions. Inspection of counts reported in Appendix B of the 1999 survey report indicate that very few of the indicator species were detected (usually < 10 individuals of each species). Thus we conclude that we lack the information to properly test the accuracy of our predictions for this habitat type. Figure D-10 shows that this habitat changes little in 2015, according to our predictions.

FUTURE MONITORING RECOMMENDATIONS

Conscious of the limitations in the data and of our modeling approach (see Appendix B), we suggest following the recommendations in the Salton Sea Ecosystem Monitoring and Assessment Plan (Case III et al. 2013), or MAP, for an integrated data management approach. The amount of information from the Salton Sea, especially scientific works, is very limited. The only comprehensive survey of the sea avifauna occurred in 1999 (Shuford et al. 2000) and any subsequent surveys have been limited. The USGS only recently was awarded funds to begin monitoring Yuma Ridgway's Rails, and preliminary results based only on one year of data will not be available until next year. The MAP proposes the integration of all data sources through a single repository, or through data standards and distributed repositories that permit data discovery, as the reviewers of this work pointed out.

A strong inference approach is possible while following the recommendations in the MAP. The coordinated development and interpretation of data permits the establishment of adaptive management mechanisms through judicious trial and error, as briefly depicted in the MAP. It is also possible to develop models that incorporate the relative importance of salinity and other parameters in differentially explaining the behavior of populations of birds at the sea. This approach would then provide for means to assess the relative importance of each influencing factor through the support provided to each model by future survey data (see Nichols et al. 2015 for a discussion of this approach and how it translates to policies and management). Further, management decisions could be based on a model average of all competing models. Considering that rapid changes are expected to occur at the sea in the coming years and that little is known about use of the Salton Sea by bird species or the relative importance of factors at local-to-flyway scales, the development of a strong inference approach to developing, maintaining, and disseminating knowledge to management agencies seems not only appropriate but critical.

Several of the abovementioned reports (e.g., Shuford et al. 2000, 2002; Jehl et al. 2002; Case III et al. 2013, Howell and Shuford 2008) note that the Salton Sea is of great regional importance, as birds come in large numbers to breed, overwinter, or stopover during migration. Thus it is important to also understand how the management of the Salton Sea will affect, and be affected by, changes at other locations and larger spatial scales (e.g., flyway level). Although not specifically addressed in the current work, the use of volunteer-generated data permits an understanding of the status of the Salton Sea and of management actions at multiple spatial scales (Fink et al. 2010).

KEY CONCLUSIONS

From this report, we can draw several important conclusions:

- Birds used approximately 58,000 acres of habitat in both 1999 and 2015.

- Five key habitat types are used by birds at the Salton Sea: playa; mudflats and shallow water; mid-depth water; deep water; and permanent vegetated wetlands.

- The area of each of the five habitat types used by birds was comparable between 1999 and 2015, even though the actual physical locations of those habitats changed as the sea receded.

- Four factors appear to be strong drivers of bird use of Salton Sea habitat: amount of shallow water, sediment composition, amount of open water, and proximity to rivers and river mouths.

- Report results may not provide a good comparison of the *quality* of habitat, or of the size of bird populations, between 1999 and 2015.

- The amount and quality of the data and how they were collected limited the ability to quantify the effects of selenium, salinity, water temperature, water body size, food resources, and flyway impacts. A lack of standardized bird monitoring data and issues around the scale and shelf life of environmental data also presented challenges.

- The recommendations in the Salton Sea Ecosystem Monitoring and Assessment Plan pertaining to developing, maintaining, and disseminating knowledge to management agencies, along with future standardized bird surveys, would enable future updates and improvements to these models.

ACKNOWLEDGMENTS

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APPENDIX A: BREEDING WATERBIRDS

The Salton Sea has been an important nesting site for waterbirds since shortly after its inception (Grinnell 1908), and it currently supports 39 species of breeding waterbirds. Of these, 27 species breed regularly, though not necessarily every year, at, or in close proximity to, the Salton Sea (Table A-1). Another 12 species breed very rarely or irregularly, or bred formerly, at or near the Salton Sea (Table A-2). Consequently, conservation efforts at the sea in the breeding season on behalf of these 12 species are unlikely to be effective in substantially augmenting local or regional breeding populations. Hence, the focus here is on the 27 species that currently breed regularly at the Salton Sea.

TAXONOMIC AFFINITIES

The 27 regular breeders include three species of waterfowl (1 dabbling duck, 2 diving ducks), three species of grebes, five species of rails or coots, four species of shorebirds, four species of larids (gulls, terns, skimmers), one species of cormorant, and seven species of ardeids (bitterns, herons, egrets, and night-herons).

COLONIAL NESTING WATERBIRDS

Nesting substrates. Of the 27 regular breeders, 12 species are colonial nesters that generally breed in mixed assemblages of like species. Western and Clark's grebes nest together, or by themselves, building floating nests near dense vegetation at freshwater lakes and river mouths. The four larids – California Gull, Western Gull-billed Tern, Caspian Tern, and Black Skimmer – typically nest on the ground in mixed-species colonies on the same or adjacent islands. Formerly most larid nesting sites were on nearshore islands at the south end of the sea, but currently all are on earthen islands or floating platforms in impoundments near the southern or southeastern shore. The five ardeids – Great Blue Heron, Great Egret, Snowy Egret, Cattle Egret, and Black-crowned Night-Heron – usually nest in mixed species colonies in trees sometimes accompanied by nesting Double-crested Cormorants. Although the largest cormorant colonies have been on Mullet Island, where they nested on the ground, most cormorant colonies have been in trees. Some cormorants and Great Blue Herons nest at the Salton Sea on artificial structures, including duck blinds, barges, and power poles (Table A-2).

Foraging habitat. During breeding, the Western and Clarks grebes likely forage primarily at their nesting sites in the large freshwater lakes in the Imperial Valley and rivers mouths at the Salton Sea, but some may forage in the sea itself. Of the four larids, three species – California Gull, Caspian Tern, and Black Skimmer – forage mainly if not exclusively at the Salton Sea during breeding. The foraging niche of the Western Gull-billed Tern is much broader, as it feeds along the shoreline of the Salton Sea and in adjacent impoundments, irrigation canals, scrub habitats, and (particularly flood-irrigated) agricultural fields. Although Double-crested Cormorants forage both in the Salton Sea and in freshwater lakes and impoundments, the thousands previously nesting on Mullet Island apparently obtained the bulk of their sustenance from the Salton Sea. Overall the five ardieds are generalists, though they vary in the amount on which they depend on the Salton Sea versus adjacent freshwater habitats and agricultural fields for foraging (Table A-1). The Cattle Egret forages almost exclusively in agricultural fields in Imperial Valley, the Snowy Egret mainly in freshwater habitats, but the other three species may feed on the shoreline of Salton Sea and in freshwater habitats and agricultural fields far from the sea.

SOLITARY NESTERS

Of the 27 regular breeders, 15 are generally solitary nesters, though the Black-necked Stilt and American Avocet may nest in loose colonies in favorable habitat. Of the 15, 12 species are associated during breeding either mainly or entirely with freshwater habitats, including managed and natural marshes, lakes, rivers, streams, and irrigation canals (Table A-1). The three exceptions are all shorebirds. The Black-necked Stilt has the greatest freshwater tendencies of the three, but it does nest adjacent to the Salton Sea and can forage along its shoreline, particularly at river mouths. The American Avocet breeds adjacent to the Salton Sea, often at brackish water impoundments and can forage in these or along the shoreline of the sea. The Snowy Plover nests and forages almost exclusively on alkali playa and barnacle or sandy beaches near the shore of the Salton Sea, but sometimes nests 100 m or more from the shoreline.

Of the 15 solitary nesters, nine species – Redhead, Ruddy Duck, Pied-billed Grebe, California Black Rail, Yuma Ridgway's Rail, Virginia Rail, Common Gallinule, American Coot, and Least Bittern – nest exclusively in areas with permanent or semipermanent freshwater marshes with relatively deep water and varying amounts of tall emergent vegetation. The three species of rail and the Least Bittern spend the vast majority of their time within the cover of emergent vegetation. The Cinnamon Teal also requires permanent or semipermanent marshes for nesting, but forages in relatively shallow water and avoids tall emergent vegetation. The Killdeer occupies the widest niche, nesting widely on open, often gravelly, ground and foraging along the shoreline of the sea (especially at river mouths), in variety of agricultural fields, on the edges of lakes and reservoirs, and on extensive lawns in towns.

TRENDS, DYNAMICS, AND LIMITING FACTORS

Trends and dynamics. The size and composition of the breeding waterbird community at the Salton has varied greatly over time with the colonization by certain species, the extirpation of others, and fluctuations in population of many species. Hurlbert et al. (2007) documented strong temporal dynamics in populations of fish-eating birds that followed the boom-and-bust cycle of fish populations at the Salton Sea. Historical records indicated that the fish biomass at the sea increased dramatically throughout the 1970s (after the introduction of tilapia), crashed in the late 1980s, recovered in the mid-1990s, and crashed again in the early 2000s. In particular, the highly sporadic recruitment of tilapia year classes seemed to be the major factor driving the large variations in fish biomass at the sea in recent decades. These authors speculated that fish crashes primarily reflect three physiological stressors – rising salinity, cold winter temperatures, and high sulfide levels and anoxia associated with water mixing events. Another rebound in fish populations appears to have occurred starting in the mid-2000s, but few hard data exist (e.g., from recent fish surveys).

Although trends over broader regions might explain some of the changes in waterbird populations at the Salton Sea, the regional trends have not shown similar large population crashes and recoveries (Suryan et al. 2004, Hurlbert et al. 2007, Collis et al. 2012, Adkins et al. 2014). Among the species showing dramatic population fluctuations at the Salton Sea are the Double-crested Cormorant and Caspian Tern. Numbers of breeding pairs of Double-crested Cormorants reached high levels from 1996 to 1999 (a peak of at least 5425 pairs in 1999; Shuford 2010), did not nest on Mullet Island in at least 2001 and 2002 (Molina and Sturm 2004), and rebounded again ten years later (at least 6594 pairs in 2012; Molina and Shuford 2013, Shuford 2014). Cormorants have not nested on Mullet Island since 2012, as declining water levels enabled land predators to easily reach the island, discouraging cormorant

nesting. Caspian Terns ranged from 800–1500 pairs from 1996–1998 and >1000 pairs annually from 2007–2012 (K. Molina unpubl. data in USFWS 2014); and few to no pairs in recent years (C. Schoneman, pers. comm).

Population declines and large mortality events of nonbreeding Eared Grebes at the Salton Sea may also be caused by periodic crashes of the grebe's main prey item there, the pile worm (*Neanthes succinea*), from high sulfide levels and anoxia associated with water mixing events (Anderson et al. 2007). It is unclear if similar crashes have occurred for other invertebrate populations that make up the diets of some breeding shorebirds, such as stilts and avocets, that forage along the shoreline of the sea. Likewise the population trends of breeding stilts and avocets are unknown, as no sea-wide nesting surveys have ever been attempted for these birds.

There is no evidence that populations of herons, egrets, and night-herons are fluctuating greatly in response to crashes and rebounds of fish populations in the Salton Sea (Hurlbert et al. 2007), although data on these species are limited. It may be that these species are buffered from changing fish populations in the sea by their generalist diets, which include a variety of vertebrate and invertebrate prey, and use of additional freshwater and agricultural foraging habitats.

Limiting factors and threats. The main limiting factor for many breeding species that depend on the Salton Sea appears not to be the extent, but rather the quality, of suitable nesting or foraging habitat. The boom-and-bust cycles of fish populations (particularly tilapia) in the sea make it difficult to support relatively stable populations of fish-eating birds. This may become a moot point, however, as the sea declines and salinity increases to the point that no fish are able to survive except small numbers near the inflows of rivers and agricultural canals. This may cause a permanent crash in some populations of fish-eating birds (e.g., for Caspian Terns) unless restoration projects ensure that large impoundments have the proper conditions to support robust fish populations, which could include desert pupfish (*Cyprinodon macularius*) (Sakai et al. 2011). Species of ardeids are likely to be much less affected given their more generalist diets and use of freshwater and agricultural habitats. The decline in the level and increase in salinity of the Salton Sea is unlikely to have much effect on the various solitary nesters that breed in freshwater marshes as long as these habitats continue to have an adequate water supply and are managed similarly to how they are today.

A lack or paucity of suitable nest sites safe from mammalian predators is a key limiting factor for ground-nesting colonial waterbirds, such as the Western Gull-billed Tern, Caspian Tern, Black Skimmer, and Double-crested Cormorant. As the sea has declined and a receding shoreline has stranded former nearshore islands, there has been a reduction of nesting sites for ground-nesting colonial waterbirds (Molina 2004, USFWS 2014). Creation of additional earthen islands, or floating platforms, at the Sonny Bono Salton Sea National Wildlife Refuge (NWR) has provided some relief, but, even with the use of electric fences to deter predators, coyotes and raccoons have reduced nesting success or caused abandonment of island colonies. This pattern of colonization and initial breeding success followed by heavy predation after two or three years is not sustainable for supporting robust populations of ground-nesting birds. Consequently, U.S. Fish and Wildlife (2014) has developed a predator management plan for the Sonny Bono Salton Sea NWR that focuses on the Western Gull-billed Tern and Black Skimmer because of their high vulnerability to predation and their heightened conservation status (Molina and Erwin 2006; Molina 2008a, b; Molina et al. 2010). In addition to direct predator control, the plan includes recommendations for structural features of impoundments and islands that will limit predator

access (USFWS 2014). Other ground-nesting larids and shorebirds will, of course, benefit as well. Ground-nesting larids may also be affected by predation or displacement by nesting California Gulls, by displacement by larger nesting waterbirds such as cormorants, or by nests destroyed by nonbreeding pelicans vying for loafing space on small islands (USFWS 2014).

Pesticides and other contaminants in the Salton Sea are a potential threat to breeding waterbirds through concentration in their fish prey (Sapozhnikova et al. 2004), but there is no documentation of substantial effects on reproductive success to date (summary in USFWS 2014). Selenium is also a potential threat to waterbirds. Studies in the Salton Sea area have confirmed reduced reproduction of certain fish and bird species from elevated selenium levels, including embryo mortality in Black-necked Stilts and several species of colonial-nesting ardieds (USFWS 2014). The selenium concentrations in agricultural drainage water of the Imperial Valley is elevated enough to cause some reproductive impairment, but it currently is not high enough to pose a significant ecological threat to the large numbers of birds that pass through the area on migration. This might change, however, as the concentration of selenium in agricultural waste water is expected to increase with on-farm water conservation related to water transfer agreements (T. Anderson, pers. comm.). The greatest threat to waterbirds from selenium might come from heightened concentration of this element in impoundments built to restore habitat and fed by agricultural drainwater. Hence, there is a need to monitor selenium in water, sediments, and biota at the sea and particular in impoundments where it might be concentrated to harmful levels (Case et al. 2013).

Human disturbance is a potential threat to breeding waterbirds, including species breeding at the Salton Sea (e.g., Safina and Burger 1983). It is possible that human disturbance has decreased on islands and at river mouths at the sea in recent years as reduced boating activity accompanied a declining interest in sport fishing (Molina 1996). However, vigilance is needed to ensure that current and future human activities do not disrupt successful nesting.

It is likely, at least in the short term, that some species such as the Snowy Plover will benefit from the declining water level as it increases their suitable nesting habitat. Surveys of the number of breeding plovers at the Salton Sea were relatively stable at 226 in 1978, 198 in 1988, and 221 in 1999 (Henderson and Page 1981, Page et al. 1991, Shuford et al. 2004) then jumped to 306 in 2007 (Thomas et al. 2012) following a period of dropping water levels and increased playa and beach habitat. This pattern appears to be comparable to that at Mono Lake, where there has been a positive relationship between the amount of exposed alkali playa with a declining lake level and the size of the population of nesting Snowy Plovers (Shuford et al. 2016). The continuing decline in the level of the Salton Sea will expose a large amount of lakebed, which will lead to excessive dust emissions that pose a human health hazard. If water is used to shallowly flood the exposed playa to reduce dust emissions, it likely will further increase the size of the Snowy Plovers population at the Salton Sea, as has been the case at Owens Lake after shallow flooding there to control dust (Ruhlen et al. 2006).

Overall, limiting factors and threats are the greatest for breeding fish-eating waterbirds that depend on the Salton Sea for sustenance and those birds that nest on the ground at the few sites where islands remain. These species should be given high priority in current and future management and restoration projects. We also caution not overlooking the needs of species, particularly threatened and endangered species such as the California Black Rail and Yuma Ridgway's Rail, that nest in freshwater marshes that may not be substantially affected by the declining level of the Salton Sea.

Table A-1. Seasonal status, relative abundance, and habitat use of 27 species of waterbirds that breed regularly at or near the Salton Sea.

Species	Status and abundance	Habitat use	Source
Cinnamon Teal (*Anas cyanoptera*)	Occurs year round: common, spring and fall; uncommon summer (breeds) and winter.	Freshwater marshes and impoundments, reed-lined ditches and canals, marshy lake fringes, river channels, small ponds.	Patten et al. 2003
Redhead (*Aythya americana*)	Fairly common, year round (breeds).	For breeding, freshwater marshes and lakes with dense fringing stands of cattail or *Phragmites*; also canals with slow-moving water and cover. In winter, many move to the Salton Sea, others remain on large water bodies in valleys.	Patten et al. 2003
Ruddy Duck (*Oxyura jamaicensis*)	Abundant, winter; fairly common, summer (breeds). Vast majority at Salton Sea; only small numbers in Imperial Valley.	Breeding habitat similar to that for the Redhead; winters in large numbers on the Salton Sea, as well as on freshwater lakes and reservoirs.	Patten et al. 2003
Pied-billed Grebe (*Podilymbus podiceps*)	Fairly common, year round (breeds).	Freshwater marshes, lakes, slow-moving rivers, sloughs, lagoons. Small numbers winter on Salton Sea.	Patten et al. 2003
Western Grebe (*Aechmophorus occidentalis*)	Common, year round (breeds); less numerous in summer. In winter, mainly at Salton Sea.	Breeds at larger lakes in the Imperial Valley (where outnumbers Clark's Grebe by 4:1 or more) and river mouths at the Salton Sea (where outnumbered by the Clark's Grebe at the north end).	Patten et al. 2003
Clark's Grebe (*Aechmophorus clarkii*)	Uncommon, year round (breeds). In winter, mainly at Salton Sea.	See Western Grebe.	Patten et al. 2003

Table A-1 (cont'd)

Species	Status and abundance	Habitat use	Source
California Black Rail (*Laterallus jamaicensis coturniculus*)	Rare and local, year round (breeds).	Marshes at seeps along the All-American and Coachella canals, (some fed by seepage from canals) at mouths of creeks and rivers at the Salton Sea, and along rivers, lagoons, or wildlife areas in the Imperial Valley in mosaics of cattail, willow, *Salicornia*, and *Phragmites*. A thick understory and moist mud or a thin skim of water seem important.	Evens et al. 1991, Patten et al. 2003
Yuma Ridgway's Rail (*Rallus obsoletus yumanensis*)	Year round; uncommon breeder, rare winter. Mainly in managed and natural marshes fringing the south end of the Salton Sea (small numbers formerly at north end).	Requires dense freshwater marshes (cattail, *Phragmites*) with abundant crustacean prey.	Patten et al. 2003, C. Marantz pers. comm., eBird
Virginia Rail (*Rallus limicola*)	Uncommon, year round (breeds); likely more numerous in winter.	For breeding, dense cattail marshes (also bulrush and, perhaps, *Phragmites*) with standing fresh water. Non-breeders also in flooded areas with an overstory of mesquite or tamarisk.	Patten et al. 2003
Common Gallinule (*Gallinula galeata*)	Fairly common, year round (breeds).	Breeds in cattail clumps on the edges of rivers, wide irrigation canals, and freshwater ponds, lakes, and impoundments. Forages mainly in open water near cover at pond or river edges.	Patten et al. 2003
American Coot (*Fulica americana*)	Year round; common as breeder, abundant in winter.	Breeds in dense cover, particularly cattail and bulrush, at edges of ponds, lakes, rivers, and large irrigation canals. Forages in open water.	Patten et al. 2003

Table A-1 (cont'd)

Species	Status and abundance	Habitat use	Source
Black-necked Stilt (*Himantopus mexicanus*)	Abundant, year round (breeds irregularly). Most occur at Salton Sea (shoreline) and adjacent impoundments.	Breeds on the ground in loose colonies close to water. Birds forage in shallow pools and impoundments, being concentrated near river mouths. Also feeds in freshwater ponds, large canals, and in flood-irrigated fields (primarily bare fields or low-stature hay fields [bermudagrass, alfalfa]).	Patten et al. 2003; PRBO unpubl. data, Shuford pers. obs.
American Avocet (*Recurvirostra americana*)	Abundant, year round (small numbers breed). Most occur at Salton Sea (shoreline) and adjacent impoundments.	Nest sites tend to be in or near backwaters or shallow pools isolated from, but adjacent to, the sea. Favors shallow brackish waters for foraging, along the shoreline and especially in impoundments and backwaters adjacent to the sea.	Patten et al. 2003
Snowy Plover (*Charadrius nivosus*)	Fairly common, year round (breeds). Exclusively at the Salton Sea; a few in adjacent impoundments.	Nests primarily on barren alkali playa and sand and barnacle beaches, sometimes far from the shoreline of the sea; occasionally nests on the alkali-encrusted bottoms of dry impoundments. Forages on similar shoreline habitats.	Shuford et al. 1995, 2004; Patten et al. 2003
Killdeer (*Charadrius vociferus*)	Common, year round (breeds).	Forages along the shoreline of the sea (especially at river mouths), in agricultural fields (wet or dry) from bare to short vegetation, on the edges of lakes and reservoirs, and on extensive lawns in towns (ball fields, parks, golf courses). Nests on open, often gravelly, ground.	Patten et al. 2003

Table A-1 (cont'd)

Species	Status and abundance	Habitat use	Source
California Gull (*Larus californicus*)	Common, winter; fairly common, summer (small numbers breed, recently only at the south end of the Salton Sea).	Since colonizing the Salton Sea in 1996, has bred on nearshore islands (bare earth, sand, barnacle, or rocky substrate) and on barren islets or floating platforms in impoundments. Forages mainly along the shoreline of the Salton Sea; many fewer in flood-irrigated and dry agricultural fields and freshwater reservoirs, lakes, and ponds throughout the Imperial Valley.	Molina 2000, 2004; Patten et al. 2003, USFWS 2014
Western Gull-billed Tern (*Gelochelidon nilotica vanrossemi*)	Fairly common, spring and summer (breeds); casual, winter. Recently has bred only at the south end of the Salton Sea and in adjacent impoundments; small numbers formerly nested at the north end of the Salton Sea.	Nests on islets or eroded levee fragments (with bare earth, sand, barnacle, or rocky substrate) and on floating platforms nearshore or in impoundments (mainly). Forages along the shoreline of the Salton Sea and in adjacent impoundments, and in scrub habitats, (particularly flood-irrigated) agricultural fields, and irrigation canals near the sea.	Patten et al. 2003, Molina 2004, 2008a; Molina et al. 2009, 2013; USFWS 2014
Caspian Tern (*Hydroprogne caspia*)	Common, spring to fall; uncommon to irregularly fairly common, winter.	Nesting habitat similar to that of the Gull-billed Tern. Forages along the shoreline of the Salton Sea, but also in rivers and wide irrigation canals and in ponds, lakes, and reservoirs in the Imperial Valley.	Patten et al. 2003
Black Skimmer (*Rynchops niger*)	Fairly common, spring to late fall (breeds). Recently has bred only at the south end of the sea and in adjacent impoundments; small numbers formerly nested at the north end of the sea and at Ramer Lake in the Imperial Valley.	Nesting habitat similar to that of the Gull-billed Tern. Forages primarily in relatively shallow nearshore areas of the sea.	Patten et al. 2003; Molina 1996, 2004, 2008b; Molina et al. 2009; USFWS 2014

Table A-1 (cont'd)

Species	Status and abundance	Habitat use	Source
Double-crested Cormorant (*Phalacrocorax auritus*)	Common, year round (breeds); numbers higher in winter.	Recently the largest colony was on earthen and rocky substrate at Mullet Island, which is now (as of 2013) abandoned; at the sea, also nests in submerged trees or snags near river mouths and on artificial structures (blinds, barges, power poles) and trees and snags at large lakes (e.g., Finney and, especially, Ramer lakes). Forages in shallow to moderate depths in the Salton Sea and at modest to large impoundments and lakes.	Patten et al. 2003, Molina and Sturm 2004; Molina and Shuford 2013; Shuford 2014
Least Bittern (*Ixobrychus exilis*)	Fairly common, spring to fall (breeds); uncommon, winter.	Freshwater marshes (especially dense cattail stands; also *Phragmites*, tamarisk) along rivers, wide irrigation ditches, and lake edges.	Patten et al. 2003
Great Blue Heron (*Ardea herodias*)	Common, year round (breeds). Largest numbers at Salton Sea.	At the Salton Sea has nested on Mullet Island (pre-2013), in nearshore snags and submerged trees, and on artificial structures (duck blinds, barges, power poles). Nests sporadically at lakes/impoundments. Forages in ditches and canals, ponds, lake shores, along the edge of the Salton Sea, and in well-flooded to dry agricultural fields.	Shuford et al. 2000, Patten et al. 2003, Molina and Sturm 2004
Great Egret (*Ardea alba*)	Common, year round (breeds); more numerous in winter.	Breeding colonies in partially submerged trees and snags at the Salton Sea (especially near river mouths) and at lakes; also has nested in mature eucalyptus groves lacking standing water. Forages in shallow waters of ditches and canals, lake shores, impoundments, the shore of the Salton Sea, and partially flood-irrigated fields.	Shuford et al. 2000, Patten et al. 2003, Molina and Sturm 2004, Shuford pers. obs.

Table A-1 (cont'd)

Species	Status and abundance	Habitat use	Source
Snowy Egret (*Egretta thula*)	Common, year round (breeds); more numerous in winter.	Breeds in similar substrates as described for the Great Egret. Forages in shallow waters of ditches and canals, riverbanks, lake shores, shallow pools and ponds, and partially flood-irrigated fields, and infrequently along the shore of the Salton Sea.	Shuford et al. 2000, Patten et al. 2003, Molina and Sturm 2004, Shuford pers. obs.
Cattle Egret (*Bubulcus ibis*)	Abundant, year round (breeds); colonist since mid-1960s. Most foraging in Imperial Valley.	Breeds in similar substrates to the other species of egrets, but forms the largest colonies (e.g., Alamo River delta, Finney and Ramer Lakes, Westmorland eucalyptus grove). Forages primarily in agricultural fields, particularly flood-irrigated alfalfa and bermudagrass (short to tall). Also forages in dry fields, particularly when hay is being mowed, baled, or otherwise worked by farm machinery; also follows grazing animals.	Shuford et al. 2000, Patten et al. 2003, Molina and Sturm 2004, Shuford pers. obs.
Green Heron (*Butorides virescens*)	Fairly common, year round (breeds).	Breeds solitarily in riparian vegetation bordering rivers, marshes, etc. Forages close to cover along rivers, ditches, lake or pond edges, and, rarely, in partially flood-irrigated agricultural fields.	Patten et al. 2003, Shuford pers. obs.
Black-crowned Night-Heron (*Nycticorax nycticorax*)	Common, year round (breeds).	Breeds in colonies in partially submerged trees and snags near the shore of the sea and at lakes; also mature eucalyptus groves lacking standing water. Forages in shallow waters of ditches and canals, riverbanks, lake shores, shallow pools and ponds, on mudflats and the mouths of rivers at the Salton Sea, and partially flood-irrigated fields.	Shuford et al. 2000, Patten et al. 2003, Molina and Sturm 2004

Table A-2. Seasonal status, relative abundance, and habitat use of 12 species of waterbirds that breed very rarely, locally, or irregularly, or bred formerly, at or near the Salton Sea. Consequently, conservation efforts at the sea on behalf of these species in the breeding season are unlikely to be effective in substantially augmenting regional breeding populations.

Species	Relative abundance	Habitat use	Source
Fulvous Whistling-Duck (*Dendrocygna bicolor*)	Apparently now extirpated. Formerly uncommon to common, year round (peak summer and fall); was restricted to Imperial Valley and managed wetlands at south end of Salton Sea.	Bred in freshwater marshes with a patchwork of open water and dense cattail stands (also *Phragmites*). Generally forages close to shore or protective cover, but also in stubble fields near water. In postbreeding period, often used flood-irrigated fields.	Patten et al. 2003, Hamilton 2008
Mallard (*Anas platyrhynchos*)	Fairly common, winter; rare, summer (breeds occasionally).	Uses freshwater marshes, impoundments, lakes, reservoirs, lagoons, and, occasionally, flood-irrigated agricultural fields.	Patten et al. 2003, Shuford pers. obs.
Northern Pintail (*Anas acuta*)	Common, winter; rare, summer (has bred).	Most numerous wintering duck in freshwater marshes adjacent to the Salton Sea and scattered across the Imperial Valley. Also on lakes and reservoirs and foraging in partly flood-irrigated stubble fields.	Patten et al. 2003
Bufflehead (*Bucephala albeola*)	Uncommon, winter; casual, summer (has bred). Most occur at the Salton Sea.	A few on freshwater lakes and reservoirs.	San Miguel 1998, Patten et al. 2003
Eared Grebe (*Podiceps nigricollis*)	Abundant, winter; fairly common, summer (has bred a few times). Vast majority at Salton Sea; only small numbers in Imperial Valley.	Winters in any substantial water body; infrequently, agricultural drains or rivers.	Patten et al. 2003

Table A-2 (cont'd)

Species	Status and abundance	Habitat use	Source
Laughing Gull (*Leucophaeus atricilla*)	Fairly common, summer and fall; rare winter and spring (has bred irregularly). Most abundant at the Salton Sea.	Forages along the shoreline of the Salton Sea, at freshwater lakes and ponds, and flood-irrigated fields adjacent to the Salton Sea. Has bred on islets and eroded levees.	Molina 2004; Patten et al. 2003
California Least Tern (*Sternula antillarum browni*)	Rare, spring and summer. Up to three pairs have bred irregularly at the Salton Sea since 2011.	Mostly Salton Sea shoreline near inflows of rivers; very rarely occurs on lakes or lagoons in the Imperial Valley.	Patten et al. 2003; Marschalek 2012; Frost 2014, 2015.
Forster's Tern (*Sterna forsteri*)	Common, summer (irregular breeder); fairly common, winter.	Has bred in mixed colonies with other larids, and on levees and on hummocks of vegetation on flooded mudflats. Forages mainly at the Salton Sea, but also at freshwater ponds, lakes, and reservoirs and larger agricultural drains or irrigation canals in the Imperial Valley.	Molina 2004; Patten et al. 2003
Neotropic Cormorant (*Phalacrocorax brasilianus*)	Formerly a casual summer vagrant. Since 2010, up to 10 pairs have nested in a colony of Double-crested Cormorant at Ramer Lake.	Presumably forages in the Salton Sea, nearby impoundments, and large freshwater bodies in the Imperial Valley.	Patten et al. 2003, eBird (www.ebird.org)
American White Pelican (*Pelecanus erythrorhynchos*)	Common, winter; fairly common, summer (formerly bred, up until mid-1950s).	Occurs mainly at the Salton Sea, but also on large freshwater lakes, lagoons, or reservoirs in the Imperial Valley.	Patten et al. 2003, Shuford 2005, Shuford pers. obs.

Table A-2 (cont'd)

Species	Status and abundance	Habitat use	Source
Brown Pelican (*Pelecanus occidentalis*)	Common, summer and fall (records of breeding or attempted breeding in the mid-1990s); rare, winter.	Vast majority of birds at the Salton Sea. At least occasionally (summer to early fall), any substantial water body in the Imperial Valley.	Sturm 1998, Patten et al. 2003
White-faced Ibis (*Plegadis chihi*)	Common, year round (breeds uncommonly and sporadically).	Nest at lakes in tall stands of cattails and partially submerged tamarisk snags. Forages mainly in flood-irrigated fields, particularly alfalfa and bermudagrass (short to tall), but also shallow water and muddy edges of marshes, rivers, and earthen irrigation ditches.	Patten et al. 2003, Molina and Sturm 2004, Shuford et al. 1996, 2000, Shuford pers. obs.

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APPENDIX B: DETAILED METHODS

CONTENTS

DETAILED DESCRIPTION OF METHODS

Overall, the approach consisted of three steps: 1) modeling the suitability of habitats in the landscape for each species; 2) categorizing the results for the indicator species for each habitat as present or absent, to determine the most important areas for each habitat, with lower and upper bound estimates to account for uncertainty; and 3) adding up the areas of preferred habitat to obtain a total area estimate, with lower and upper bounds. We followed the same approach as in Veloz et al. (2015), but without the use of data corrected for imperfect detection. We explain each step in detail below.

BIRD OBSERVATIONS DATA DETAILS

The present work used freely available data from the volunteer science projects eBird (Sullivan et al. 2009) and the Pacific Flyway Shorebird Survey (PFSS) (Reiter 2011). These data are generated from volunteer scientists who, as part of a structured survey (PFSS) or as a recreational activity (eBird), record every bird species they see (and often also the quantity) in birdwatching trips to the area using geographic coordinates (Sullivan et al. 2009). These data are known to include error often associated with unrestricted survey effort: observers report birds seen near and far without regard to a limiting sampling distance, spending varying amounts of time - from minutes to hours. These datasets are also

susceptible to bias from sampling at non-randomized or controlled locations and dates (Munson et al. 2010). On the upside, the amount of records available is several times larger than the single 1999 survey. Whereas the 1999 survey event resulted in < 2,000 records, a single year of volunteer science data can be > 200,000 records. When filtered to control for error and bias, as described below, the dataset still comprises > 2,000 records per year.

We filtered eBird data (Sullivan et al. 2009) to include only "approved" records (i.e., records vetted by eBird's reviewers), where the observer reported all species detected, which is important for establishing the survey events, and only records using the following survey protocols: traveling count (see below for treatment of total distance traveled), stationary count, exhaustive area count, and random location counts. Similar uses of eBird data include Fink et al. (2010), and Hurlbert and Liang (2012). We also included only one checklist from those survey events where a known group of observers participated in the survey and all reported separately.

Traveling counts include data from a wide range of areas covered by the reporting birdwatcher. In order to standardize the survey effort and make these counts comparable to other survey protocols in eBird and PFSS, we used a traveling distance cutoff that matches the resolution of our models, which was 500 m. However, for two species (Common Gallinule and Least Bittern) the number of detections was greatly reduced at that cutoff distance, so we extended the datasets for these three species to include traveling counts up to 2.5 km long. This undoubtedly introduced some error into the models, as the observational data were collected at a larger scale than the resolution of the models. Nevertheless, it resulted in a better model fits for these three species.

There are good reasons to use data from a mixture of survey methods to train our models. All methods we considered contribute significant amounts of data, and help reduce spatial bias in data collection. This also means that unless accounted for as a fixed effect, survey method will introduce noise and uncertainty in the predictions. Fixing the effect of survey methods would mean that our predictions would be conditional on a particular survey method (e.g., amount of suitable habitat under survey protocol "x"). This would be an important step if our goal was to estimate the magnitude of the covariate effects on habitat preference. Since we are only interested in predicting the preferred habitats, not in understanding magnitude of effects, we opted not to fix the effect of survey methods in our models. Thus, our predictions are unconditional on any survey method. All survey methods have a similar ontology: survey an area of approximately the same size, for approximately the same amount of time, with the same tools. Therefore, the predictions will have some error due to unexplained variance from the use of different survey methods, but given the overall similarity of survey methods, we think the error is small.

The data for each species was obtained as follows. First, we generated an overall survey effort table by listing the unique locations and dates of every survey in our dataset. We then filtered this effort table for the months for which each species would be modeled (more on this below; also see Table 1 in the report). The same filter of survey months was then applied to the observational data for the species (i.e., all records in which the species was detected). Lastly, we merged the filtered effort and observation tables, assigning 0 counts to those survey events where the species was not detected.

For each indicator species, we filtered the data to include only records for the months determined to be the period when the species is most common in the Salton Sea (see "Species modeling periods" below for information on how the periods were determined). We used data collected between January 2011 and December 2015. We evaluated model fits for 54 different taxa, eventually using the 18 most

abundant (and with better model fits) among these, sorted into five different habitat types. The species selected as indicators of specific habitats, the habitat definitions, and the periods of the year for which each species was filtered are listed in Table 1 of the report. The center of the lake is > 2.5 m deep and not listed as a habitat in our table, as described in the report.

SPECIES MODELING PERIODS

In order to determine which months a species is more frequently present, we must account for survey effort. This is because the number of surveys varied by month, with typically the hot summer months (June through September) being undersampled (see Figure B-1 below). The selection of the survey periods for each species was made by modeling the counts with a generalized linear model. The model had a negative binomial error distribution, and only month and number of survey events as covariates, and count as response parameter. We then predicted to each month while holding the number of survey events constant, to determine which months are expected to have the largest number of birds independent of survey effort. The predicted monthly abundances are shown in Figure B-2.
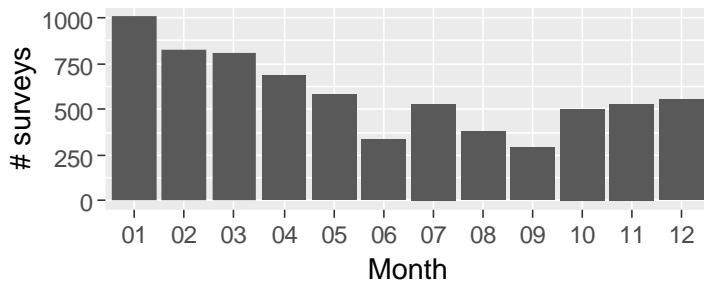
Figure B-1. Survey effort (number of surveys) by month for the period 2011-2015.
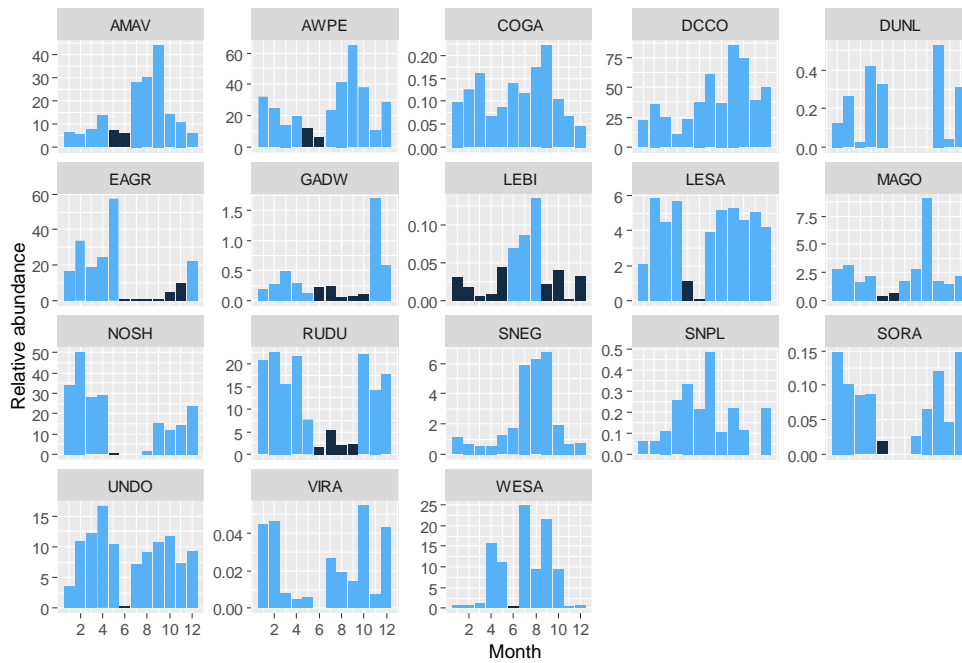
Figure B-2. Predicted abundance, corrected by survey effort, by month for the 18 indicator species in the period 2011-2015.
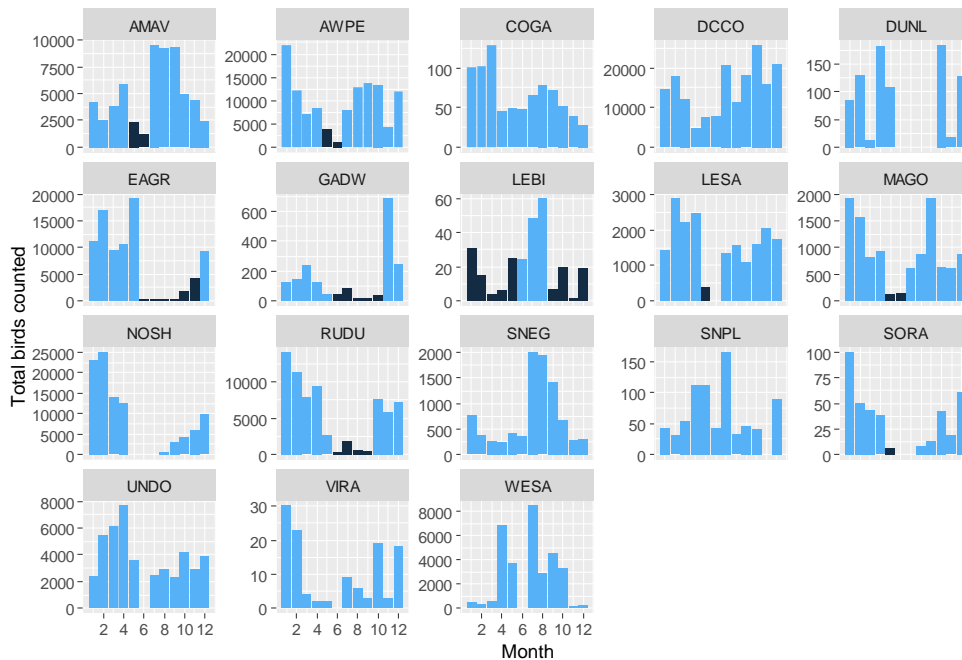
Figure B-3. Sum total of counts per month for the 18 indicator species in the period 2011-2015, uncorrected for survey effort.

We visually compared these to the sum total of counts per month (Figure B-3) and the data reported in Howell and Shuford (2008) as ways to check that our selected intervals for each species were reasonable.

Table 1 of the report lists all the chosen indicator species and the months modeled for each.

GEOSPATIAL COVARIATE DATA

We sought to use covariates that are related to water level which was estimated for each pixel from the current water level and the bathymetry layer (USGS, https://www2.usgs.gov/saltonsea/LiDAR.html). For all covariates excepting those measuring distances to features, we opted to assess their influence on probability of species presence at two different scales: locally (i.e., within the pixel) and at a larger scale. We did so by generating values averaged from radii of 250 m and 2,500 m from the center of each pixel.

The water level data were obtained from the USGS (USGS, Water Gauge #10254005; http://waterdata.usgs.gov/ca/nwis/uv?site_no=10254005). Water depth was then binned to 0-15 cm, 15-30 cm, 30 cm-2.5 m, and > 2.5 m. We obtained landcover data from the 2011 National Landcover Database (Multi-Resolution Land Characteristics Consortium, http://www.mrlc.gov/nlcd2011.php) and the National Wetlands Inventory (USFWS, https://www.fws.gov/wetlands/). Covariates of distance to features were calculated using the Euclidian Distance tool of ArcGIS 10.2 (ESRI 2013). Slope was calculated using the Slope tool of ArcGIS 10.2 (ESRI 2013). The shoreline contour, for the calculation of distance to shoreline, was interpolated from the DEM using the Contour tool of ArcGIS 10.2 (ESRI 2013). Sediment survey data for the Salton Sea was provided by USGS (Agrarian Research, https://www2.usgs.gov/saltonsea/docs/SSA/Salton Sediment Report 20 Oct 03.pdf). See reference for discussion of sampling methods. From these points, we interpolated the fractions of clay, organic matter, sand, and silt reported by the survey into a raster covering the entire Sea. We used an inverse distance weighted method, specifically the IDW Interpolation tool in ArcGIS 10.2 (ESRI 2013). To minimize error and avoid egregious extrapolation, we then removed all areas of the interpolated raster that were more than 1 km from a survey point unless that area was completely surrounded by the 1 km buffer of survey points.

We resampled each layer to resolutions of 500 x 500 m and 5000 x 5000 m calculating either averages or sums as appropriate, using packages rgdal (Bivand et al. 2015) and raster (Hijmans 2015) in R version 3.2.1 (R Core Team 2015). The landscape covariates are listed with processing information and original data sources in Table B-1 below.

Table B-1. List of covariates, their description, how processed, and data sources.

Covariate	Description	Data processing	Data source
WaterDepthMeters	Average water depth in pixel	Average of DEM value, rescaled to current water level for each 500-m pixel	a, b
WaterShallowsSqm_0to15cm	Area of pixel covered by water between 0 and 15 cm deep	Reclassification of DEM value by depth, then sum the area within each 500-m pixel	a, b
WaterShallowsSqm_15to30cm	Area of pixel covered by water between 15 and 30 cm deep	Reclassification of DEM value by depth, then sum the area within each 500-m pixel	a, b
WaterShallowsSqm_30to200cm	Area of pixel covered by water between 30 and 250 cm deep	Reclassification of DEM value by depth, then sum the area within each 500-m pixel	a, b
WaterShallowsSqm_200to1000cm	Area of pixel covered by water > 250 cm deep	Reclassification of DEM value by depth, then sum the area within each 500-m pixel	a, b
ExposedShoreSqm	Area of land in pixel uncovered by water that was covered at the baseline water level of -69.5 m (-228 ft) NAVD	Reclassification of DEM value by depth, then sum the area within each 500-m pixel	a, b
ShorelineDistanceMeters	Average distance to shoreline of a pixel	Shoreline interpolated from the DEM; then calculated Euclidian distance to it, then averaged within each 500-m pixel	a, b
RiverDistanceMeters	Average distance to one of the three rivers flowing into the Salton Sea	Calculated Euclidean distance from each original 10- m pixel, and then averaged within 500-m pixel	c
RiverMouthDistanceMeters	Average distance to the point where one of the three rivers flow into the Salton Sea	Calculated Euclidean distance from each original 10- m pixel, and then averaged within 500-m pixel	c
SlopeDegrees	Average slope of the pixel	Calculated slope at each original 10-m pixel, and then averaged within each 500-m pixel	a
FreshwaterEmergentSqmNWI	Area of pixel covered by this type of wetland	Rasterized polygons at 10-m resolution, and aggregated the area within each 500-m pixel	d
FreshwaterPondSqmNWI	Area of pixel covered by this type of wetland	Rasterized polygons at 10-m resolution, and aggregated the area within each 500-m pixel	d
LakeSqmNWI	Area of pixel covered by this type of wetland	Rasterized polygons at 10-m resolution, and aggregated the area within each 500-m pixel	d
RiverineSqmNWI	Area of pixel covered by this type of wetland	Rasterized polygons at 10-m resolution, and aggregated the area within each 500-m pixel	d

OtherWetlandSqmNWI	Area of pixel covered by this type of wetland	Rasterized polygons at 10-m resolution, and aggregated the area within each 500-m pixel	d
NonLakeWetlandTotalSqmNWI	Area of pixel covered by this type of wetland	Rasterized polygons at 10-m resolution, and aggregated the area within each 500-m pixel	d
BarrenSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
HerbaceousSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
PastureSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
CultivatedSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
WetlandsWoodySqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
WetlandsHerbaceousSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
AgTotalSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
WetlandsTotalSqmNLCD2011	Area of pixel covered by this type of landcover	Calculated by summing the area for each pixel	e
ClayFraction	Fraction of clay in the submerged sediments in the pixel	Calculated by interpolating from samples using inverse of distance as weight	f
OrganicMatterFraction	Fraction of organic matter in the submerged sediments in the pixel	Calculated by interpolating from samples using inverse of distance as weight	f
SandFraction	Fraction of sand in the submerged sediments in the pixel	Calculated by interpolating from samples using inverse of distance as weight	f
SiltFraction	Fraction of silt in the submerged sediments in the pixel	Calculated by interpolating from samples using inverse of distance as weight	f

Data sources: a - Digital Topo-Bathymetric Model of the Salton Sea (USGS - https://www2.usgs.gov/saltonsea/LiDAR.html); b – Salton Sea Water Gauge (USGS Gauge #10254005 - http://waterdata.usgs.gov/ca/nwis/uv?site_no=10254005), c - Redlands Institute Salton Sea River Data (http://www.spatial.redlands.edu/salton/data/gisdata.aspx); d - National Wetlands Inventory (USFWS - https://www.fws.gov/wetlands/); e - National Landcover Database 2011, Multi-Resolution Land Characteristics Consortium (http://www.mrlc.gov/nlcd2011.php); f - Characterization of Shallow Sub-Surface Sediments of the Salton Sea, (Agrarian Research - https://www2.usgs.gov/saltonsea/docs/SSA/Salton Sediment Report 20 Oct 03.pdf, data provided by USGS)

HABITAT SUITABILITY MODEL

Once attributed, we fit a boosted regression tree (BRT) model with binomial error distribution to detection/non-detection data, where a 0 value for a species in a survey means no detection. The BRT is a powerful regression-and-classification algorithm that fits small (1-5 branches) trees consecutively on the data based on the salient regression coefficients of models fit to the residuals of the cumulative set of

trees, so as to increase model predictive accuracy as more trees are added to the model (Friedman 2001). It automatically handles variable interactions and determines variable relative importance. It uses standard cross-validation techniques to reduce over-fitting. The BRT method is designed to produce a model that has high predictive accuracy, not to formally test ecological significance of variables (Elith et al. 2008). Nevertheless, it provides valuable insights on the importance of covariates on the landscape use by habitat indicator species. We tentatively explored fitting a Poisson error distribution to the count data for those species with <90% of the surveys being zeroes, but the model fits were largely inadequate (i.e., relatively high deviance). This is understandable, because the model is seeking a probability distribution with mean value such that there is a good probability of zero counts (as the data have many zero-detection events) along with events with high (sometimes in the tens of thousands) counts per event.

As explained in the report, we used the base-10 log of the total number of birds detected in a survey as weights for those survey records with detections for a particular species. This weighing of records provided additional information, not just presence/absence, reflecting the total abundance of the species at a survey, which we considered relevant to establishing habitat preference. Because amount of preferred habitat will be based on the combination of indicator species for the habitat, it is important that the predictive models accurately reflect the probability of detection of the species in each pixel. We assume that the probability of detection is directly related to suitability: more preferred habitats have higher probability of detection of the species. We evaluated model accuracy through three different means. First, we looked at the amount of deviance explained among competing species. Commonly, species with most data resulted in a better fit. We were able to choose species and opt for using the binomial error link by evaluating the amount of deviance explained. Second, we reviewed the list of most important covariates and their functional form with the help of expert field ornithologists. A good model would show as top covariates those expected to be the most influential in the species' selection of habitats, and the functional form of the effect should match that expectation. Third, a visual inspection of the predictions by field ornithologists familiar with how the species use the Salton Sea helped decide on the merits of including taxa as avian habitat suitability indicators.

Spatial bias in the data can be a consideration when fitting landscape models. We are confident that, by using data from various eBird survey methods and PFSS, and because the area being modeled is relatively small, spatial bias effects will be limited.

We did not conduct exhaustive determination of variable importance using common methods, such as evaluating the change in deviance when removing one variable at the time. We are not interested in identifying the complete set of important covariates. Though our covariates have some ecological relevance, their effect on avian habitat preference is often indirect. For example, the sediment layer we used may correlate with arthropod presence, the true driver of bird presence and which we lack. So, we decided to just identify the top three variables as ranked by the summary of the model. These are likely to be among the most important, if not the top three most important, if identified using more exhaustive methods.

FROM PROBABILITY OF OCCURRENCE TO ESTIMATING AMOUNT OF PREFERRED HABITAT

With the probability of presence estimates at hand, we categorized them into presence/absence (1/0) values by using the prevalence of the taxon in the landscape. The prevalence was estimated as the percentage of cells in which the species was detected. There are many proposed methods to hurdle

probability of occurrence into presence/absence, and simulations have shown that prevalence is as good, if not better than, other proposed alternatives (Liu et al. 2005; Lobo et al. 2007). Therefore, for each habitat type we produced a stack of rasters from all indicator species with the mean presence estimates.

We then calculated a mean total area of preferred habitat for each habitat type using the weighted means method described in the report. We similarly calculated an aggregate weighted mean comprising the individual habitat types. For this we used the layer of overlap of all indicator species for each habitat, and then applied the same weighted mean as we did for estimating individual habitat type mean areas.

Since we are masking the center of the lake > 2.5 m, and inland areas > 1 km from the shoreline excepting wetlands, the binning of the predicted probability of occurrence into presence/absence is applied after the mask.

ESTIMATING IMPACT OF SEA LEVEL CHANGES

We wanted to estimate how the total preferred area for each habitat type might have changed between 1999 and 2015. The pattern of change is illustrative of what we may expect into the future, and would help visualize the impacts due to water level changes. Thus, we hind-casted with our model to two previous time intervals to estimate total preferred area per habitat. We recalculated all covariates related to the Salton Sea's water level for year 1999. For this period we used a different layer of land cover (NLCD 2001) which better informed the land conditions of the period than the layer used to train the model. We then predicted to 1999 and estimated total area of preferred habitat for each of the habitat type using the same methodology described above. Similarly, we hind-casted to 2015.

GOODNESS-OF-FIT INFORMATION

Parametrization of boosted regression tree models should be such as to ensure there is a limited risk of under- or over-fitting the model by using too few or too many trees. This is avoided through procedures described in Elith et al. (2008). However, our experience tells us that models fit using a moderate tree complexity and middle-of-the-road learning rate usually result in models with adequate numbers of trees (800-4,000 trees). We used the same learning rate for all models (0.005), except for Dunlin and Virginia rail models (0.001). We used the same tree complexity (3 branches per tree) for all models. The following table provides details about the results of the BRT model for each species.

Table B-2. Individual species model information.

| Species	% 0's	N. trees	Total Deviance	Residual Deviance	% Deviance Explained	AUC	Cross-val. AUC ± SE
EAGR	71.63	3950	2.27	1.49	34.6	0.824	0.786 ± 0.012
RUDU	80.66	6300	2.05	1.50	26.8	0.796	0.734 ±0.009
AWPE	66.73	5200	2.34	1.60	31.4	0.826	0.793 ± 0.013
DCCO	70.05	5600	2.37	1.66	30.0	0.812	0.772 ± 0.010
SNPL	92.73	600	0.48	0.25	48.7	0.894	0.859 ±0.015
AMAV	74.17	1100	2.01	1.34	33.5	0.812	0.753 ± 0.013
MAGO	85.48	700	1.4	0.86	38.7	0.863	0.827 ±0.009
UNDO	79.80	900	1.91	1.28	33.0	0.828	0.771 ± 0.012
DUNL	95.68	850	0.45	0.27	39.2	0.867	0.764 ± 0.018
WESA	86.3	1500	1.53	0.87	43.1	0.848	0.778 ± 0.016

LESA	77.55	1550	1.81	1.26	30.3	0.825	0.733 ± 0.008
SNEG	72.22	950	1.43	1.01	29.4	0.800	0.736 ±0.010
GADW	95.57	400	0.51	0.33	35.1	0.861	0.748 ± 0.034
NOSH	78.85	900	2.12	1.53	27.7	0.811	0.740 ± 0.017
BLSK	91.30	700	0.87	0.53	38.8	0.841	0.712 ± 0.042
LEBI	95.66	2300	0.18	0.06	66.3	0.788	0.768 ±0.057
VIRA	98.28	1050	0.17	0.09	48.5	0.978	0.887 ±0.027
SORA	94.04	800	0.27	0.18	32.2	0.778	0.721 ±0.027
COGA	95.55	2850	0.17	0.11	34.9	0.797	0.734 ±0.032

TOP PREDICTORS BY SPECIES

The following are the top three predictors of preferred habitat in the BRT models for each species. The ranking as top predictor is a combination of how high in the tree structure the covariate is used as a criterion to split the data (higher in the tree means higher importance) and how many times the covariate is used in branching the tree. The x-axis shows the value of the covariate, and the y-axis reflects the amount of change in preference (negative values indicate lower preference). The importance of these graphs is to understand the general relationship between the covariate and habitat preference. For example, for SNPL, increasing distance to shoreline past 1 km rapidly decreases habitat preference, whereas habitat preference changed little within the first 1 km.

Table B-3. Partial dependence plot of top 3 predictors in individual species' models.

Species	Partial dependence plots of top 3 predictors
EAGR	
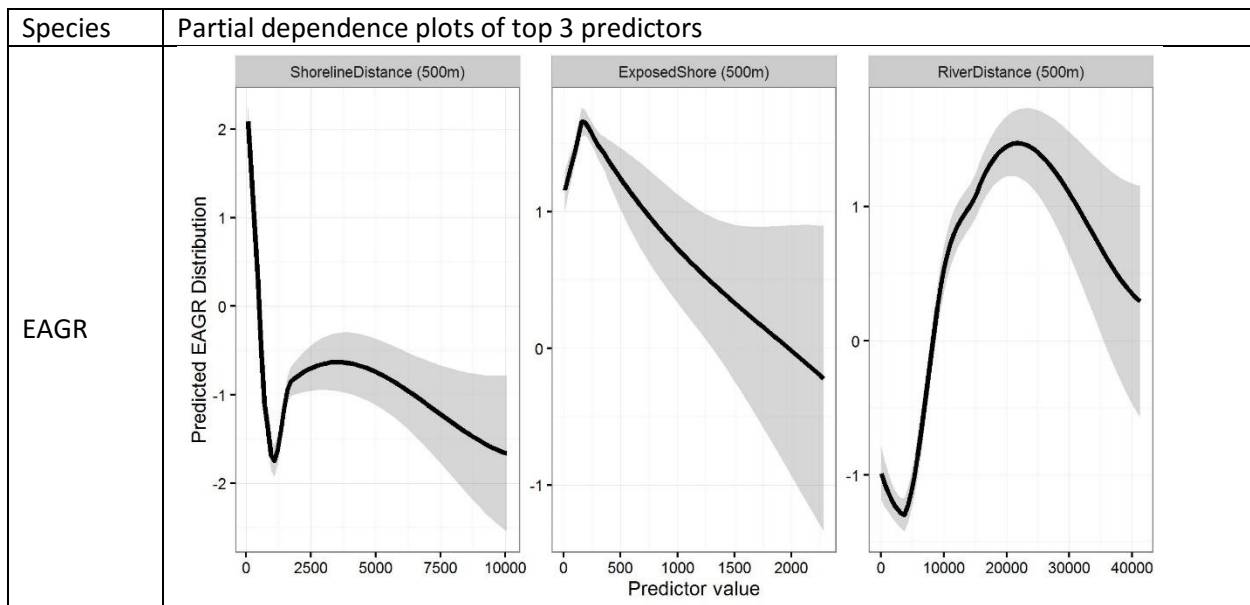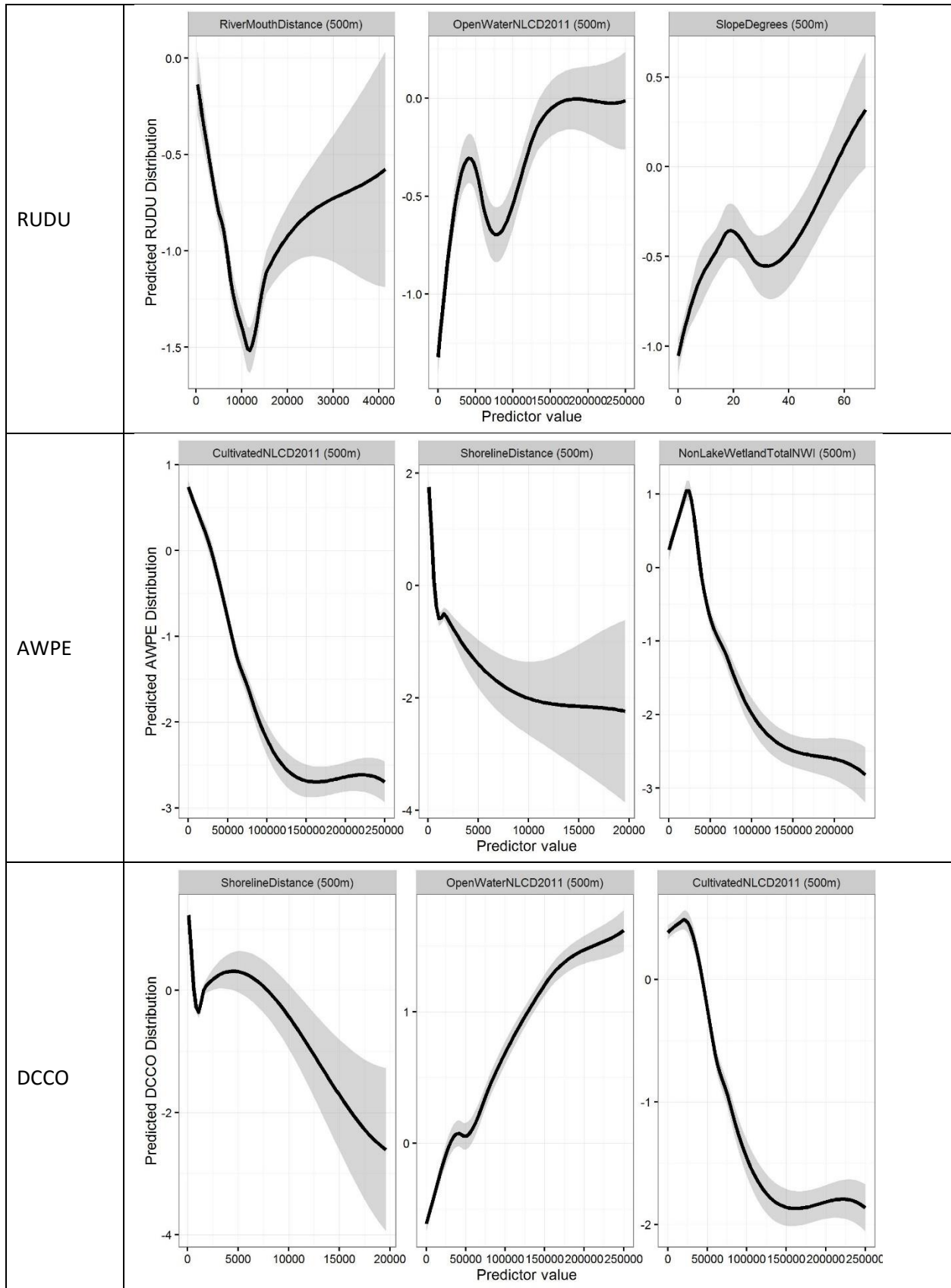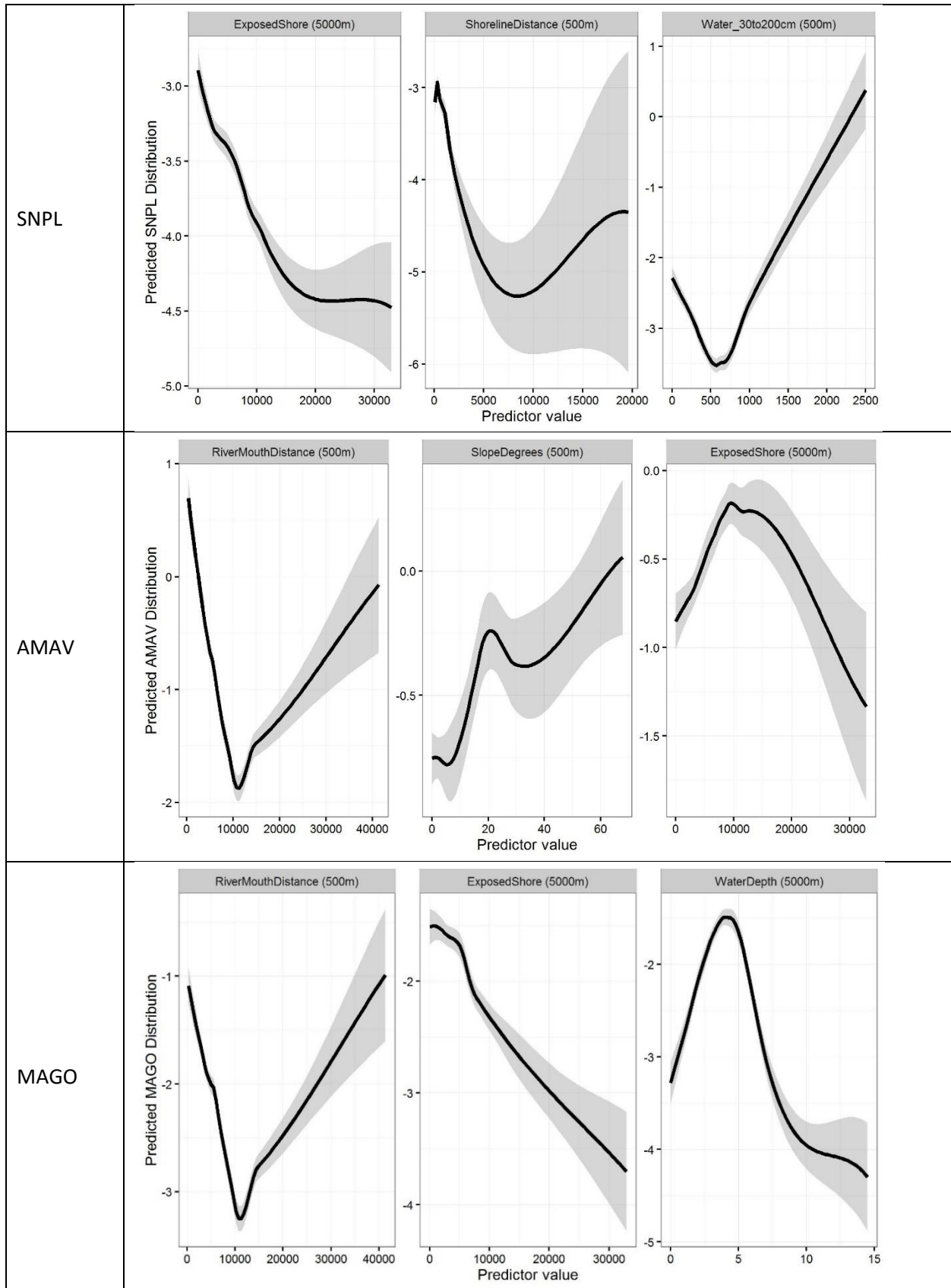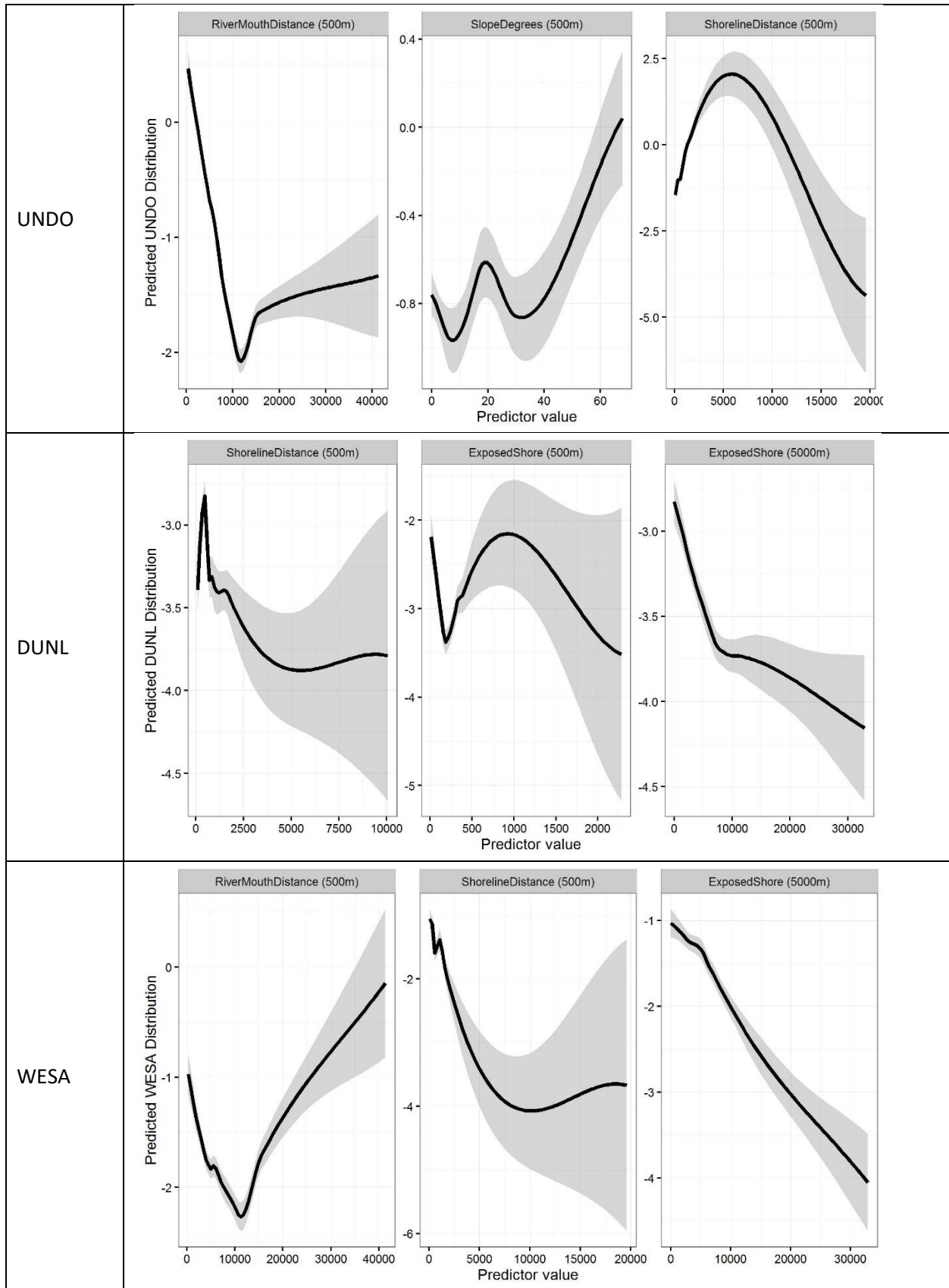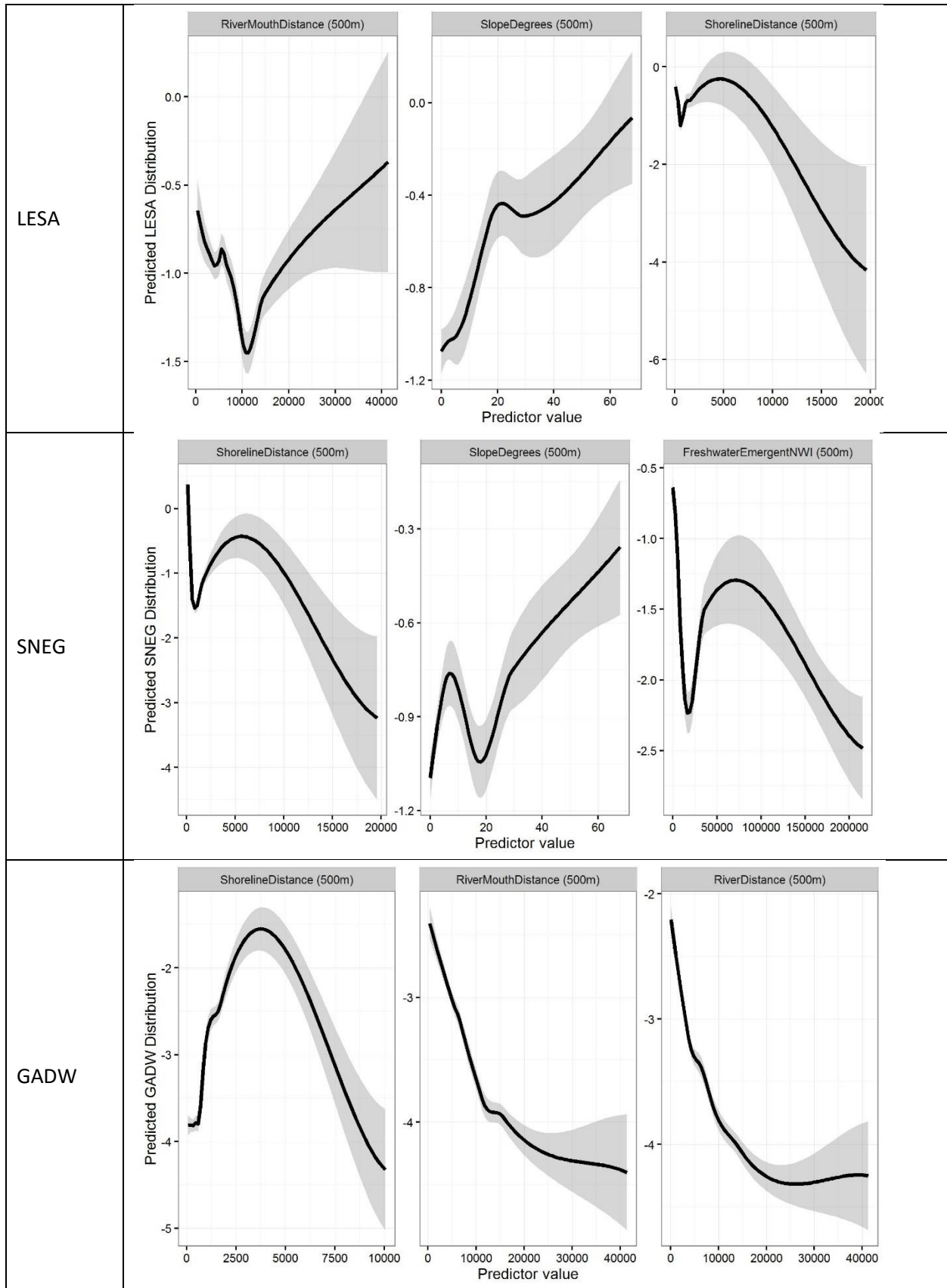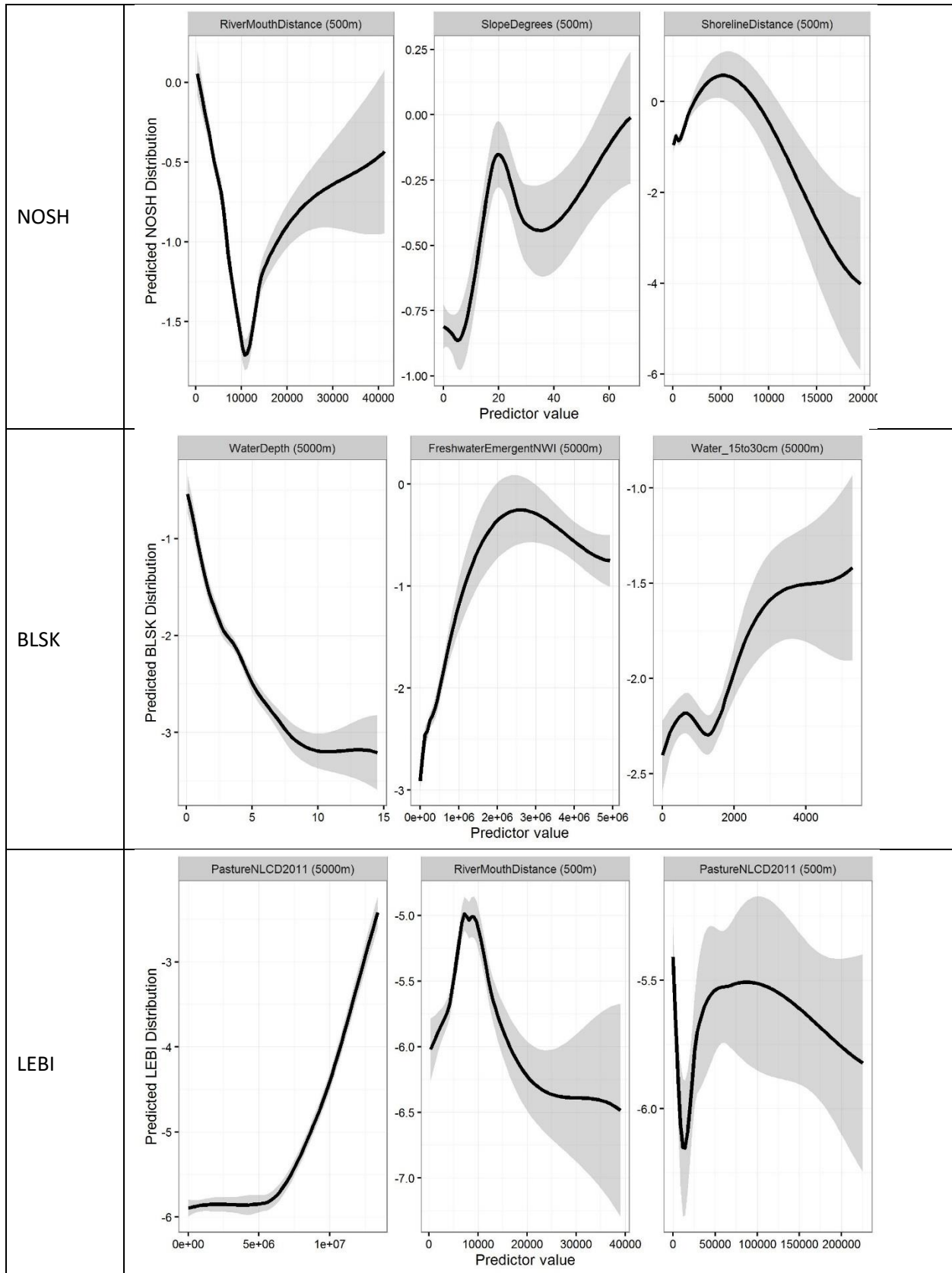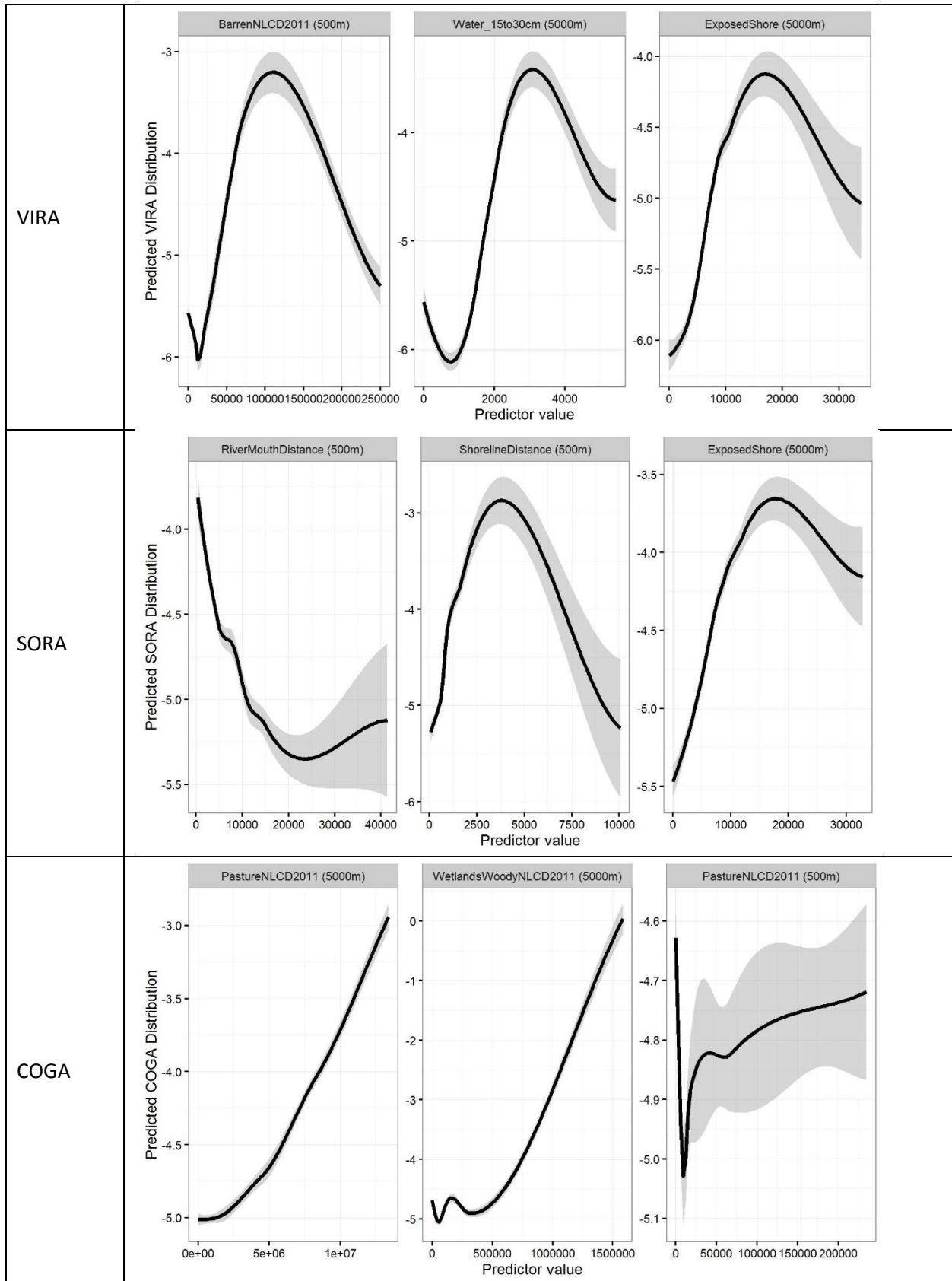
LIMITATIONS

The amount and quality of the data, how these were collected, and other challenges set some limitations to the scope and conclusions of the present report. The most important ones are:

Selenium. High concentrations of selenium in certain areas of the Salton Sea were considered by the Science Panel for the PEIR as the most important water management concern (CNRA 2006). The alternatives explored in the PEIR were specifically developed to address abatement. Though it would be desirable to incorporate abatement alternatives in the recipe cards, it is beyond the scope of this work to study how selenium abatement can be part of the management/mitigation suggestions. Further, we did not evaluate how selenium concentration may affect the amount of preferred avian habitats. In theory, it may be possible to overlay the locations with high selenium levels on top of preferred avian habitats to remove from our estimates those areas known to be dangerous to wildlife. Thus, it is entirely possible that our estimates of preferred habitat are higher than the real values once selenium contamination is taken into account.

Salinity. There is no available dataset to describe salinity gradients across the sea. However, geographic detail may not be needed. The Salton Sea could still be understood at the larger landscape scale from salinity point estimates. The most critical information lacking in the data pertains to the consequences of changes in salinity. Each saline environment behaves differently depending on the invertebrate fauna present and the biophysical processes that maintain the salinity and provide the organic matter that fuels the food web. We used the South Bay Salt Pond data provided by Dr. De la Cruz (De la Cruz et al. *in review*), but the food web and other conditions in the southern San Francisco Bay are quite different from that of the Salton Sea. Thus we have no basis to expect that our assumption about the behavior of the system comparable to that of the South Bay Salt Ponds will hold true. One aspect of the effects of salinity will, however, remain unchanged. The tilapia in the sea are the most important source of food for strictly piscivorous birds. The fish will likely struggle to breed at salinities much higher than present levels (Popper et al. 1975). Increased salinity will result in drops of populations of obligate fish-eating pelecaniformes (cormorants and pelicans). An evaluation of avian use and selenium risks at a pilot complex of four saline habitat ponds on the southeast corner of the Salton Sea (Anderson 2008) found that bird diversity decreased with salinity but water level had little effect on marsh birds, wading shorebirds, and dabbling waterfowl. The exception is diving waterbirds, for whom low water depth in the ponds likely explained low densities.

Temperature. Fish like tilapia are attracted to cooler temperatures, which may mean that certain pockets of deeper water are particularly important to fish-eating birds. We are not aware of a dataset to describe temperature gradients across the sea, and thus such effects are not explicitly captured in our models.

Body of water size. A large body of water like the Salton Sea may provide some beneficial buffering functions, such as temperature regulation, to adjacent shallower water and shoreline-adjacent habitats. Such functions would be lacking if newly constructed habitats independent of or separated from a large body of water. Further, species like Eared Grebe likely prefer a minimum water area to maintain a buffer from disturbance, and there likely is some minimum size that is necessary to enable a pelican to take off. On average larger bodies of water are going to have more food and support more birds.

Food resources/dissolved oxygen. Certainly food resources are critically important to habitat quality. What allows species like American White Pelicans and Eared Grebes to occur in such huge numbers on saline lakes are the very high numbers of alkali flies and brine shrimp, which can multiply to much greater densities in saline lakes because of the lack of other invertebrate or fish predators. However, food availability is not explicitly included in our models. In effect, we are making the assumption that if there is available habitat, there will also be adequate food resources in those habitats to support bird populations. That may not be true at present, especially for the fish eaters. We are not aware of a spatially explicit dataset describing food resource gradients across the sea. As a future refinement, including dissolved oxygen as a measure of productivity could improve the modeling performance, should such information be available.

Available bird monitoring data. We show the great effect that the choice of indicator species has on the estimation of avian habitat. We chose the most common and most abundant species. An ideal approach would use a wider range of species. Unfortunately, the volunteer science data are poorly controlled for effort and may have strong spatial bias. We were able to reduce the effects of these sources of error by incorporating data from a period of several years when the water level did not change much, permitting us to amass records from several thousand survey events after all data filters were applied. Given that volunteer scientists report observations from the sea in the hundreds of thousands every year, it is highly recommended to reach out and engage with them to request simple changes in their survey and reporting methods, so as to increase the quality of the data and permit more accurate modeling of avian habitats.

Scale of data attribution. Though a volunteer scientist may report seeing a bird at a particular location, in reality the bird may be hundreds of meters away, in land or in water. We attributed the record with covariate data based on the reported location of the observer. This inevitable approach results in errors in covariate values. Small changes in the way bird watchers collect and report data would go a long way in helping reduce improper covariate attribution.

Shelf life of covariate data. Some of the covariate data are one-off works, and some are updated once a decade or more. For example, some National Land Cover Dataset data used to predict for 1999 were in reality produced in 2001. This temporal mismatch produces attribution errors similar to those described above for scale mismatches. Ideally, the geospatial covariate data would be collected at the same or approximate spatial and temporal scales of the observational data. One approach that may be explored in the future is the use of hyperspectral remote sensing data.

Flyway effects. One of the reasons we chose to use volunteer scientist data for our analyses is that it permits analyses at multiple scales. Other authors (e.g. Jehl et al. 2002) have shown that sometimes the behaviors of populations of birds observed in the Salton Sea are the result of larger scale effects (e.g., flyway level declines like those observed in cormorants and pelicans) or effects of phenomena that occur elsewhere in the flyway. We did not analyze the changes in available avian habitats with any consideration of changes in bird abundances at the flyway level. For example, it is possible that at the flyway scale populations of the indicator species grew during the 1999-2015 period. With this hypothetical background, the seemingly small reduction of total avian habitats at the Salton Sea would stand as more significant. Future analyses of avian habitat changes should be understood at local (e.g., areas of the south end of the Salton Sea and Imperial Valley), regional (the entire sea basin), and flyway levels.

Proper estimation of uncertainty. We took a simple approach to bounding our estimates of total area. A more rigorous approach would include repeating the models including permutations of indicator species (e.g., including species A and B but not C; then B and C but not A, and so on), obtaining weighted averages under different configurations of species, and then obtaining the proper variance from the universe of possible models. Such a variance estimate is likely to be smaller than what we reported (i.e., tighter confidence limits), deeming our results as conservative. We will seek a more appropriate calculation of confidence limits when publishing our results.

Quality of habitat and bird populations. Because of the limitations described above, our results may not provide a good comparison of the *quality* of habitat between 1999 and 2015 or, similarly, of the *bird populations* between 1999 and 2015. This is an important distinction. The Salton Sea can be the same size, but if conditions internal to the sea cause permanent declines in tilapia and pile worms the number of birds supported will be vastly different.

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REVIEWERS' COMMENTS

The following are the most relevant comments and our answers.

About data selection, spatial scale of observational data and choice of survey protocols:

Q: You have included spatial predictors at 500m and 5000m. So, including traveling count protocol with a maximum length of 2.5km is an obvious compromise. Have you investigated whether the models are sensitive to this choice?

A: First, note that although covariate attribution is at the 500-m and 5,000-m scales, the cell size is 500 m. Traveling counts represent more than 60% of all the data we have. We evaluated the use of counts only from surveys that scanned < 500m and surveys scanning < 1 km. Since the filter results in a substantial exclusion of data, we expanded the timeline to include data years 2011-2015. Clearly, the 2.5-km cutoff results in more data and more information, but also more error, as we would be attributing a count to a cell of 500-m on the side with scans that span 2.5-km. After adding weights and adjusting the learning rate, we found out that for all but 3 species a cutoff of 500-m resulted in similar (by deviance explained and cross-validated AUC) or better fits than a 1-km or 2.5-km cutoff. For the remaining 3 species, the 2.5-km cutoff resulted in a much better model fit, so we kept that cutoff.

Q: It might be helpful to include a couple of lines of text to explain your rationale for including different types of protocols (e.g., traveling count, stationary count, etc.).

A: We are using several data collected using protocols for two reasons. First, we are able to use more data by mixing protocols. We are aware that we are introducing some error by not holding the methodology constant, but the trade-off is more data. Second, the larger datasets may reduce spatial bias in sampling. By using data from different protocols, the dataset encompasses a larger variety of locations in covariate space.

Q: Did you do any geographic and/or environmental filtering of your data to control for spatial biases such as sampling bias?

A: We are aware of techniques to reduce sampling bias. However, considering the fact that samples were more or less homogeneously distributed in space (and somewhat in covariate space), we thought using these techniques would result in little improvement.

Q: Combining data from multiple years is fine, but state explicitly here that you assume that habitat selection won't vary between years.

A: We are simply stating that we assume that the relationship between these covariates and the use of the habitat by the species remains invariant during this period, which is reasonable.

Q: How was the 5-km buffer around the lake selected for filtering data?

A: The 5 km buffer was an arbitrary distance used to ensure wetlands around the lake were included. Note that we then masked any habitat type around the sea other than wetlands.

Species Selection and periods of presence:

Q: Can you state explicitly how you chose the indicator species, for reproducibility?

A: For each habitat type, we sought the species most commonly seen (i.e., most commonly present in the data after filtering for survey effort). After examining model fits for 54 taxa, we opted for using 22 based on the goodness of model fits and those species thought to better characterize the habitat.

Q: There is always some inherent bias when using expert opinion. You may want to just identify this.

A: The experts consulted focused on the most common, easiest to identify correctly, and typical representative species of each habitat type.

Q: Using the model to estimate expected total count by month, with constant survey effort is a good idea. How did you use this model output to delineate the selected months?

A: The selection of months was a compromise between predicted and observed abundance by month, and seasonality. Using the filtered data (currently using traveling counts at 2.5-km), we looked at the pattern of absolute (sum of counts) and predicted abundance to choose the months to include for each species. We used a first-pass selection of months with at least 5% of the year-round abundance. But an absolute criterion, such as a cut-off point of total or predicted counts, may result in some months excluded due to high variance and limited sampling. Ultimately, our choice was a balance among the predicted and observed counts.

About over-dispersion, and Z=zero-Inflation in the data:

Q: Why not deal with these issues by including covariates that will allow the model to capture these sources of variation? At least with the eBird data, you can include survey effort covariates, day-of-the-year (seasonality effects), number of observers, etc.

A: We could fix for survey method effects, but this would mean that our predictions would be conditional on survey method, time of the day, day of the year, etc. We are solely interested in predicting the presence of suitable habitat - unconditional of survey method. We could "control" the effect of survey method by using data collected under only one method, but there are good reasons to use a mixture of methods: all methods contribute significant amounts of data, and help reduce spatial bias in data collection. Lastly, we could acknowledge the noise (error) introduced by aggregating data from different survey protocols, assuming that the error introduced is randomized with respect to the method, if our results are still meaningful. We understand that the predictions have some error due to unexplained variance from the use of different survey methods. Given the overall similarity of survey methods, we think the error is relatively small.

About a Poisson vs Bernoulli response model and modeling counts:

Q: From my reading of the report, it's not clear when you decided to use a Poisson response and a Bernoulli response?

A: We are using a Bernoulli response for all models.

Q: My colleagues and I have had some success modeling expected counts from eBird data using a two-step hurdle model (see Johnston et al. Ecological Applications, 2015).

A: The paper mentioned does offer an interesting approach, and we did something akin to it. Considering that we do not want to estimate numbers of birds, a probability distribution for the counts is not really needed. However, although not fitting a count distribution helps us avoid the considerable challenge of fitting the highly over-dispersed data, we are also losing some potentially important information by only using 0's and 1's. The counts may reflect something about suitability, and so rather than fit a conditional (on the species being present) cell mean, we should capture the information from both processes (probability of presence, and density conditional on presence) that result in the counts simultaneously. This was done using weights, as follows: All 1's were weighted

using the log of the mean of counts where the species was detected within each cell, and all 0's were given weight =1. This weighing of data for the training of the model helped us effectively capture the information about suitability from the probability of presence process, and the count process.

Q: Do you identify what constitutes a "better model fit" for the species that you ultimately included? Was there some cut off?

A: the decision was based on the amount of deviance explained, and the visual inspection of predictions.

Q: You might consider using bootstrapping to estimate standard errors, based on methods described in Leathwick et al. 2006 (Mar Ecol Prog Ser 321: 267–281).

A: We used bootstrap-generated standard errors and discovered that there is great variance in the bootstrap samples, indicating the need to increase samples to obtain more precise and accurate models in the future.

About the choice of landscape variables and scale of attributions vs observations:

Q: Can you try to be more strategic in determining which sets of variables to include for each species?

A: We understand that there is value in being selective about the predictors to use for each species. Unfortunately, the covariates available are not direct ecological explanatory variables. They are all indirect metrics of suitability, so we expect to (and did) find significant noise in the data, which highlights the importance of large sample sizes. We are strong believers that these models should use ecologically relevant covariates, but these data are simply lacking.

Q: There is a potential for a mismatch between reported survey locations and the actual locations of the birds reported. This may lead to misattribution of the data.

A: Save for the deep water habitat indicators, all other species are probably only detected < 500 m of the observer (perhaps < 200 m). We understand that there is attribution error when we assign the covariate values to the deep water species as if detected within 500-m of the observer, when in reality they may have been detected farther away into the sea. We are masking out deep waters of the lake (deeper than 2 m) as not suitable for these species. Thus, predictions of suitability are confined to where we know birds are being detected.

Q: It may be wise to explore how spatially autocorrelated the data are.

A: We did not try to account for spatial autocorrelation (i.e., if this cell has a high value, surrounding cells will too). That is likely to be the case, but we are not concerned with it, because we are not interested in defining the niche precisely (e.g., exactly how much shallow water percent explains the presence of the species vs the fact that the next cell over has the species and also shallow water). We want to predict accurately, and the autocorrelation information in the data may be helpful to that end.

Q: Did you assess collinearity among your covariates?

A: We did evaluate covariate correlations. There were high correlations (>0.9) among only 5 covariate pairs, and these were between the 500-m and the 5,000-m scale values for land cover covariates. The highest correlation we found was between distance to river and distance to river mouth. Dormann et al (2013) show that BRT is among the methods that perform well when the collinearity structure for training and prediction sets is quite different. Luckily, the distance to river and distance to river mouth correlation will not change between train and prediction, now and into the future. So, our only concern about BRT choosing one among two highly correlated variables, and that this correlation may change into the future (or past) in a way that makes prediction less accurate, is moot.

About the definition of preferred habitat:

Q: I am not a fan of using arbitrary percentages of species to define whether a pixel is "optimal", "suitable", or "not suitable". Do you even need to do this?

A: We are not using arbitrary percentages. We are calculating a weighted mean (weighted by the number of species overlapping) of the total area, summing up area with half, half +1, and so on up to the area where all species overlap. Note that we only use percentages for hurdling the probability results from the logistic model into 0's and 1's. Liu et al (2005) and Lobo et al. (2008) (see literature cited in the report for full references) show that a simple and reliable method to hurdle the results is to use the prevalence (a percentage) of the species in the landscape. This is definitively a conservative approach, as the prevalence is likely to be higher than estimated from our data. The consequence of using a conservative hurdle is higher confidence in the determination of preferred habitat (i.e., higher likelihood of a cell determined to be preferred as being indeed preferred).

Q: You probably want to illustrate how sensitive the data is to your thresholds of suitable (70% of the species present). How do the results change if you define this as 60%, 80%, etc.?

A: Indeed, we provide the range of possible values if preferred habitat is understood as "the area where all indicator species overlap" (lower end) and as "the area where half of the indicator species overlap" (upper end).

Q: Might having a different number of indicator species for each habitat type affect the modeling results?

A: Yes, perhaps the best interpretation is that the definition of the habitat type is broader as more species are added. We thought we reached a good compromise in the selections we made.

Salinity:

Q: Is there any way to incorporate the likely spatial variation in salinity, either using a range of estimates or through a simple model relating salinity to depth or distance from freshwater source?

A: There is no reliable way to model heterogeneity in values of salinity, though measurements indeed indicate that there are small spatial differences. These small differences may result in possibly consequential differences in suitability, but we lack the means to determine even that. Analyses in other systems suggest small changes of < 10 ppt have undetectable consequences on

bird abundances with current sample sizes and sampling techniques. At the scale at which we are modeling, nonetheless, the additional work you suggest is not likely to result in any meaningful improvements.

APPENDIX C: GRAPHICS SUPPORTING RECIPE CARDS

The tables and graphs below show preferred ranges of habitat parameters as derived from the landscape models. For each habitat group, we present the parameters with the most explanatory power, along with the preferred ranges of those parameters. Included are probability density graphs supporting these conclusions.

PLAYA

Parameter	Preferred Range
Amount of exposed shoreline	From a few thousand m^2 to > 5 ha.
Amount of shallow water	< 3 hectares, but can be more.
Proximity to the shoreline	A permanent shoreline should be within 1 km.
Amount of lands with minimal development or undeveloped	Preferred playa habitats should be with a matrix of several ha of minimally developed lands.
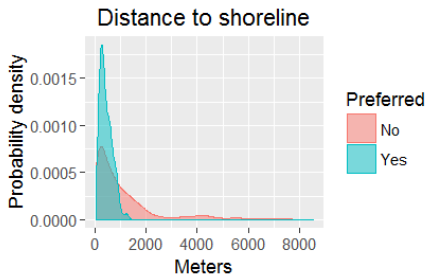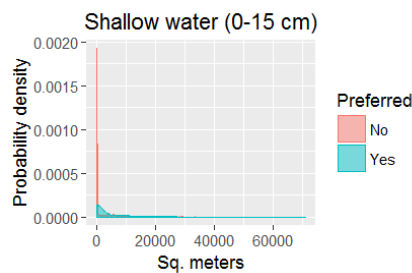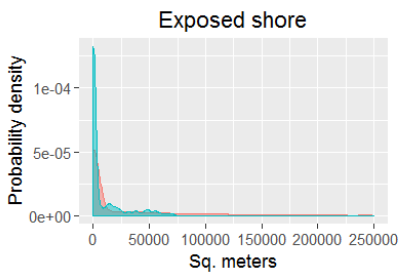
MUDFLATS AND SHALLOW WATER

Parameter	Preferred Range
Shallow waters (< 15 cm) locally and in the larger landscape	At least 25% of the area as shallow waters.
Exposed shore, mudflats, near and in the larger landscape	Some amount of exposed shore and mudflats, including > 90% mudflats.
Proximity to the shoreline	A permanent shoreline should be within 1 km.
Distance to rivers and river mouths	Within 5 km from a river or river mouth
Sand, silt, and organic contents	Submerged sediments should have silt (10-45%), sand (15-50%) and organic contents (<20%). Little silt.
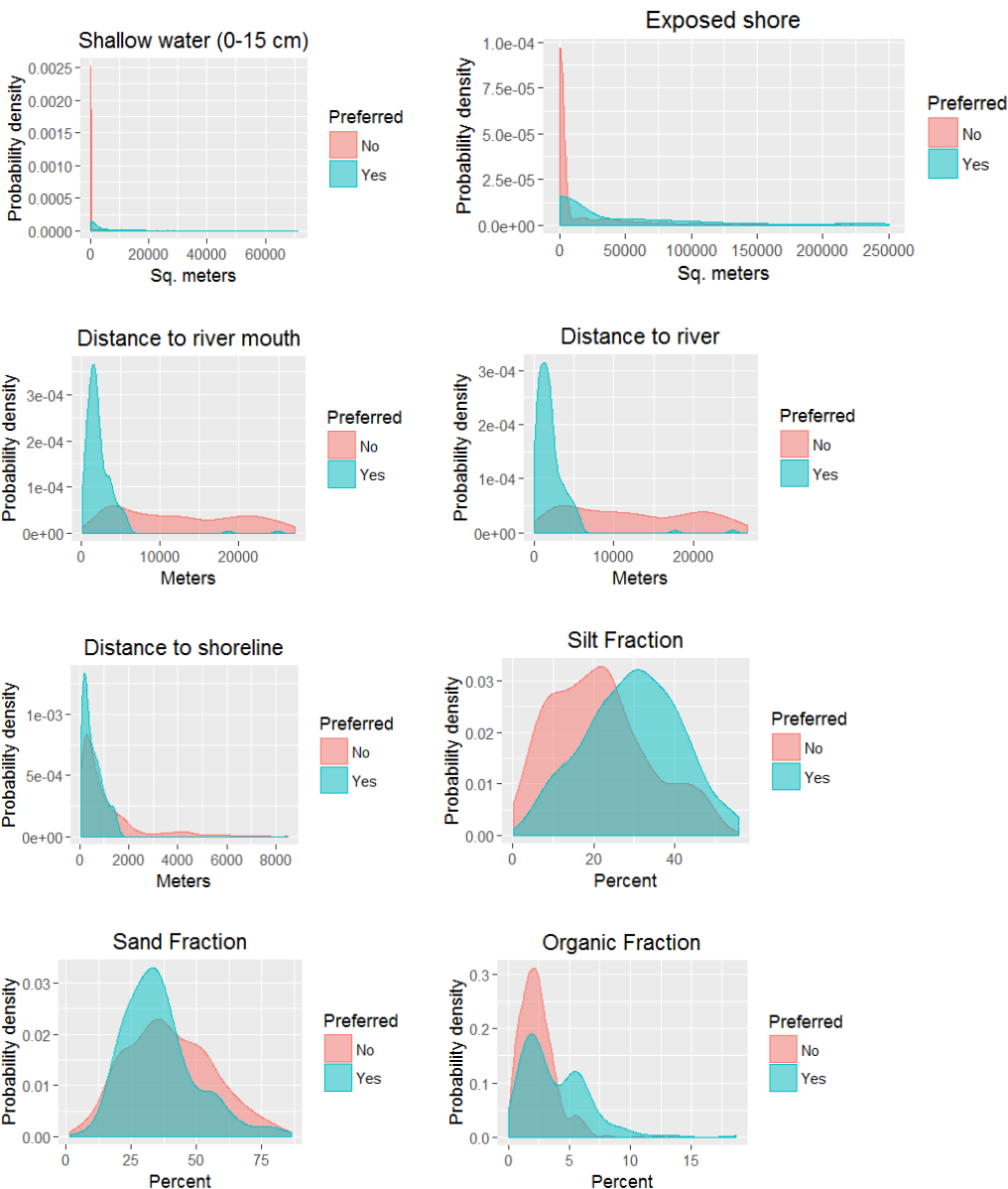
MID-DEPTH WATER

Parameter	Preferred Range
Amount of mid-depth water	From a few thousand m^2 to > 2 ha.
Depth of surrounding waters	< 1.5 m.
Proximity to the shoreline	Up to within 300 m.
Distance to rivers and river mouths	Within 6 km
Amount of exposed shoreline	Anywhere from a few thousand m^2 to several ha.
Area of open water	5 to 20 ha.
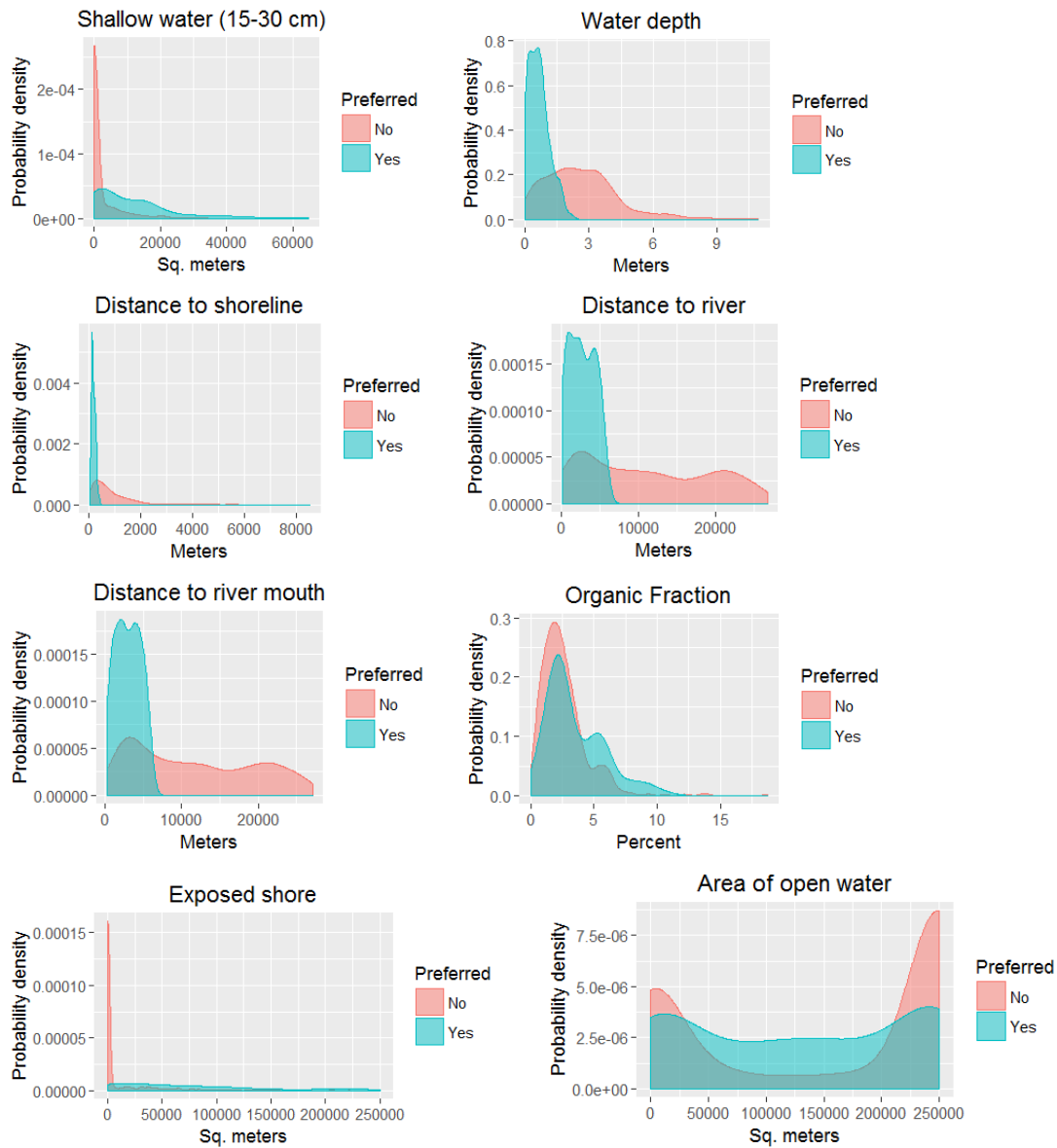
DEEP WATER

Parameter	Preferred Range
Area of deep water	From a few thousand m^2 to > 25 ha.
Depth of surrounding waters	1-4 m.
Proximity to the shoreline	Up to 1.5 km.
Distance to rivers and river mouths	Preferably within 5 km.
Area of open water	As much as possible. Species in this habitat type like large water bodies.
Percent silt, sand, and organic content of submerged sediments	2% or more organic content, 20%-60% sand fraction, 10%-40% silt
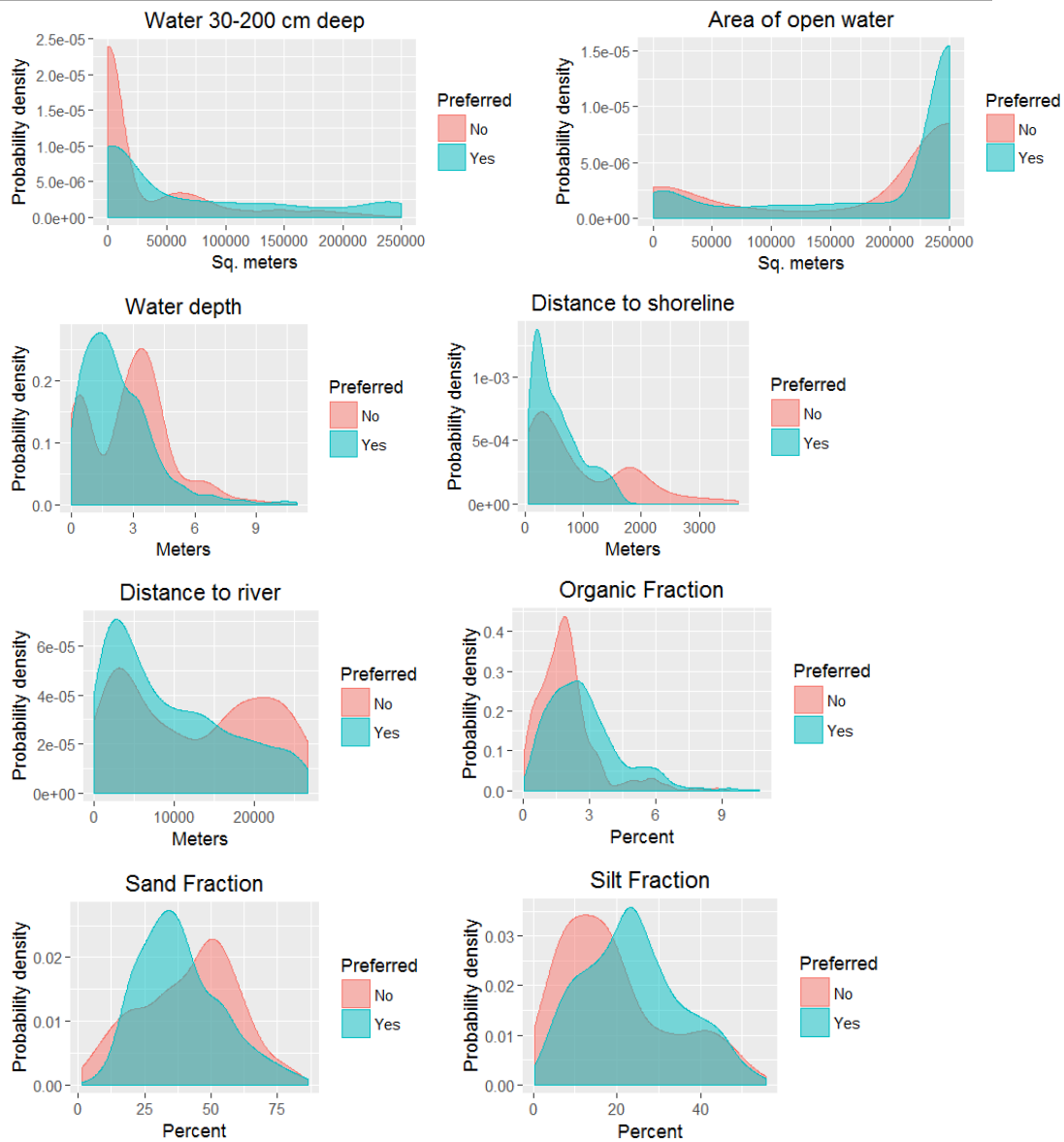
PERMANENT VEGETATED WETLANDS

Parameter	Preferred Range
Area of freshwater wetland	From 1 to > 10 ha.
Depth of surrounding waters	Less than 1 m
Area of exposed shore	At least 10 ha.
Distance to rivers and river mouths	Preferably within 10 km.
Area of herbaceous vegetation	From a few thousand m^2 to < 10 ha.
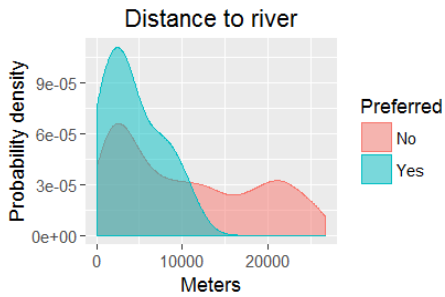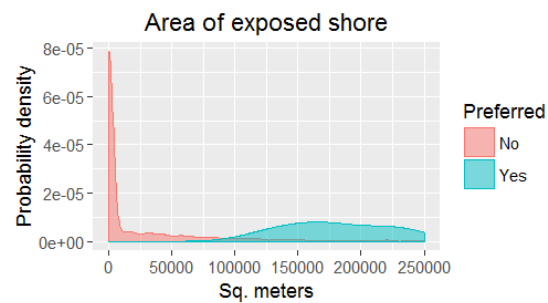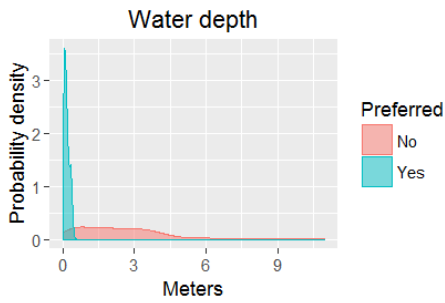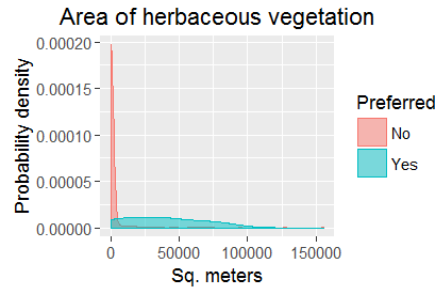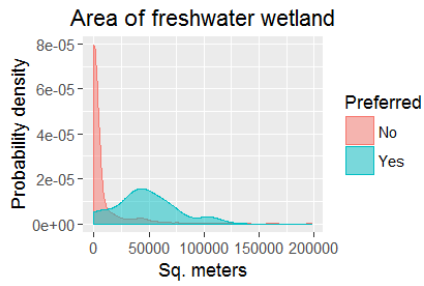
APPENDIX D: MAPS OF PREFERRED HABITATS BY TYPE

The maps below show preferred habitat areas in 1999 and 2015 for the five types of habitat we have identified at the Salton Sea.
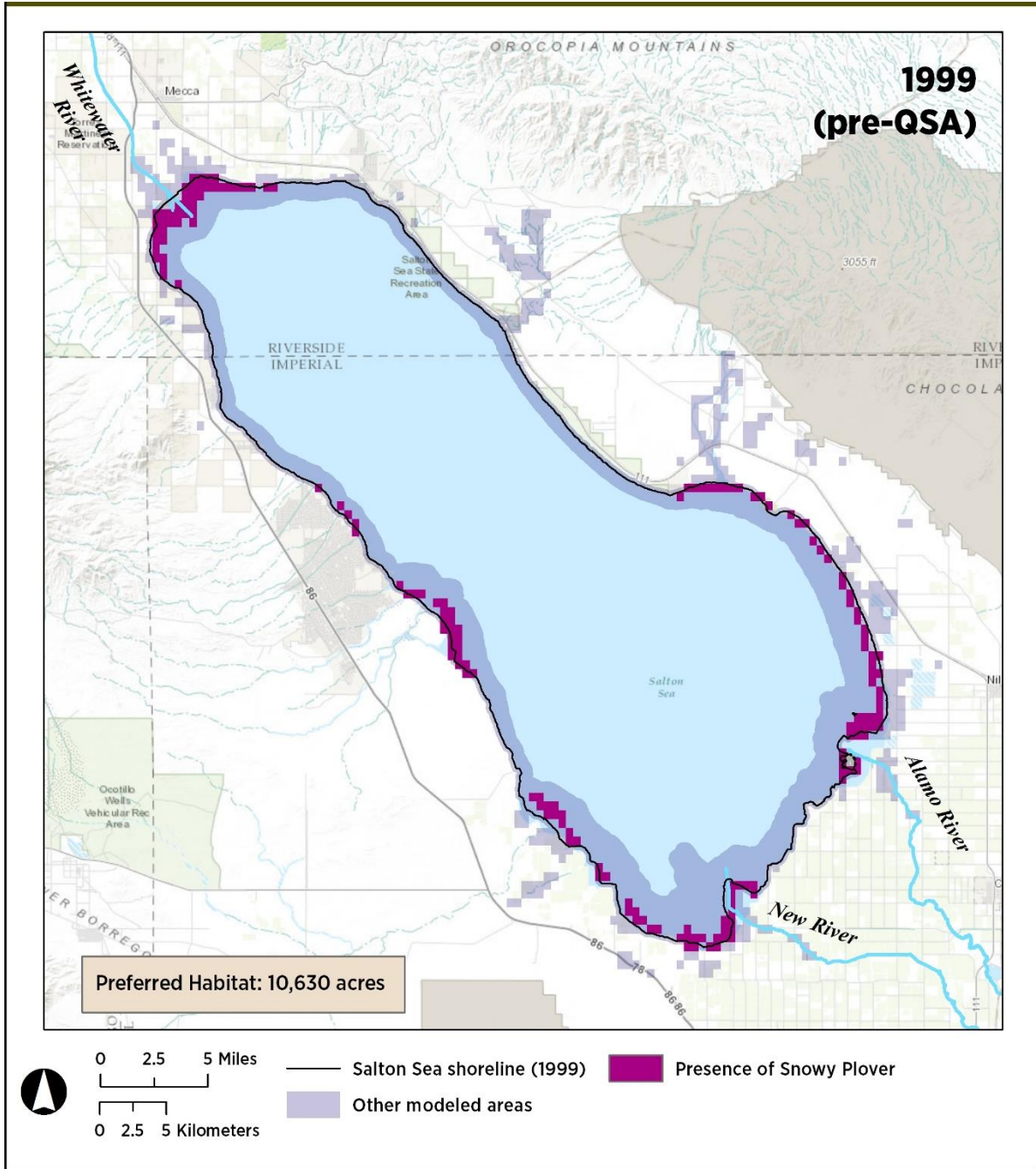
Figure D-1. Map of preferred habitat for playa nesting birds in 1999.
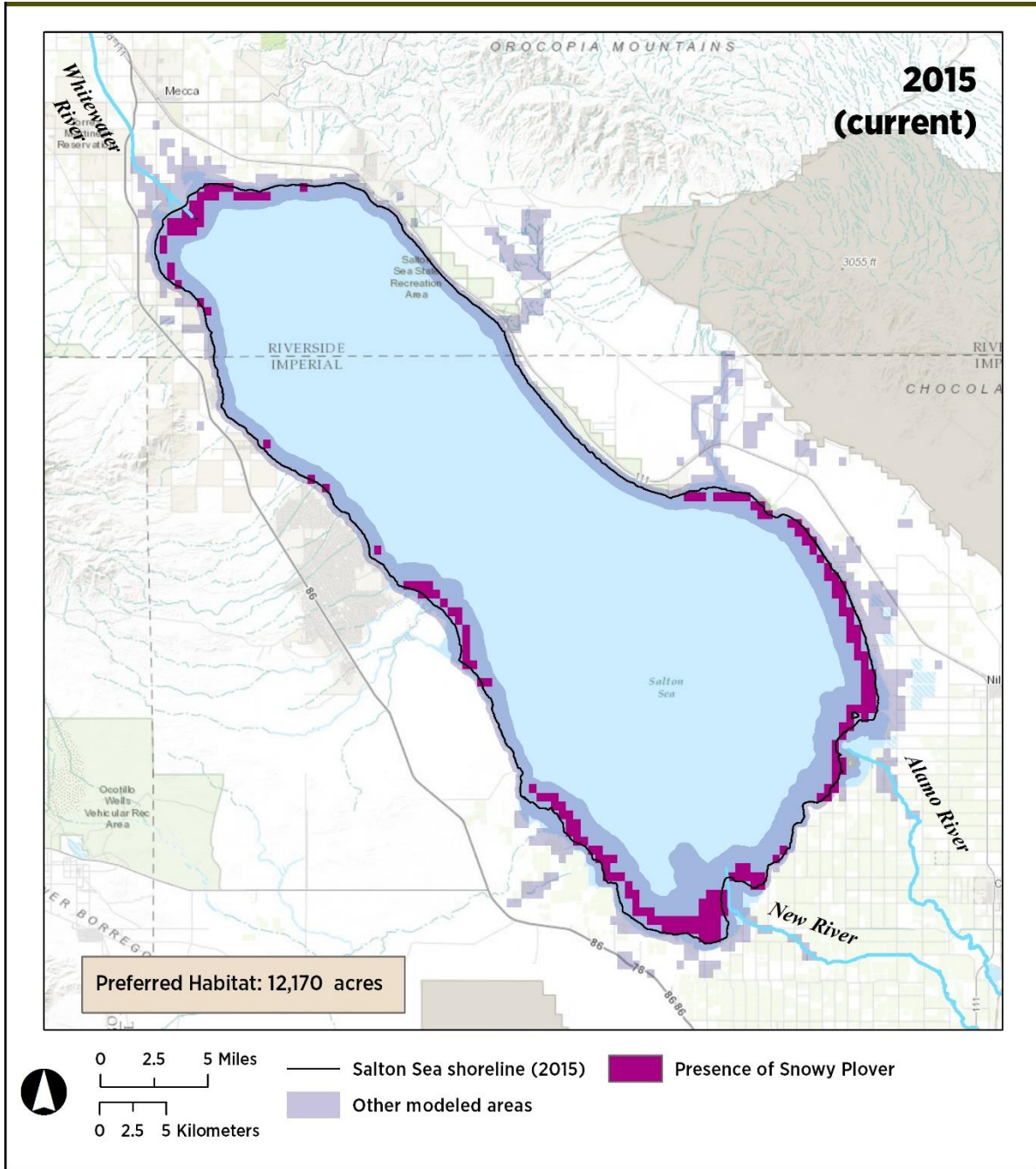
Figure D-2. Map of preferred habitat for playa nesting birds in 2015.
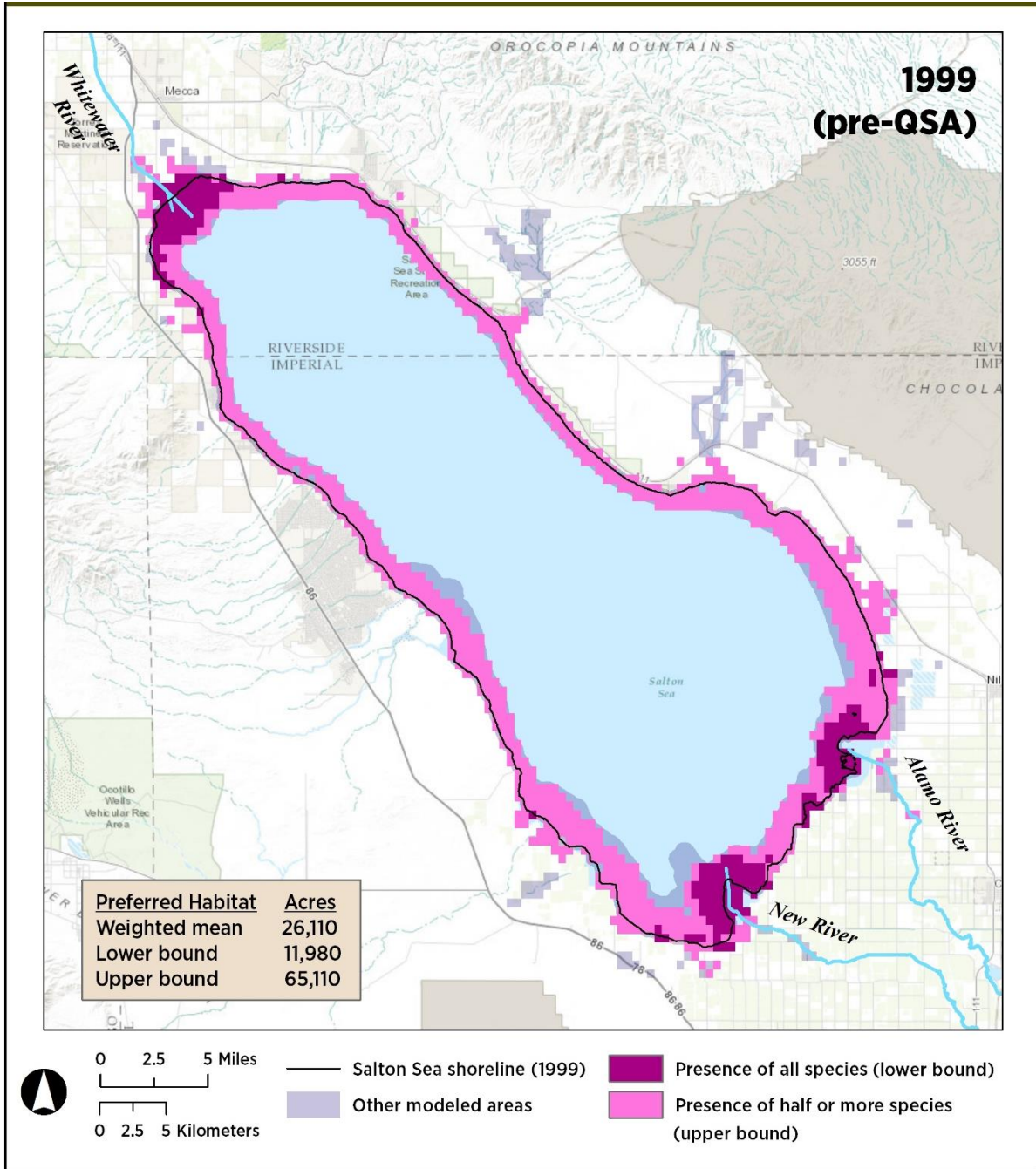
Figure D-3. Map of preferred habitat for mudflats and shallow water species in 1999.
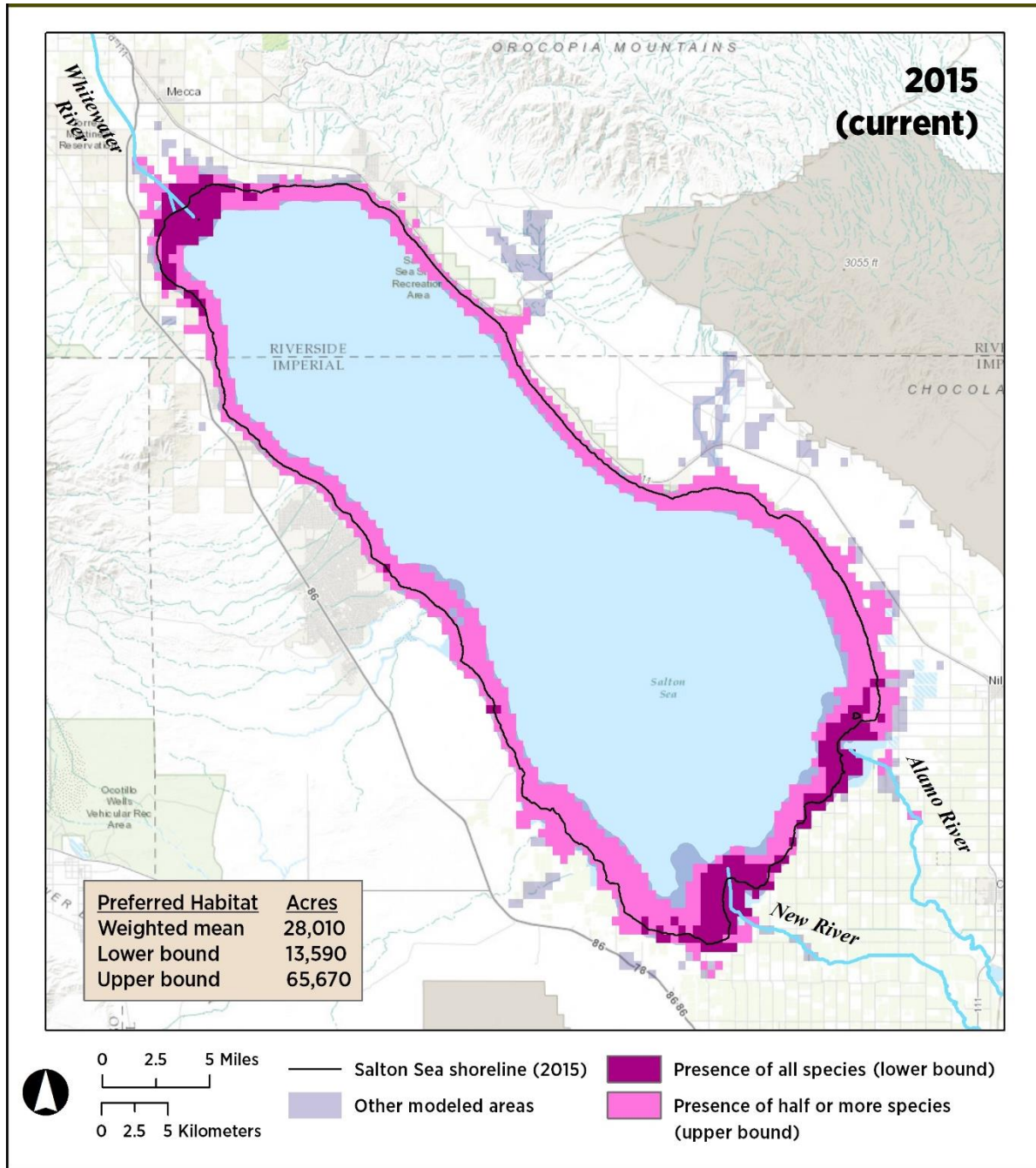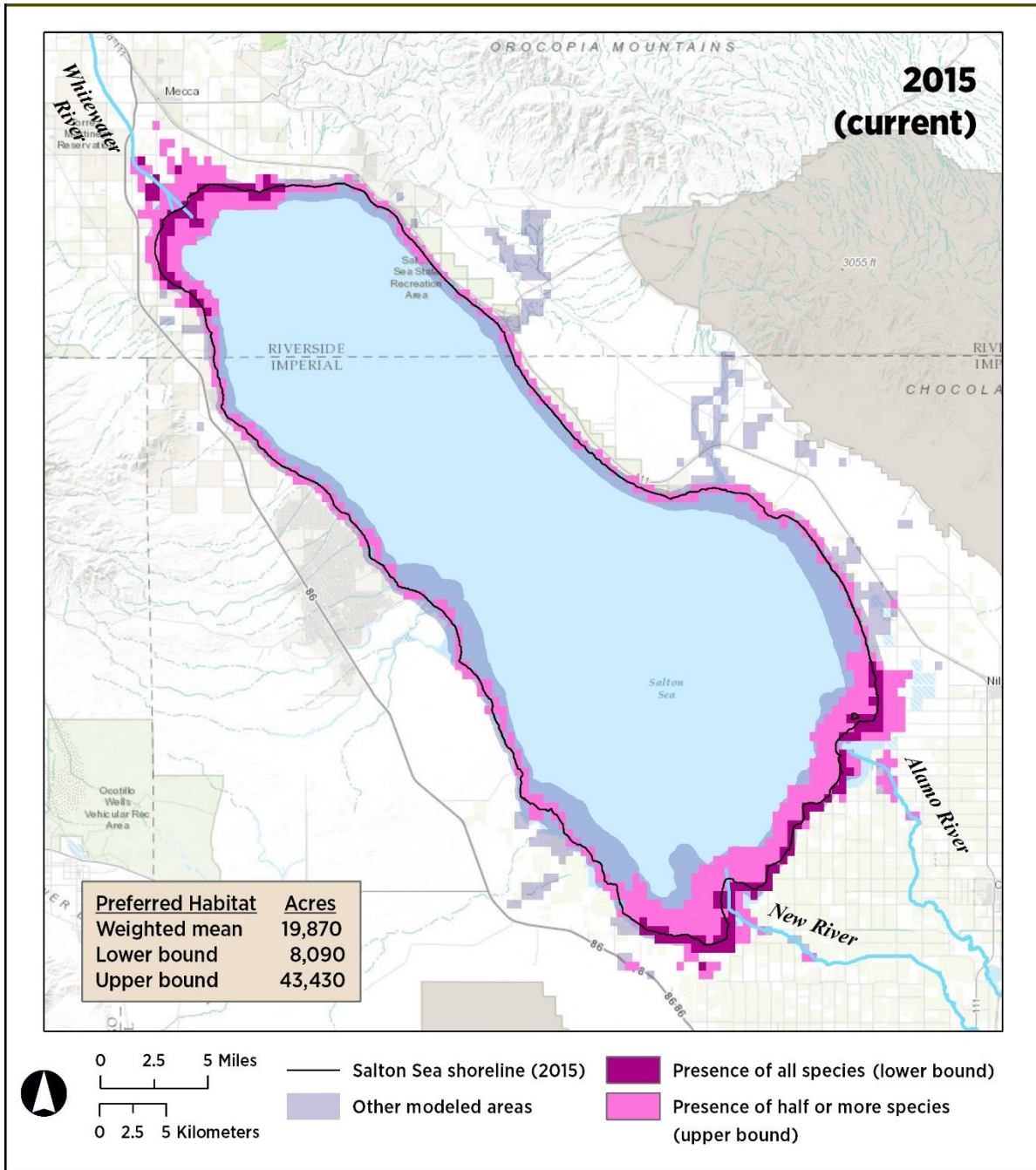
Figure D-4. Map of preferred habitat for mudflats and shallow water species in 2015.
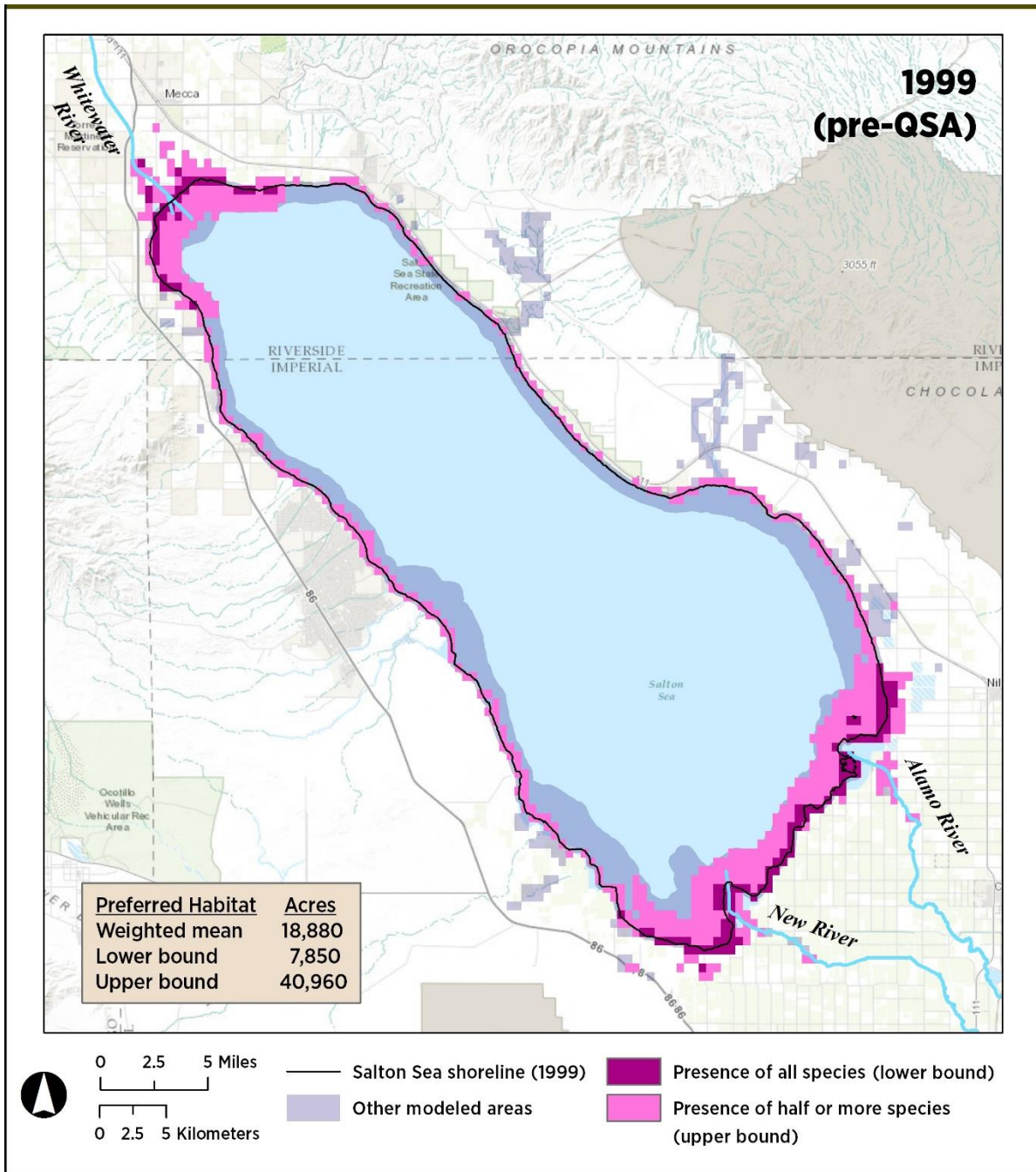
Figure D-5. Map of preferred habitat for mid-depth water species in 1999.

Figure D-6. Map of preferred habitat for mid-depth water species in 2015.
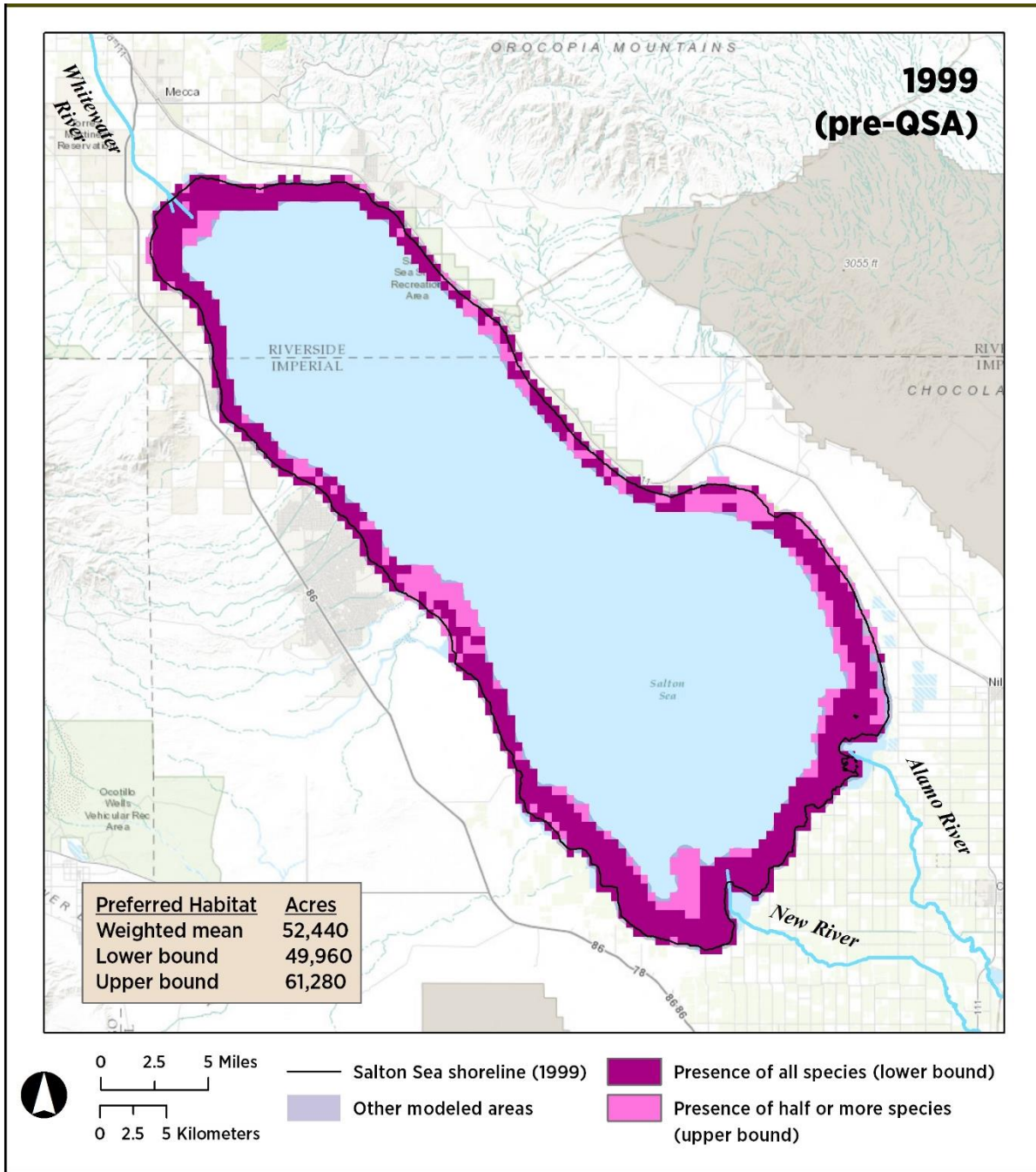
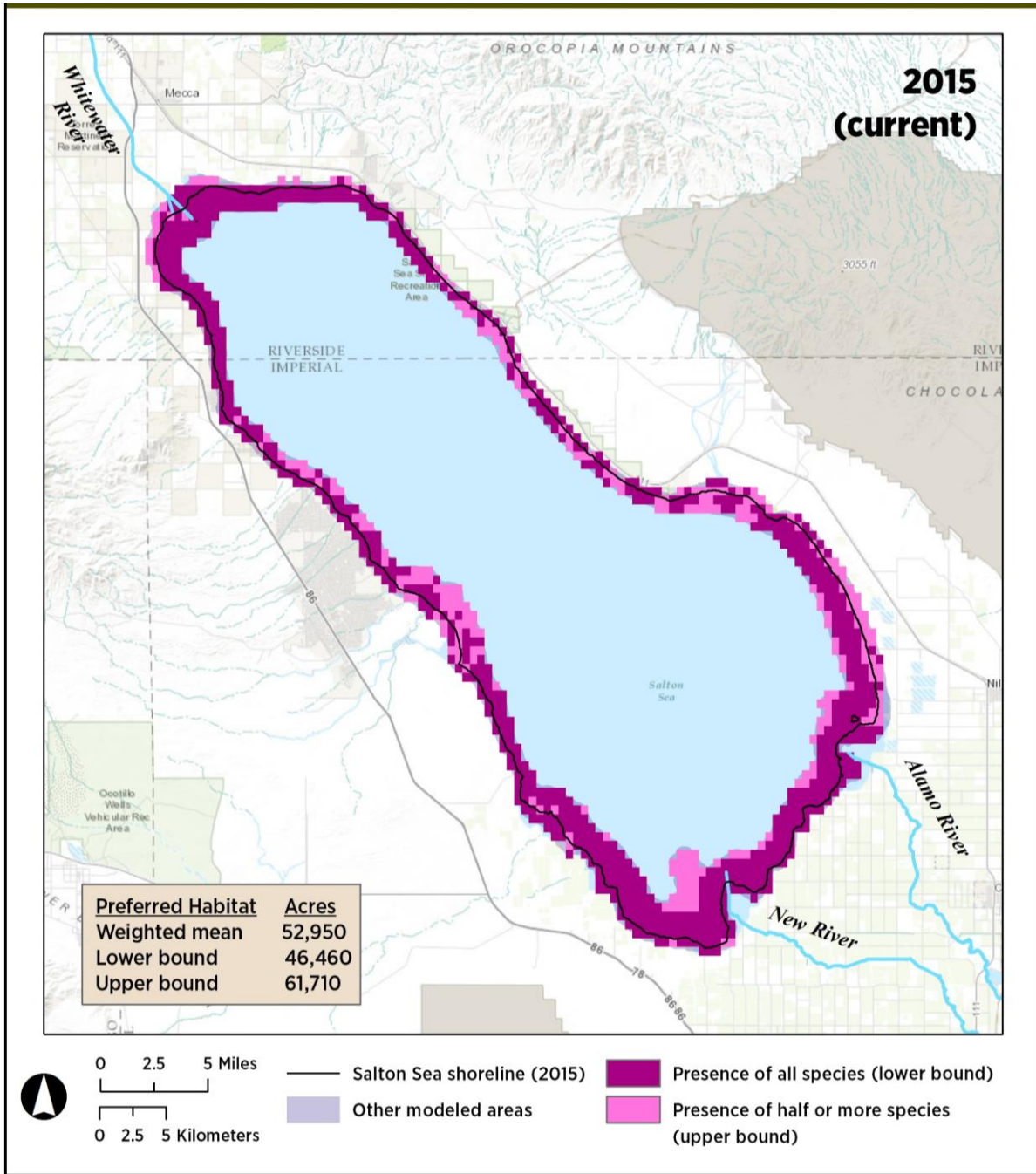Figure D-7. Map of preferred habitat for deep water species in 1999.

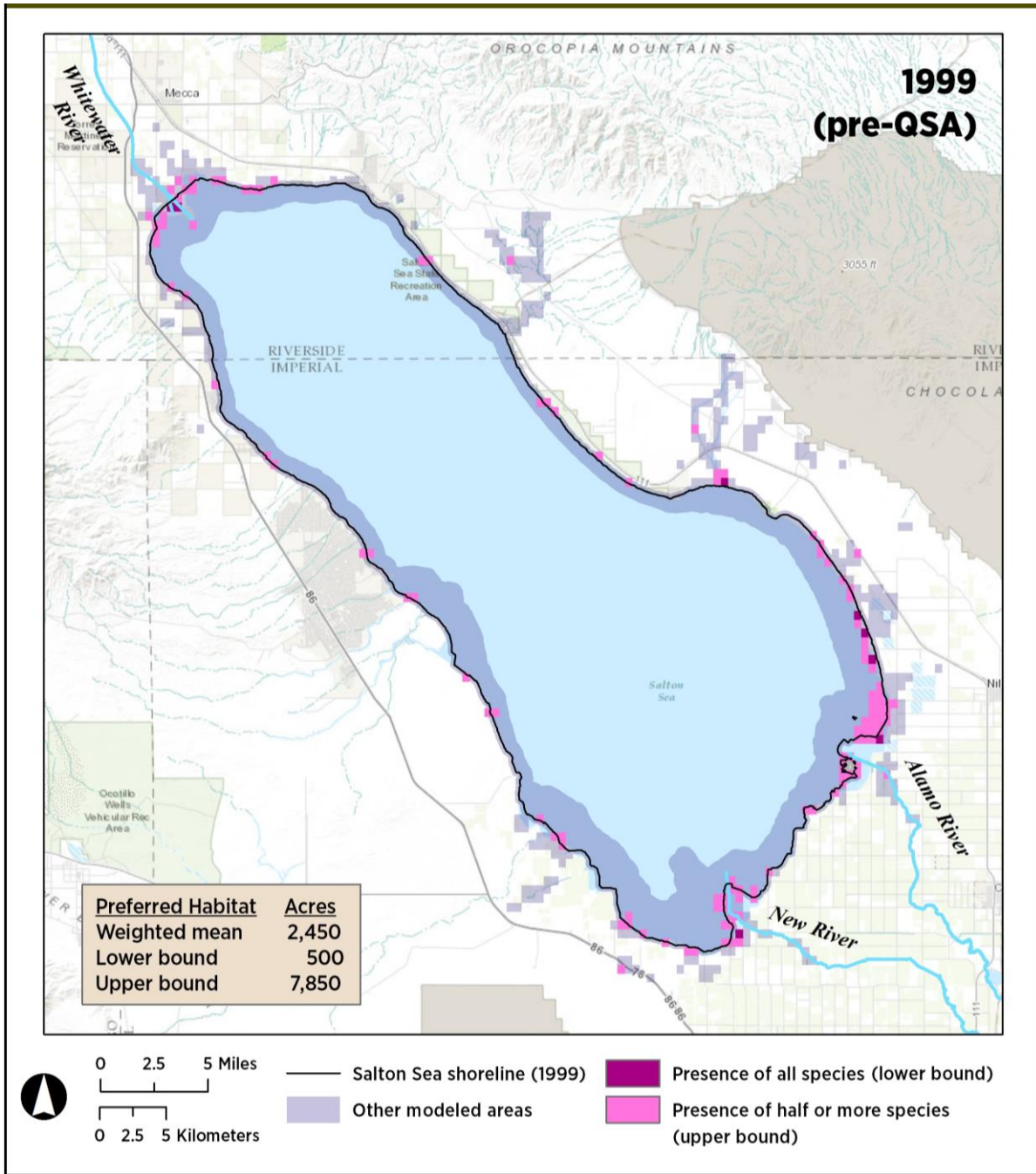Figure D-8. Map of preferred habitat for deep water species in 2015.

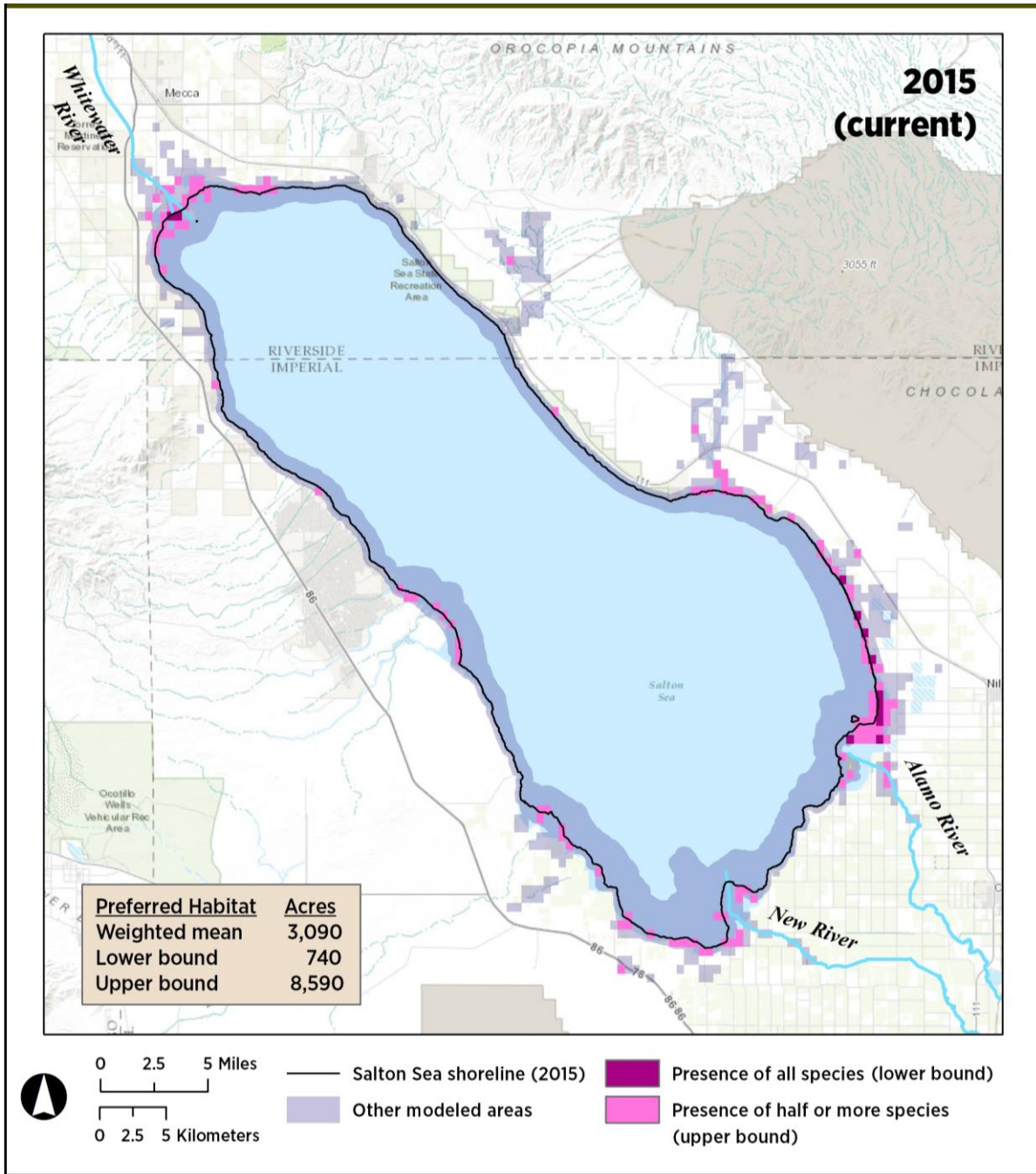Figure D-9. Map of preferred habitat for permanent vegetated wetlands species in 1999.

Figure D-10. Map of preferred habitat for permanent vegetated wetlands species in 2015.