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The Salton Sea as critical habitat to migratory and resident waterbirds

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Abstract

Concern about the Salton Sea ecosystem, based on potential impacts of increasing salinity, contaminants, disease outbreaks, and large die-offs of birds, is heightened because of tremendous prior loss and degradation of wetland habitat in western North America. In 1999, we used a variety of survey methods to describe patterns of abundance of birds at the Salton Sea and in adjacent habitats. Our results further documented the great importance of the Salton Sea within the Pacific Flyway to wintering, migratory, and breeding waterbirds. Exclusive of Eared Grebes, we estimated about 187 000 individual waterbirds at the Salton Sea in January, 88 000 in April, 170 000 in August, and 261 000 in November. Additional surveys of Eared Grebes in November and December suggested the total population of all waterbirds was about 434 000 to 583 000 in those months, respectively. We also documented breeding by about 14 000 pairs of colonial waterbirds. Waterbirds were particularly concentrated along the northern, southwestern, southern, and southeastern shorelines and river deltas. By contrast, some species of wading birds (Cattle Egret, White-faced Ibis, Sandhill Crane) and shorebirds (Mountain Plover, Whimbrel, Long-billed Curlew) were much more numerous in agricultural fields of the Imperial Valley than in wetland habitats at the Sea. Various studies indicate the Salton Sea is of regional or national importance to pelicans and cormorants, wading birds, waterfowl, shorebirds, and gulls and terns. Important taxa are the Eared Grebe, American White Pelican, Double-crested Cormorant, Cattle Egret, White-faced Ibis, Ruddy Duck, Yuma Clapper Rail, Snowy Plover, Mountain Plover, Gull-billed, Caspian, and Black terns, and Black Skimmer. Proposed restoration projects should be carefully assessed to ensure they do not have unintended impacts and are not placed where large numbers of breeding, roosting, or foraging birds concentrate. Similarly, plans to enhance opportunities for recreation or commerce at the Sea should aim to avoid or minimize disturbance to birds. Future research should focus on filling gaps in knowledge needed to effectively conserve birds at the Salton Sea.

Introduction

The Salton Sea, as an integral part of the Río Colorado Delta region, supports large numbers and a great variety of avian species and is one of the most important wetlands to birds in North America (e.g. Jehl, 1994). A number of bird species have populations in the Salton Sea area that are of regional or continental importance in size or are highly vulnerable. Also, the Salton Sea serves as a vital migratory stopover and wintering area for species that breed elsewhere in western North America. Because of this connectivity, the health of populations of many species of waterbirds is linked to that of the Salton Sea. Great concern recently has been expressed about the future of the Salton Sea ecosystem because of historically increasing salinity, contamination from agricultural and urban sources, disease outbreaks, and large die-offs of waterbirds (e.g. USFWS, 1997; Tetra Tech, 2000). This concern is heightened by the tremendous prior loss and degradation of wetland habitat in western North America (Dahl et al., 1997) and ongoing threats to other large saline lakes in the region (Jehl, 1994).

Although key previous information on the avifauna of the Salton Sea has been summarized (Shuford et al., 1999; Patten et al., in press), various proposals to deal with problems of ecosystem health are hampered by the limited quantitative data available on the current status and ecology of birds using this area. As part of a multi-disciplinary reconnaissance survey coordinated by the Salton Sea Science Subcommittee (papers this volume), we conducted a year-long study to document the abundance, distribution, annual phenology, and broadscale habitat associations of birds using the Salton Sea and adjacent habitats. Here we report the patterns of abundance of waterbirds at the Salton Sea in 1999, compare them with prior data, and discuss both the regional and continental importance of bird populations at the Salton Sea. We also interpret the relevance of our findings to plans for restoration at the Sea and make recommendations for further research.

Study area and methods

The study area was the saline Salton Sea and adjacent areas in Riverside and Imperial counties, California, U.S.A. Aspects of the physical characteristics, limnology, and aquatic life of the Sea are described elsewhere in this volume. Habitats surveyed included the shoreline and open water of the Salton Sea; adjacent fresh or brackish marshes and freshwater impoundments; and isolated freshwater marshes, lakes, ponds, and the extensive irrigated agricultural fields of the Imperial Valley (Figs 1–3). To obtain data on bird use of this area, we used a suite of survey methods and protocols described below. Scientific names of all birds recorded on surveys are listed in Table 1.

Comprehensive waterbird surveys

We used comprehensive surveys to document the overall abundance, distribution, and broadscale habitat associations of most waterbirds using the Salton Sea and nearby wetlands and marshes. These surveys were conducted over four short periods during mid-winter (22 January–5 February), spring migration (17–18 April), fall migration (13–16 August), and early winter (11–15 November). In contrast to the other three, the 22 January to 5 February survey involved two separate surveys of the Sea, one to cover shorebirds (22–30 [mostly 22–27] January) and another to cover all other waterbirds (29 January–5 February). On each census, a team of observers surveyed the entire Salton Sea shoreline and open water zone within 0.5 km of shore, adjacent marshes and impoundments, and various sites in the Imperial Valley, including the Finney-Ramer Unit of Imperial Wildlife Area (WA) south of Calipatria and private duck clubs near Brawley. For a detailed description of the areas and area boundaries (and additional maps), see Shuford et al. (2000). The number of observers (project staff and skilled volunteers) ranged from 7 to 19 per survey. Observers counted birds with the aid of binoculars and spotting scopes, generally traveling by vehicle or on foot. During summer months, surveys of the shoreline from Iberia Wash at Salton City south to, and including, the New River (Fig. 1) were accomplished with the aid of an airboat to reduce the risk of heat exhaustion while covering this long, isolated stretch.

On these surveys, we recorded all shorebirds and other waterbirds except Eared Grebes, American White Pelicans, Brown Pelicans, Double-crested Cormorants, American Coots, and waterfowl, which were counted on aerial surveys as described below. On the January comprehensive survey, Western and Clark's grebes were not surveyed in all areas, and the Pied-billed Grebe and all rails, gulls, and terns were not surveyed in areas 3–5.

We instructed observers, when possible, to identify all birds to species. Groups of unidentified waterbirds fell mostly into seven categories: large grebes of the genus *Aechmophorus*, either Western or Clark's grebes; white egrets, mostly Snowy and Cattle egrets; yellowlegs, either Greater or Lesser yellowlegs; small sandpipers of the genus *Calidris*, primarily Western Sandpipers, Least Sandpipers, and Dunlins; dowitchers, either Short-billed or (primarily) Long-billed dowitchers; phalaropes, either Wilson's or Red-necked phalaropes; and various gulls of the genus *Larus*. For analytical purposes we grouped all dowitchers as dowitcher spp. owing to the difficulty of identifying most individuals to species. We assigned other unidentified waterbirds to species using methods described in Page et al. (1999), leaving some in unidentified categories when the ratio of unidentified–identified was high.

Aerial surveys for various waterbirds

Pelicans and cormorants

Mostly in tandem with photographic surveys of nesting colonies, K. Molina and D. Shuford conducted aerial surveys of American White and Brown pelicans and Double-crested Cormorants around the periphery

Table 1. List of 107 species of native waterbirds recorded on surveys of the Salton Sea, California, in 1999. Taxonomy follows AOU (1998)

Common Loon *Gavia immer*
Pied-billed Grebe *Podilymbus podiceps*
Eared Grebe *Podiceps nigricollis*
Western Grebe *Aechmophorus occidentalis*
Clark's Grebe *Aechmophorus clarkii*
Black Storm-Petrel *Oceanodroma melania*
American White Pelican *Pelecanus erythrorhynchos*
Brown Pelican *Pelecanus occidentalis*
Double-crested Cormorant *Phalacrocorax auritus*
American Bittern *Botaurus lentiginosus*
Least Bittern *Ixobrychus exilis*
Great Blue Heron *Ardea herodias*
Great Egret *Ardea alba*
Snowy Egret *Egretta thula*
Tricolored Heron *Egretta tricolor*
Cattle Egret *Bubulcus ibis*
Green Heron *Butorides virescens*
Black-crowned Night-Heron *Nycticorax nycticorax*
White-faced Ibis *Plegadis chihi*
Wood Stork *Mycteria americana*
Fulvous Whistling-Duck *Dendrocygna bicolor*
Greater White-fronted Goose *Anser albifrons*
Snow Goose *Chen caerulescens*
Ross's Goose *Chen rossii*
Canada Goose *Branta canadensis*
Brant *Branta bernicla*
Wood Duck *Aix sponsa*
Gadwall *Anas strepera*
American Wigeon *Anas americana*
Mallard *Anas platyrhynchos*
Blue-winged Teal *Anas discors*
Cinnamon Teal *Anas cyanoptera*
Northern Shoveler *Anas clypeata*
Northern Pintail *Anas acuta*
Green-winged Teal *Anas crecca*
Canvasback *Aythya valisineria*
Redhead *Aythya americana*
Ring-necked Duck *Aythya collaris*
Greater Scaup *Aythya marila*
Lesser Scaup *Aythya affinis*
Surf Scoter *Melanitta perspicillata*
White-winged Scoter *Melanitta fusca*
Black Scoter *Melanitta nigra*
Bufflehead *Bucephala albeola*
Common Goldeneye *Bucephala clangula*
Common Merganser *Mergus merganser*
Red-breasted Merganser *Mergus serrator*
Ruddy Duck *Oxyura jamaicensis*
Yuma Clapper Rail *Rallus longirostris yumanensis*
Virginia Rail *Rallus limicola*
Sora *Porzana carolina*
Common Moorhen *Gallinula chloropus*
American Coot *Fulica americana*
Sandhill Crane *Grus canadensis*
Pacific Golden-Plover *Pluvialis fulva*
Snowy Plover *Charadrius alexandrinus*
Semipalmated Plover *Charadrius semipalmatus*
Killdeer *Charadrius vociferus*
Mountain Plover *Charadrius montanus*
Black-necked Stilt *Himantopus mexicanus*
American Avocet *Recurvirostra americana*
Greater Yellowlegs *Tringa melanoleuca*
Lesser Yellowlegs *Tringa flavipes*
Solitary Sandpiper *Tringa solitaria*
Willet *Catoptrophorus semipalmatus*
Spotted Sandpiper *Actitis macularia*
Whimbrel *Numenius phaeopus*
Long-billed Curlew *Numenius americanus*
Marbled Godwit *Limosa fedoa*
Ruddy Turnstone *Arenaria interpres*
Black Turnstone *Arenaria melanocephala*
Red Knot *Calidris canutus*
Sanderling *Calidris alba*
Western Sandpiper *Calidris mauri*
Least Sandpiper *Calidris minutilla*
Baird's Sandpiper *Calidris bairdii*
Dunlin *Calidris alpina*
Stilt Sandpiper *Calidris himantopus*
Ruff *Philomachus pugnax*
Short-billed Dowitcher *Limnodromus griseus*
Long-billed Dowitcher *Limnodromus scolopaceus*
Common Snipe *Gallinago gallinago*
Wilson's Phalarope *Phalaropus tricolor*
Red-necked Phalarope *Phalaropus lobatus*
Red Phalarope *Phalaropus fulicaria*
Laughing Gull *Larus atricilla*
Franklin's Gull *Larus pipixcan*
Bonaparte's Gull *Larus philadelphia*
Heermann's Gull *Larus heermanni*
Mew Gull *Larus canus*
Ring-billed Gull *Larus delawarensis*
California Gull *Larus californicus*
Herring Gull *Larus argentatus*
Thayer's Gull *Larus thayeri*
Lesser Black-backed Gull *Larus fuscus*
Yellow-footed Gull *Larus livens*
Western Gull *Larus occidentalis*
Glaucous-winged Gull *Larus glaucescens*
Gull-billed Tern *Sterna nilotica*
Caspian Tern *Sterna caspia*
Common Tern *Sterna hirundo*
Forster's Tern *Sterna forsteri*
Least Tern *Sterna antillarum*
Black Tern *Chlidonias niger*
Black Skimmer *Rynchops niger*
American Golden-Plover *Pluvialis dominica*
Black-bellied Plover *Pluvialis squatarola*

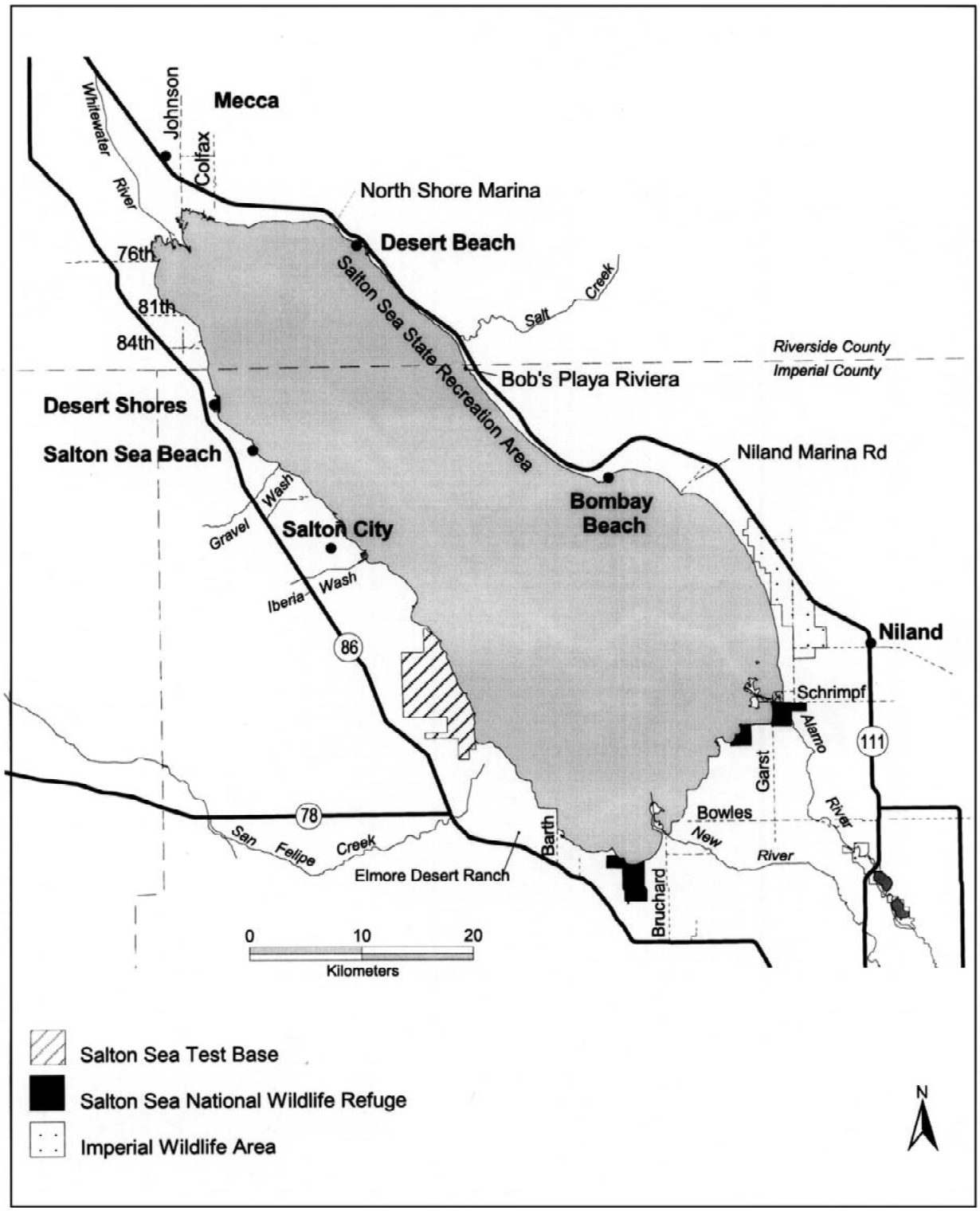

Figure 1. Overview map of the Salton Sea, California, and vicinity.

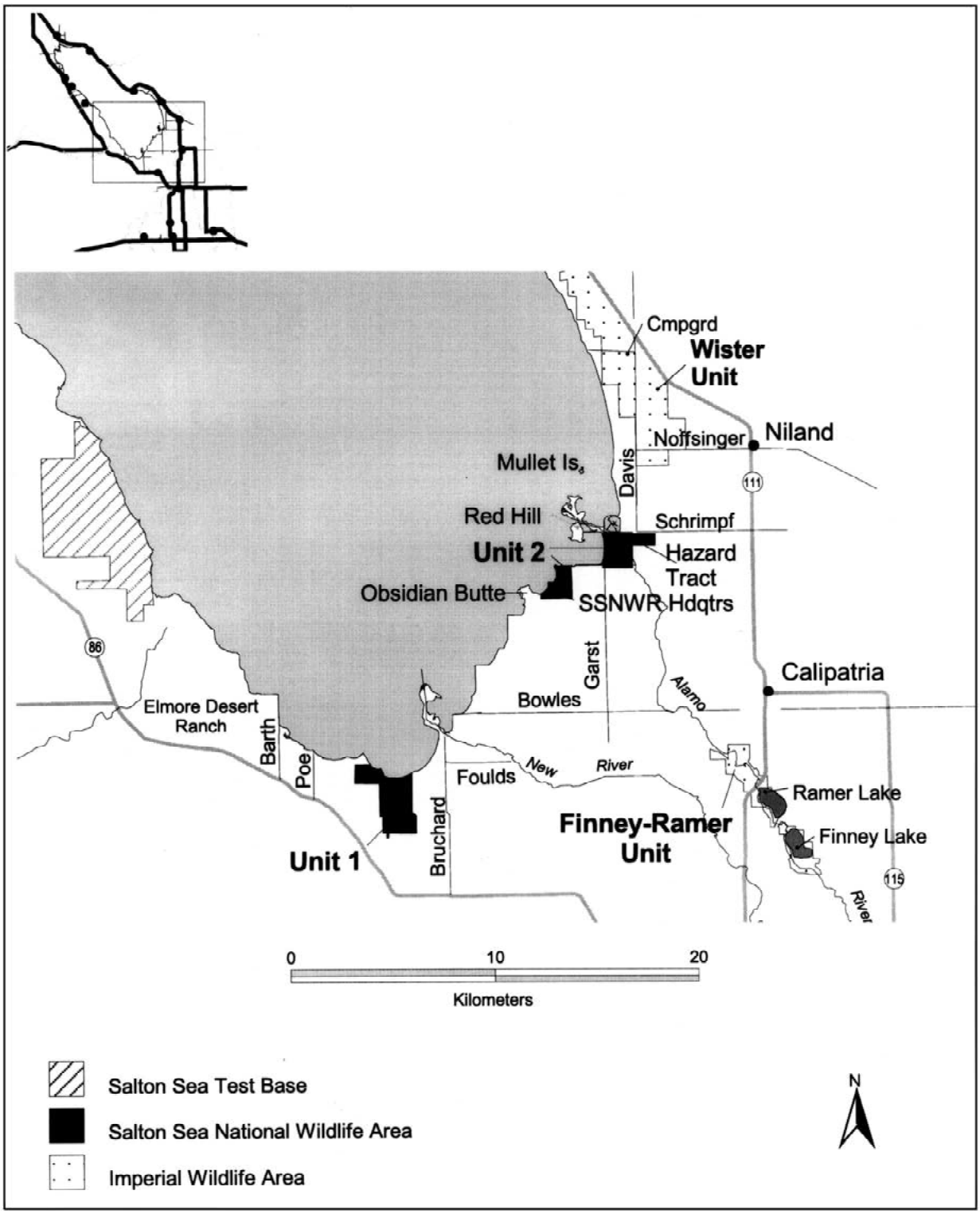

Figure 2. Map detail of the south end of the Salton Sea and adjacent portion of the Imperial Valley, California.

of the Salton Sea from a fixed-wing Cessna aircraft. We began all surveys at the southern shoreline at the end of Garst Road and conducted one or two counterclockwise circumnavigations of the Sea (Figs 1 and 2). We maintained a course parallel to and about 0.5 km from the shoreline, flying at heights from 60 to 90 m and at speeds of 70–100 knots. All individuals of the above species were counted off both sides of the plane. In addition, we also counted birds while flying multiple parallel transects across various pond complexes adjacent to the Sea. Aerial survey dates were: 28 January, 12 February, 5 March, 16 April, 28 May, and 16 August.

Eared Grebes, Aechmophorus *Grebes, and Ruddy Ducks*

We initially attempted to count Eared Grebes using new aerial photographic techniques pioneered at Mono Lake, California (Boyd & Jehl, 1998), but abandoned that effort because of an inability to distinguish on photographs among Eared Grebes and relatively large numbers of Ruddy Ducks, other waterfowl, and, particularly, dead or dying fish floating on the Sea's surface. Instead, R. McKernan and K. Molina conducted aerial surveys for this and other species on 19 March, 28 March, 29 November, and 17 December. They counted birds from a Cessna 172 high-wing airplane flying at speeds of 70–90 knots at altitudes varying between 60 and 90 m above the water. The survey route for each flight included: (1) transect one, which covered the entire inshore zone of the Sea by flying a route parallel to and about 0.5 km out from the shoreline, (2) transect two, which traversed a north-south track over the open water zone about 6–8 km out from the west shoreline, and (3) transect three, which traversed a south–north track over the open water zone about 8–10 km out from the eastern shoreline. Observers viewed from opposite sides of the aircraft and counted birds out to the distance at which species could be readily identified, which usually was about 0.5 km. Only birds positively identified were included in totals. Although surveys focused on Eared Grebes and Ruddy Ducks, observers also counted large grebes (*Aechmophorus* spp.), American White and Brown pelicans, and Double-crested Cormorants. On the 19 March survey, all species but the Eared Grebe were counted only from the inshore side of the plane.

Waterfowl

Salton Sea National Wildlife Refuge (SSNWR) biologists conducted aerial waterfowl surveys of the Salton Sea shoreline, adjacent marshes and impoundments, and Imperial Valley duck clubs and reservoirs on 8 January, 9 March, 3 April, 27 May, and 18 November 1999 using techniques established in prior years. Observers counted from a fixed-wing aircraft flying at heights varying from 75 to 90 m above the land and water's surface at speeds of 70–100 knots. All observations were made by a single observer (aided at times by the pilot) looking off the right (shoreward) side of the plane. Surveys began with impoundments in the Imperial Valley then shifted to a counterclockwise circumnavigation of the Salton Sea on which the plane followed a course parallel to and about 0.4 km from shore. The circumnavigation was periodically broken to fly multiple parallel transects over complexes of marshes and freshwater impoundments adjacent to the shoreline. Observers focused on counting all geese, ducks, and American Coots, but also tallied Eared Grebes and American White and Brown pelicans.

Roost counts

To obtain data on the population sizes of certain waterbirds that forage primarily in irrigated agricultural fields in the Imperial Valley rather than at the Salton Sea, we conducted eight roost counts on the following dates in fall and winter: 27 January, 13 February, 13 March, 14 August, 15 September, 21 October, 11 November, and 16 December. Counts were conducted at most known nighttime roosting sites for these species in the Imperial Valley. Counts were taken simultaneously at three to six sites on each survey. Observers (at least 2 at each site) were asked to be in place about 1.5 h before dusk and to count the number of Great Blue Herons, Great, Snowy and Cattle egrets, White-faced Ibis, and Sandhill Cranes that arrived at, or departed from, a site before nightfall. To guard against double-counting birds that left sites before dark to eventually roost at another site, we subtracted the departures from the sum of the arrivals and those present at the onset of the count to arrive at a net total. Observers terminated counts when birds stopped arriving or when it became too dark to see.

Agricultural transects

To assess occurrence patterns of birds in agricultural fields, we conducted monthly surveys of five roadside transects, each 8.05 km (5 mi) long, located in the northern Imperial Valley just south of the Salton Sea (Fig. 3). Project staff conducted surveys on 15 January, 6 February, 6 March, 2 April, 16 May, 7 June, 8 July,

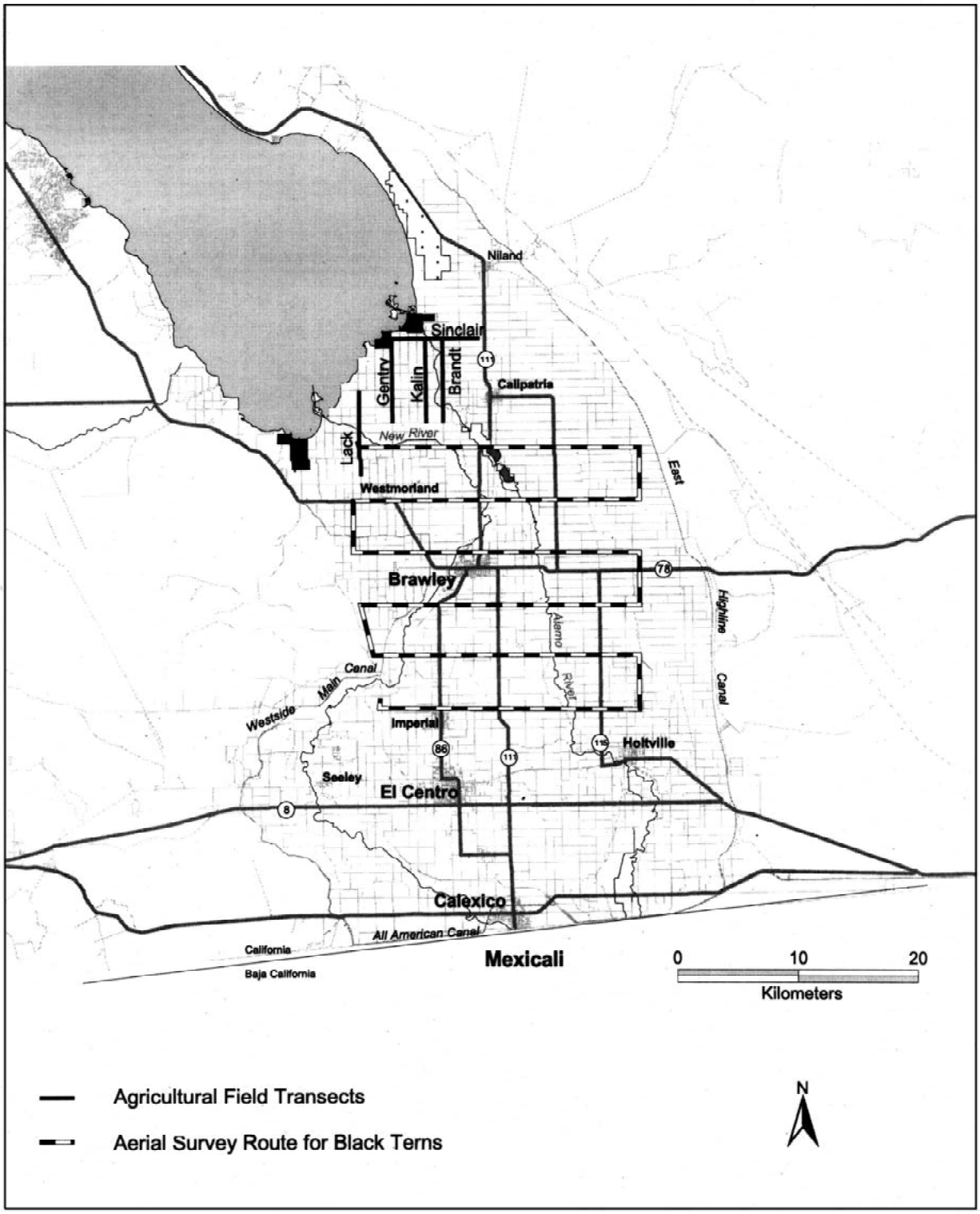

Figure 3. Overview map of the Imperial Valley, California, showing the location of roadside transects of agricultural fields (Lack, Gentry, Kalin, Brandt and Sinclair roads) and aerial survey route for Black Terns in 1999.

11 August, 9 September, 14 October, 10 November, and 10 December. To reduce sampling bias, observers alternated the order in which they surveyed transects and the starting point of individual transects between successive survey periods. They recorded the numbers of all species of birds found in agricultural fields adjacent to both sides of each roadside transect.

Colonial nesting waterbird surveys

We used airboat surveys of the entire Salton Sea shoreline as the primary method to document the distribution and abundance of all major cormorant and ardeid (heron, egret, night-heron) colonies. K. Sturm and associates conducted shoreline airboat surveys on 40 dates between 22 January and 16 July, but not all colonies were visited on a particular date. Surveys of some of the smaller colonies continued only through April. Airboat surveys were supplemented by vehicular visits by K. Sturm or project staff to additional colonies at Ramer Lake (6 & 14 May) and the Westmorland eucalyptus grove (8 July) away from the Salton Sea shoreline. On each survey, observers recorded the number of active nests and the general stage of nesting for each species at each site. Descriptions of the colony sites surveyed and their nesting substrates can be found in Shuford et al. (2000).

We used aerial photographic surveys to avoid disturbance and maximize the accuracy of nest counts for some of the larger colonies or for ones that were least visible from a boat. We used a fixed-wing aircraft to conduct photographic surveys of colonies of the Double-crested Cormorant and Great Blue Heron nesting on bare ground and rocks at Mullet Island at the south end of the Salton Sea (Fig. 2) on 1 February, 19 February, 25 March, and 16 April. While the plane slowed to about 70–90 knots and circled at 130–160 m over the island, D. Shuford shot multiple rolls of overlapping photographs of the nesting colonies using a Canon EOS single-lens reflex camera with a 300 mm lens and ASA 200 color film. J. Roth used standardized methods developed for surveying coastal seabird colonies (G. J. McChesney & H. R. Carter, in litt.) to count the numbers of cormorant and heron nests. She sorted the photographs (slides) to obtain a subset of overlapping reference photos of the highest resolution and contrast, projected these on a large sheet of white paper (69 × 86 cm easel), and marked nests and birds with a fine marker using identifiable landmarks as reference points to avoid double-counting. We defined active nests as those in which incubating or brooding adults, eggs, or chicks were visible.

Using the same field methods, K. Sturm or D. Shuford photographed aggregations of herons, egrets, and cormorants nesting in trees and marsh vegetation at the New and Alamo river mouths on 25 March, 3 April, 16 April, 27 May, and 28 May. Subsequently, we converted slides to 10 × 15 cm glossy prints, which we first sorted to obtain a subset of reference photos of the highest resolution and contrast. We then overlapped and taped together the prints to provide a composite photo of the colonies, or sub-colonies, from which we counted adults and nests directly. Great Blue Heron and Double-crested Cormorant nests and adults were readily identifiable on prints, but it was difficult to identify Great, Snowy, and Cattle egrets to species or to distinguish their nests. Consequently, for the latter species we estimated the number of active nests by first adjusting the counts of adult white egrets from 28 May aerial photographs by the following ratios derived from a 16 June boat survey – Great Egret (2%), Snowy Egret (4%), and Cattle Egret (94%). We then divided these numbers by two (adults/nest) to obtain a minimum estimate of nesting pairs of these species. Finally, we combined the data from aerial surveys of these colonies with that from other survey methods described elsewhere to estimate the total numbers of nesting pairs at the Sea.

As part of an independent long-term study, K. Molina and associates collected data on the size and productivity of larid (gull, tern, skimmer) colonies via foot or kayak surveys conducted at weekly to semi-monthly intervals from 7 March to 8 September and generally from a distance.

Estimating total nesting pairs

Estimating the total number of nesting pairs for each species of colonial waterbird at the Salton Sea was complicated by a lack of marked nests and individuals, our inability to survey all sites on a single day, and a high level of intra- and inter-colony nesting asynchrony exacerbated by several complete colony desertions by some species. The latter resulted in failed breeders moving to other colony sites. For each species at each colony site, we estimated the peak number of nesting pairs as the greatest number of nests recorded on a single colony visit. To avoid double-counting any renesting pairs that changed colony sites after failing in their initial attempts, we excluded high counts that occurred shortly after colony failures at nearby sites. We then summed the remaining high counts for

each site to obtain an estimate of the total number of nesting pairs at the Salton Sea. Although we knew of no complete colony failures for the Double-crested Cormorant, we used the peak count from Mullet Island as the estimate of the total number of nesting pairs of that species for the Salton Sea. This seems justified as the vast majority of cormorants had initiated nests on Mullet Island by early January, and the relatively small number of nests established elsewhere on the Sea after 28 February may have represented the relocation of some adults that failed in initial attempts at Mullet.

We believe our combined methodology for surveying nesting colonies produced reasonable, minimum estimates of nesting pairs for most species. We maintained aerial coverage of the entire shoreline and adjacent habitats throughout the breeding season, minimizing the possibility that significant colonies went undetected. Still we may have missed small colonies of the more secretive species, such as the Black-crowned Night-Heron and Snowy Egret, which might have nested within dense marshes away from the Salton Sea proper. We likely underestimated peak numbers of nest attempts for arboreal nesters because of the difficulty of viewing dense aggregations of nests stratified within three dimensional and, sometimes, dense habitats. Count accuracy was greatest for the Double-crested Cormorant on Mullet Island and for all larids, which nested on the ground in the open.

Additional survey methods

We used several other methods to survey target species. To document occurrence patterns of various rails and other marsh birds, we conducted breeding season surveys using tape playbacks. These focused primarily on the federally endangered Yuma Clapper Rail and the state threatened Black Rail. As part of the annual survey of the former taxa, we conducted censuses in a variety of marsh habitats around the periphery of the Salton Sea using methods developed by the Yuma Clapper Rail Recovery Team. We focused survey efforts at previously known Clapper Rail areas, particularly the Wister Unit of Imperial WA and the SSNWR, and explored new sites, particularly at the north end of the Sea. See Shuford et al. (2000) for a list and map of sites surveyed. Refuge personnel and project staff surveyed all Clapper Rail transects twice between 24 April and 15 May. On each transect, observers picked listening stations within appropriate marsh habitat. At each station, they played a tape for 2 min, stopped to listen for responses for 2 min, and then played the tape again for 2 min. Observers recorded birds responding to the tapes as well as incidental sightings of rails.

We also surveyed Black Rails (*Laterallus jamaicensis*) in marshes around the Salton Sea using methods developed by Evens et al. (1991) to detect birds responding to taped vocalizations ("*grr*" and "*kic-kic-kerr*" calls). Within appropriate habitat, observers selected transects with a set of listening stations, totaling 42 stations in 18 areas. From 24 April to 15 May, we surveyed each transect twice with the exception of three areas that we surveyed only once. Tape playback protocol was identical to that for the Clapper Rail as described above.

For comparison to prior surveys (Shuford et al., 1995), we conducted three surveys of the entire shoreline of the Salton Sea for Snowy Plovers. The winter surveys from 22 to 30 January and 11 to 14 November, when plovers flock and are easiest to detect, were conducted as part of the comprehensive surveys described above. The breeding season survey from 21 to 31 May was a separate survey focusing entirely on Snowy Plovers. At that season, surveying is made more difficult by adults sitting cryptically on nests and by adults with chicks sometimes moving long distances to mob observers. To minimize these problems, we instructed the five observers involved to follow a more stringent protocol in May than in winter. They used both binoculars and spotting scopes to repeatedly scan long distances up and down beaches and alkali flats to try to detect incubating adults before the plovers snuck off nests and scattered. We also asked observers to zig-zag back and forth across beaches and alkali flats to try to detect roosting or incubating plovers or those foraging behind shoreline berms where they otherwise might not be visible from the upper beach. On very wide beaches and alkali flats, two observers worked in tandem, one covering the upper beach or alkali flats and the other the immediate shoreline, zig-zagging as needed.

We estimated the winter population size of the Mountain Plover by conducting three comprehensive surveys of most (80–90%) of the agricultural lands in the Imperial Valley on 14–15 February, 13–14 November, and 11–12 December (Fig. 3). Adjusting for individuals participating on both days of two-day survey periods, the number of observers ranged from a low of 11 observers in 8 parties on the 14–15 February survey to a high of 26 observers in 15 parties on the 11–12 December survey. Observers drove all accessible roads and used binoculars and spotting scopes to

Table 2. Numbers of native waterbirds recorded on four comprehensive surveys of the Salton Sea, California, and adjacent wetlands in 1999 (see 'Methods'). Waterfowl and Eared Grebes were counted on aerial surveys at intervals that often did not coincide with comprehensive surveys (see Tables 4 and 5)

Species	22 January–5 February[a]	17–18 April	13–16 August	11–15 November
Pied-billed Grebe	25	15	47	56
Western Grebe	0[b]	379	363	714
Clark's Grebe	0[b]	340	371	222
Black Storm-Petrel	0	0	1	0
Am. White Pelican[c]	16 697	3738	554	19 197
Brown Pelican	16	0	1995	38
Double-crested Cormorant	18 504	11 160	3023	15 179
American Bittern	0	1	2	5
Least Bittern	2	0	7	7
Great Blue Heron	1566	925	1741	1380
Great Egret	275	229	1027	958
Snowy Egret	107	350	1103	759
Cattle Egret	42	238	1213	54
Green Heron	6	8	53	8
Black-crowned Night-Heron	116	69	608	114
White-faced Ibis	361	434	205	826
Wood Stork	0	0	6	0
Clapper Rail	8	12	16	7
Virginia Rail	5	0	6	3
Sora	10	8	2	17
Common Moorhen	12	18	62	62
Black-bellied Plover	1310	575	253	1381
Pacific Golden-Plover	0	1	0	0
Snowy Plover	275	285	351	170
Semipalmated Plover	73	131	139	122
Killdeer	277	215	259	228
Black-necked Stilt	3941	3465	15 857	5938
American Avocet	7318	7001	10 037	18 800
Greater Yellowlegs	81	14	113	82
Lesser Yellowlegs	62	12	28	69
Solitary Sandpiper	0	0	1	0
Willet	1162	682	582	1531
Spotted Sandpiper	7	7	19	11
Whimbrel	0	43	31	0
Long-billed Curlew	373	33	394	1380
Marbled Godwit	1297	928	1036	1205
Ruddy Turnstone	17	44	10	0
Red Knot	0	371	1	20
Sanderling	52	249	39	37
Western Sandpiper	1573	14 700	34 394	22 526
Least Sandpiper	2006	1226	942	3773
Baird's Sandpiper	0	0	1	0
Dunlin	799	141	1	964
Stilt Sandpiper	164	1	15	206
Ruff	1	0	3	0
dowitcher spp.	6356	6492	7153	11 589
Common Snipe	24	1	2	5

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Table 2. contd.

Wilson's Phalarope	1	23	3065	2
Red-necked Phalarope	0	32	32	20
Red Phalarope	0	3	0	0
Laughing Gull	0	0	7	1
Franklin's Gull	0	5	0	0
Bonaparte's Gull	297	403	27	626
Heermann's Gull	0	0	1	0
Mew Gull	2	0	0	0
Ring-billed Gull	28 523	5049	4800	22 833
California Gull	6987	3293	5730	11 313
Herring Gull	7026	291	1	6900
Thayer's Gull	0	0	0	2
Lesser Black-backed Gull	0	0	0	1
Yellow-footed Gull	1	1	789	15
Western Gull	4	0	3	3
Glaucous-winged Gull	6	1	0	0
Western × Glacous-winged Gull	1	0	0	0
Gull-billed Tern	0	69	11	0
Caspian Tern	22	269	2404	44
Common Tern	0	0	6	0
Forster's Tern	0	19	1402	172
Black Tern	0	2	4011	0
Black Skimmer	0	6	777	38
Total individuals	107 790	64 007	107 132	151 613
Total species[d]	49	55	63	54

[a] On this survey, Western and Clark's grebes were not counted in all areas and the Pied-billed Grebe, all rails, and all gulls and terns were not counted in areas 3–5.
[b] Although not counted, present and included in species total for this survey.
[c] An additional aerial survey in December tallied 24 974 pelicans.
[d] Species totals for April, August, and November include both Short- and Long-billed dowitchers.

carefully scan fields with appropriate plover habitat, i.e. those with barren ground or sparse low growth. On all surveys, observers recorded and mapped the location of all flocks and described the types of fields on which plovers occurred.

In conjunction with the August comprehensive ground survey, we also counted all Black Terns on a 16 August aerial survey, which followed the same protocol described above for pelicans and cormorants. In addition, we conducted aerial surveys for Black Terns over irrigated agricultural fields in the Imperial Valley by flying six parallel transects about 240 km long and spaced 5 km apart (Fig. 3).

Results

Species richness and abundance

In 1999, we recorded a total of 107 species of native waterbirds on our various surveys (Table 1). On the four comprehensive surveys of the Salton Sea and nearby wetlands, we recorded a total of 70 species of waterbirds: 49 in January, 55 in April, 63 in August, and 54 in November (Table 2). We recorded a total 107 790 individuals on the January comprehensive, 64 007 in April, 107 132 in August, and 151 613 in November. Additional counts or estimates of waterfowl and coots at the Salton Sea and of herons, egrets, ibis, and cranes coming to roosts after foraging in Imperial Valley fields swelled the seasonal totals to about 186 913 in January, 88 431 in April, 169 809 in August, and 261 499 in November (Table 3). These totals do not include Eared Grebes, surveyed in 1999 only in

March, November, and December (Table 4). Adding the Eared Grebe count for November provides an estimate of about 434 049 waterbirds at the Salton Sea that month. If numbers of other waterbirds remained relatively constant from November to December and the Eared Grebe count for the latter month were added, there probably were about 583 000 waterbirds at the Salton Sea in December.

Pelecaniformes (pelicans and cormorants), wading birds (herons, egrets, ibis, storks), shorebirds, and larids (gulls, terns, skimmers) were the groups that together accounted for ≥99% of the individuals on our comprehensive surveys. Three species of fish-eating pelecaniformes were among the most numerous birds at the Salton Sea in 1999. Of these, the American White Pelican and the Double-crested Cormorant reached highest numbers in winter with peak counts, respectively, of 24 974 individuals in December and 18 504 in January (Table 2). Of the 10 native species of long-legged wading birds recorded on comprehensive surveys, 8 were ardeids and the others were the White-faced Ibis and the Wood Stork (Table 2). Wader numbers totaled 2475 individuals in January, 2254 in April, 5965 in August, and 4111 in November (Table 2). Of the ardeids, the Great Blue Heron, Great Egret, Snowy Egret, and Cattle Egret each exceeded 1000 individuals on at least one comprehensive survey of the Salton Sea and adjacent wetlands (Table 2). Three species of waders were much more numerous in agricultural lands in the Imperial Valley than at the Salton Sea. Peak counts of birds coming to nighttime roosts after foraging in irrigated fields in the Imperial Valley were 40 000 Cattle Egrets in August, 37 438 White-faced Ibis in October, and 320 Sandhill Cranes in October. The latter species occurred only in agricultural areas of the Imperial Valley. Monthly counts at roost sites there in January and February and from October to December ranged from 255 to 320 cranes, except for an anomalous count of 37 birds in November, when we probably overlooked a roost site.

We detected 29 species of shorebirds on 4 comprehensive surveys of the Salton Sea area in 1999. Shorebird totals were 27 169 individuals in January, 36 675 in April, 74 758 in August, and 70 059 in November (Table 2). The ten taxa that exceeded 1000 individuals on at least one survey in 1999 were the Black-bellied Plover, Black-necked Stilt, American Avocet, Willet, Long-billed Curlew, Marbled Godwit, Western Sandpiper, Least Sandpiper, dowitchers, and Wilson's Phalarope. During three seasons three taxa accounted for at least 75% of the totals: American Avocet, Western Sandpiper, and dowitchers in April and November and Black-necked Stilt, American Avocet, and Western Sandpiper in August. In January it took five taxa to exceed 75% of the shorebird total.

Table 3. Total numbers of waterbirds on various surveys at the Salton Sea, California, in 1999. Numbers in parentheses estimated because of a lack of surveys during particular months. See 'Methods' for descriptions of survey protocols

Survey type	January	April	August	November
Comprehensive surveys[a]	107 790	64 007	107 132	151 613
Waterfowl and Coot surveys[b]	59 436	16 924	(5000)	67 341
Roost counts[c]	19 687	(7500)	57 677	42 545
Totals	186 913	88 431	169 809	261 499

[a] See Table 2 for details.
[b] See Table 5 for details.
[c] Largely reflects the abundance of the Cattle Egret and White-faced Ibis, which comprise the vast majority of birds at Imperial Valley roost sites in all seasons.

Table 4. Numbers of Eared Grebes, Western/Clark's *(Aechmophorus)* grebes, and Ruddy Ducks counted on three aerial survey transects of inshore and offshore zones of the Salton Sea, California, in 1999 (see 'Methods')

Species	19 March	28 March	29 November	17 December
Eared Grebe	47 561	58 412	172 550	321 575
Aechmophorus spp.	8620	7123	1508	3830
Ruddy Duck	5120	3924	26 584	32 680

Several species of shorebirds were much more numerous in agricultural fields in the Imperial Valley than in shoreline or other wetland habitats at or near the Salton Sea. In 1999, we counted about 2486 Mountain Plovers in the Imperial Valley in February, 2790 in November, and 3758 in December. The increase in numbers across surveys may reflect a parallel increase in observer coverage. Although we did not conduct comprehensive surveys for the Whimbrel and Long-billed Curlew, prior anecdotal information indicate that thousands of individuals of these species use agricultural fields seasonally (PRBO and R. McKernan, unpubl. data).

We recorded a total of 13 species of gulls on comprehensive surveys of the Salton Sea. Totals for all species were 42 847 individuals in January, 9043 in April, 11 358 in August, and 41 694 in November (Table 2). The Ring-billed, California, and Herring gulls accounted for >98% of all individuals in January and November, whereas just the Ring-billed and California gulls accounted for >92% in April and August. The Ring-billed Gull alone accounted for 55–65% of

Table 5. Numbers of waterfowl and other waterbirds counted on five aerial surveys of the Salton Sea, California, and surrounding wetlands in 1999 (see 'Methods'). Data for 1999 courtesy of SSNWR; data for mid-winter counts 1978–1987 from Heitmeyer et al. (1989)

Species	Survey dates 1999					Mid-winter average 1978–1987
	8 January	9 March	3 April	27 May	18 November	
Gr. White-fronted Goose	16	0	0	0	0	0
Snow/Ross's goose	22 550	1303	30	0	4400	16 835
Canada Goose	76	0	0	0	17	3296
Gadwall	109	45	31	12	244	465
American Wigeon	1873	1997	4	0	1422	5623
Mallard	76	43	44	23	1938	389
Blue-winged/Cinnamon teal	204	239	61	51	48	242
Northern Shoveler	11 732	10 790	5404	22	13 264	12 670
Northern Pintail	5465	502	5	3	7465	14 091
Green-winged Teal	3759	4488	441	77	4227	3092
Unidentified dabbling ducks	3212	1482	440	39	0	0
Canvasback	256	111	6	0	379	1691
Redhead	117	24	10	7	266	336
Ring-necked Duck	2	4	0	0	0	110
Scaup spp.	557	3189	752	10	242	1760
Scoter spp.	0	1	0	0	10	0
Bufflehead	50	41	0	0	22	49
Common Goldeneye	5	2	0	0	0	0
Ruddy Duck	4828	15 213	7904	1493	14 655	16 269
Unidentified diving ducks	175	65	27	5	0	0
Total waterfowl	55 062	39 539	15 159	1742	48 599	76 918
Other waterbirds						
Eared Grebe	13 798	34 810	38 767	0	3370	-
Am. White Pelican	12 203	13 512	2674	0	22 706	-
Brown Pelican	415	0	0	23	154	-
American Coot	4374	4841	1765	735	18 742	-

all gulls at the Salton Sea in November and January, respectively. However, many thousands of Ring-billed Gulls also winter in agricultural fields of the Imperial Valley, where the species is proportionately even more dominant than on the shoreline of the Sea. Ring-billed Gulls accounted for 99.4% of the 6616 gulls identified on monthly agricultural field transects in the northern Imperial Valley just south of the Salton Sea.

We recorded five species of terns and the Black Skimmer on comprehensive surveys of the Salton Sea (Table 2). These species totaled 22 individuals in January, 365 in April, 8611 in August, and 254 in November. Numbers of Gull-billed and Black Terns probably were slightly underestimated because some individuals forage over irrigated agricultural fields. For example, we recorded totals of 31 and 539 Black Terns on 5 agricultural field transects in the northern Imperial Valley on 16 May and 11 August, respectively. By contrast, we did not see any Black Terns on a 16 August aerial survey of agricultural fields further south in the Imperial Valley (Fig. 3), suggesting that Black Terns forage over fields primarily near the Salton Sea.

Various other surveys provided additional data on the occurrence and abundance of other groups of birds. Numbers of waterfowl on five aerial surveys of the Salton Sea area in 1999 ranged from a high of about 55 062 individuals of 17 taxa in January to a low

of 1742 individuals of 9 taxa in late May (Table 5). On the January survey, dabbling ducks comprised 48% of all waterfowl, geese 41%, and diving ducks 11%. Geese were almost exclusively Snow or Ross's geese; ground observations indicate the former species typically predominates at the Sea. In January, dabbling ducks were dominated by the Northern Shoveler (50%), Northern Pintail (24%), Green-winged Teal (16%), and American Wigeon (8%), whereas diving ducks were dominated by the Ruddy Duck (83%).

The proportion of waterfowl comprised by diving ducks, and the proportion of Ruddy Ducks within that group, appear to be underestimated by the standard refuge surveys for waterfowl. The latter focus on inshore waters of the Sea and adjacent freshwater impoundments and do not cover offshore waters where substantial numbers of Ruddy Ducks can be found. Additional aerial surveys for various diving waterbirds also included estimates of Ruddy Duck numbers, which ranged from 3924 to 5120 in March, to 26 584 in November, and 32 680 in December (Table 4).

Data were collected on several taxa of high conservation concern. Observers detected a total of 279 Yuma Clapper Rails in the Salton Sea area in 1999: 271 in marshes immediately around the Salton Sea and 3 at Lower Finney Lake and 5 at Holtville Main Drain in the northern Imperial Valley. We did not detect any Black Rails on our surveys in 1999, perhaps because of their irregular occurrence in the area. Snowy Plover numbers ranged seasonally from 170 to 351 individuals (Table 2), and the estimated breeding population in late May was 221 adults.

In 1999, the Salton Sea supported over 14 000 pairs of colonial breeders comprised of 11 species representing three families (Table 6). Together the Cattle Egret, Double-crested Cormorant, Great Blue Heron, and Black Skimmer accounted for 94% of all nesting pairs. Colonial nesters bred at 21 sites on or near the shoreline of the Sea and at Ramer Lake and near Westmorland in the Imperial Valley. The Great Blue Heron, Double-crested Cormorant, and Great Egret nested at 18, 8, and 6 sites, respectively, whereas all other species nested at 1–4 sites (Table 6).

Table 6. Total numbers of nesting pairs and sites occupied by colonial breeding waterbirds at the Salton Sea, California, in 1999. Totals based on peak numbers of nesting attempts adjusted for colony desertions (see 'Methods')

Species	Total nesting pairs	Number of sites occupied
Cormorants		
Double-crested Cormorant	5425	8
Ardeids		
Great Blue Heron	888	18
Great Egret	165	6
Snowy Egret	170	4
Black-crowned Night-Heron	102	3
Cattle Egret	6660	2
Larids		
Laughing Gull	1	1
California Gull	40	1
Gull-billed Tern	101	2
Caspian Tern	211	1
Black Skimmer	377	3
Total	14 140	

Discussion

Importance of the Salton Sea to Pacific Flyway waterbirds

Our snapshot of bird use in 1999 further documented the great importance of the Salton Sea to birds in the Pacific Flyway of western North America, though such a short-term study necessarily underestimates the number of birds using a site. The Salton Sea is an important part of the Río Colorado Delta region, including the northern Gulf of California, and contains some of the highest biological diversity in the southwestern United States. This is especially true for birds. To date, 402 native and 5 non-native bird species have been recorded in the Salton Sea area, including about 100 breeding species (Patten in Shuford et al., 1999). In addition, the sheer number of birds using the Salton Sea at various times of the year is particularly noteworthy. Our surveys in 1999 suggest that a minimum of half a million waterbirds inhabited the Salton Sea in winter. While this number is impressive, in prior years the Eared Grebe population at the Sea alone has reached an estimated 3.5 million birds (R. McKernan, pers. comm. in Jehl, 1988).

As well as holding large numbers of birds, the Salton Sea also hosts populations of various species that are of continental or regional importance. For example, 90% or more of the entire North American population of the Eared Grebe may pass through the Sea in some years (J. R. Jehl, Jr., in litt.). Our peak count of about 25 000 American White Pelicans at the

Salton Sea in 1999 was similar to the range of about 26 500 to 33 000 in recent years (Setmire et al., 1990; McCaskie, 1999). These numbers represent about 23–30% of the entire North American breeding population and actually exceed the estimate of about 18 600 for the western population, which breeds and winters west of the continental divide (Johnsgard, 1993). Counts of 16 000–19 000 White-faced Ibis in the Imperial Valley further documented that area as one of the most important wintering sites for these birds in western North America (Shuford et al., 1996). Average October to April counts of Ruddy Ducks at the Salton Sea from 1984 to 1999 by R. McKernan (unpubl. data) ranged from 91 905 to 202 123 individuals (mean of means [Oct–Apr] = 150 515, SE = 8293, n = 16 yrs). What percentage of the Pacific Flyway population of the Ruddy Duck these numbers represent is unknown, but it must be large. Surveys of the endangered Yuma Clapper Rail indicate that the Salton Sea holds about 40% of the taxa's entire population in the United States (Yuma Clapper Rail Recovery Team, unpubl. data.). The total of 55 000 waterfowl in January 1999 was below the average of about 77 000 on mid-winter counts from 1978 to 1987 (Heitmeyer et al., 1989), but it is unclear if the 1999 numbers fall within the range of variation of prior years. Although the 1978–1987 average represents only about 2% of the wintering population of California's Central Valley (Heitmeyer et al., 1989), the premier waterfowl wintering area in the Pacific Flyway, the Salton Sea is still the most important site for waterfowl in the interior of southern California.

Shorebird totals at the Salton Sea in some years have exceeded 100 000 individuals in both spring and fall (PRBO and R. McKernan, unpubl. data) indicating it qualifies for designation as a site of international importance to shorebirds under criteria of the Western Hemisphere Shorebird Reserve Network (Harrington & Perry, 1995). Regional comparisons indicate the Salton Sea is one of only eight sites in the interior of western North America that holds over 10 000 shorebirds in fall and one of five such sites in spring (PRBO, unpubl. data). In terms of overall shorebird numbers, the Salton Sea is the most important area in the Intermountain and Desert region of the West in spring and the second most important, after Great Salt Lake, in fall. Shorebird populations at the Salton Sea from 1989 to 1995 averaged 24 000 in December, 90 000 in April, and about 85 000 individuals in August. Shorebird surveys in 1999 provided additional documentation for these patterns and added a total of about 70 000 shorebirds in November, a month for which prior thorough surveys were lacking. The relatively low numbers in April 1999 compared with prior years may have represented a lack of coincidence of the 1999 survey dates with the peak passage of Western Sandpipers, which can move through very rapidly in large numbers (e.g. >65 000 in 1992, PRBO, unpubl. data). Surveys in 1999 confirmed that the Salton Sea supports the largest population of wintering Snowy Plovers in the interior of western North America (Shuford et al., 1995) and is one of a handful of key breeding areas in the interior of California (Page et al., 1991).

Although California's Central and Imperial valleys are widely considered the primary wintering areas for the Mountain Plover (Knopf & Rupert, 1995), our surveys suggest the latter valley may be of more crucial importance than previously thought. The mean number for our three surveys represents about 30–38% of the species' total estimated population of 8000 to 10 000 individuals (Anonymous, 1999). On prior surveys across the California wintering range, the 2072 and 755 Mountain Plovers recorded in the Imperial Valley in 1994 and 1998, respectively, represented 61% and 35% of the totals of 3390 and 2179 individuals found statewide (B. Barnes, in litt.; CDFG, unpubl. data; K. Hunting, in litt.). The higher totals in the Imperial Valley in 1999 almost surely reflect an increase in observer coverage there over prior years rather than a population increase. Counts of Mountain Plovers on the Salton Sea (south) Christmas Bird Count, covering only part of the northern Imperial Valley, have ranged from 1 to 1003 birds (median = 180 birds) from 1979 to 1998.

In 1999, we estimated a total gull population of over 40 000 individuals at the Salton Sea, not including many additional thousands using agricultural lands in the adjacent Imperial Valley. Although data are lacking for quantitative comparisons, these numbers suggest that the Salton Sea is one of, if not the, most important area in the interior of western North America for wintering gulls. A count of over 4000 Black Terns at the Salton Sea in August 1999 appears to be the only comprehensive count at that site, although Small (1994) reported "tens of thousands" there during the period of peak occurrence in July and August. Regardless, the Salton Sea in one of the most important sites in western North America for migrating Black Terns (Shuford, 1999).

The number of species and the abundance of colonial nesting waterbirds at the Salton Sea rivals or

exceeds that at many coastal and interior colonies in western North America (Parnell et al., 1988; Price et al., 1995). Population reviews of the Double-crested Cormorant (Carter et al., 1995), Gull-billed Tern (Parnell et al., 1995), Caspian Tern (Cuthbert & Wires, 1999), and Black Skimmer (Collins & Garrett, 1996) suggest that Salton Sea populations are among the largest anywhere in western North America in recent years. For the Gull-billed Tern, the Salton Sea is one of only a few sites at which the western subspecies (*S. n. vanrossemi*) breeds (Parnell et al., 1995). Although comparative nesting numbers are not readily available for other areas, the breeding population of the Cattle Egret at the Salton Sea (up to 30 000 pairs in 1992; SSNWR files) is surely among the largest in western North America. The wintering population of Cattle Egrets at the Salton Sea is considered the third densest in all of North America (Telfair, 1994).

Population dynamics

Since its inception in 1905, the composition of the Salton Sea's avifauna has been dynamic with populations of various species of breeding and non-breeding birds fluctuating dramatically. Although it is beyond the scope of this paper to review population trends or fluctuations at the Salton Sea, it is clear that this dynamic flux has continued through the last few decades. For example, nesting Double-crested Cormorants began their explosive growth in 1996 with the colonization of Mullet Island (SSNWR files). This population continued to increase to over 5000 pairs in 1999 and now forms one of the largest concentrations of breeding cormorants in the Pacific coast states north of Mexico (Carter et al., 1995). Similarly, Brown Pelicans increased greatly at the Sea in the 1990s, and since 1996 small numbers have bred there irregularly (Sturm, 1998). By contrast, the Caspian Tern population in 1999 represented only about 30% of the average numbers at the Salton Sea in recent years (K. Molina, unpubl. data). The relatively low numbers of Eared Grebes in winter 1999 and of shorebirds in April 1999 compared with prior years suggest that populations of some non-breeding birds at the Salton Sea fluctuate greatly over time. Future detailed examinations of population trends at the Salton Sea should investigate whether patterns at the Salton Sea reflect changing local conditions or simply parallel those for the Pacific Flyway as a whole.

Connectivity with the Gulf of California

Although birds that use the Salton Sea come from widely scattered areas in western North America, many that pass through the Sea appear to do so via the Salton Trough and the Gulf of California. For shorebirds, anecdotal evidence suggests there is a strong migrant connection with the west coast of Mexico, the Gulf of California, and the Pacific Coast of the United States, particularly in spring. Butler et al. (1996) reported a Western Sandpiper banded in Panama was found at the Salton Sea in spring. The Salton Sea is also strongly linked to the Gulf of California by northward post-breeding dispersal of species such as the Brown Pelican, Wood Stork, Laughing Gull, and Yellow-footed Gull (Patten et al. in press). Further study is likely to greatly expand our knowledge of the extent of bird movement between the Sea and the Gulf of California.

Conservation concerns

The Salton Sea hosts 19 species of waterbirds of high conservation concern (Table 7), but many other species that concentrate there potentially are at great risk from disease, contaminants, or human encroachment. Birds at the Sea particularly hard hit by disease and other factors during the 1990s include the Eared Grebe (150 000 dead in 1992, unknown causes); American White Pelican (9000 dead in 1996, botulism); Brown Pelican (1200 dead in 1996, botulism); and waterfowl, shorebirds, and waders (>11 000 dead in 1998, avian cholera) (see summary in Shuford et al., 1999). Although die-offs occur sporadically at many other Pacific Flyway wetlands, the magnitude of those at the Salton Sea and the species affected, particularly diving and fish-eating birds, make them of special concern. Setmire et al. (1990, 1993) and the Imperial Irrigation District (1994) have reviewed the results of bird contaminant studies at the Salton Sea, which indicate birds are at risk from selenium, boron, and DDE. Although birds appear to be at greatest risk from agricultural drain waters in the Imperial Valley, many species that use the Salton Sea move to and from irrigated agricultural lands of the Imperial Valley and the Sea.

Additionally, human activities potentially could impact birds at sites where they concentrate at the Sea. Nesting waterbirds, which occur at the Salton Sea in large numbers, are sensitive to colony intrusions (Carney & Sydeman, 1999 and references therein), which may expose unattended eggs and young to extreme

Table 7. Seasonal status and significance of waterbirds of high conservation concern at the Salton Sea, California. FT = federally threatened, FE = federally endangered, ST = state threatened, ST = state endangered, MNMC = U.S. Migratory Nongame Bird of Management Concern (USFWS 1995), BSSC = Calif. Dept. of Fish and Game Bird Species of Special Concern[a] (CDFG, 1992)

Species	Special status designation	Seasonal status and significance
Brown Pelican	FE	Large non-breeding population and recent small and irregular breeding population. About 1200 died of botulism in 1996.
American White Pelican	BSSC, MNMC	Wintering population represents up to 30% of the entire North American breeding population and may exceed the size of the western breeding population. About 9000 died of botulism in 1996.
Double-crested Cormorant	BSSC	Large wintering and breeding population. Mullet Island colony one of largest in western North America.
American Bittern	MNMC	Small wintering and, perhaps, breeding population.
Least Bittern[b]	BSSC, MNMC	Resident population of unknown size.
White-faced Ibis	BSSC, MNMC	Large wintering and small irregular breeding population. A primary wintering area in western North America.
Wood Stork	BSSC	Small and declining post-breeding population.
Fulvous Whistling-Duck	BSSC	Small and declining breeding and wintering population.
Black Rail	ST, MNMC	Small irregular breeding population.
Yuma Clapper Rail	FE	Relatively small breeding population represents about 40% of entire U.S. population.
Greater Sandhill Crane	ST	Modest wintering population in Imperial Valley.
Snowy Plover	BSSC, MNMC	Year-round resident. Largest wintering population in the interior of the U.S. and one of a handful of key breeding areas in the interior of California.
Mountain Plover	BSSC, MNMC	Winter resident. Imperial Valley population represents about 30–40% of the species' entire population.
Long-billed Curlew	BSSC, MNMC	Relatively large wintering population, particularly in the Imperial Valley.
Laughing Gull	BSSC	Breeder and post-breeding visitor. Breeding population has declined, now very small and irregular.
California Gull	BSSC	Primarily a winter resident and non-breeding summer resident; recently established small breeding population.
Gull-billed Tern	BSSC	Breeder and summer resident. Hosts one of few breeding populations of western subspecies.
Black Tern	BSSC, MNMC	Migrant and non-breeding summer resident. One of key migratory stopover sites in western North America.
Black Skimmer	BSSC	Breeder and summer resident. Population among the largest in western North America in recent years.

[a] List currently outdated and under revision.
[b] A population estimate of 550 individuals around the Salton Sea (Setmire et al., 1993) is unsubstantiated.

thermal conditions and result in overheating and death in a short period of time (Grant, 1982; Molina, 1999). Hence, the nesting success of these populations, particularly of ground nesters, may be closely linked to the degree of colony disturbances (Molina, 1996).

Rising salinity and lowered water levels could profoundly affect the future composition of the Salton Sea's avifauna. Current models predict that within 13–22 years, depending on inflow regimes, salinities will reach 50 000 mg/l and severely affect invertebrate and fish populations and, by extension, the Sea's fish-eating bird populations (Tetra Tech, 2000). Shortly thereafter prey resources for birds likely would be dominated by brine shrimp *(Artemia franciscana)* and brine flies *(Ephydra* spp.), favoring species, such as the Eared Grebe and Wilson's and Red-necked phalaropes, that are numerous on hypersaline lakes. Various future water management projects that likely will reduce inflows to the Sea not only would accelerate the increase in salinity but also would lower water levels. The latter might reduce shoreline wetlands used by many species and would form landbridges to nearshore snags and islands, making them unsuitable as nesting sites for colonial waterbirds.

The current Salton Sea Restoration Project (Tetra Tech, 2000) addresses most of the aforementioned issues, but the solutions proposed to date focus primarily on various engineering alternatives for reducing salinity and maintaining the level of the Sea. Although reducing salinity may stave off the collapse of the Sea's fish populations and, by extension, those of fish-eating birds, it is unclear what affect, if any, a decrease in salinity will have in reducing bird mortality from diseases or other agents that may be triggered by perhaps unrelated factors. Nevertheless, any proposed projects to reduce salinity should be carefully evaluated and implemented only if they can provide substantial habitat improvements without negatively impacting the suitability of current habitats. Any proposed benefits should be weighed against the potential for concentrating contaminants and predators where large numbers of birds forage or nest and for killing large numbers of nocturnal migrants via collisions with project structures.

Research needs

Despite the studies to date, there are still large gaps in the knowledge needed to effectively solve the problems facing birds at the Salton Sea. Little quantitative information is available on the within-Sea distribution and habitat needs of most species of waterbirds, data that will be crucial to ensure that any large scale projects designed to solve problems, such as increasing salinity, will not harm important species or habitats. Time series studies are needed to see how birds use the Sea at different water elevations both on a seasonal and long-term basis. Research is needed on the effects of investigator and recreational disturbances on nesting colonies, isolated roosting sites, and areas that regularly concentrate large numbers of birds

Ongoing work should be continued to identify the causes of large scale die-offs, mechanisms of disease transmission, and factors that trigger these events before solutions can be implemented to reduce their effects. Likewise, additional studies are needed to understand the sources, mechanisms of uptake, and effect of contaminants on survival and reproduction of birds. Crucial to both disease and contaminant work will be more collaborative research on the diet of key species of birds, an area of study that has been particularly poorly represented in the past. A focus on seasonal changes in bird diets would make an important contribution to understanding the dynamics of the Salton Sea ecosystem. Long-term studies are needed of the reproductive success and demographics of colonial nesting waterbirds, which may be linked to disease, contaminant, and dietary research.

Research is needed on the daily and seasonal use patterns and movements of birds between agricultural fields in the Imperial and Coachella valleys and the Sea and movements among various portions of the Sea. Collection of data on turnover rates of migratory species would provide better estimates of the number of birds using the Sea. On a larger scale, research is needed on the dispersal patterns and migratory movements of birds between the Salton Sea and various Pacific Flyway wetlands, particularly the Río Colorado Delta and the Gulf of California. Finally, ongoing research and monitoring are needed to understand seasonal and long-term population dynamics and to assess the effectiveness of any large scale projects implemented to resolve the Sea's ecological problems.

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