DISTRIBUTION AND ABUNDANCE OF DOUBLE-CRESTED CORMORANTS NESTING IN THE INTERIOR OF CALIFORNIA, 2009–2012*

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ABSTRACT: As part of an 11-state inventory, we censused the Double-crested Cormorant (*Phalacrocorax auritus*) in the interior of California from 2009 to 2012, using a combination of aerial, ground, and boat surveys. An estimated 8791 pairs breeding in the interior of the state in 2009–2012 exceeded the 7170 pairs estimated in 1998–1999. In both periods, cormorants were breeding in 9 of 11 ecoregions, but three-fourths were at one site—Mullet Island at the Salton Sea in the Sonoran Desert ecoregion (abandoned in 2014). The ecoregions with the next highest proportions were the Sacramento Valley, San Joaquin Valley, and Modoc Plateau. The apparent increase in numbers and colony sites since 1999—consistent with the pattern through much of western North America—reflects the (short-lived) increase in numbers at the Salton Sea, an increasing number of colonies and breeding pairs in the Central Valley, and slightly better coverage on the recent surveys. Because of practical survey constraints and limited data to date, evidence of change in numbers of Double-crested Cormorants breeding in the interior of California between 1998–1999 and 2009–2012 is inconclusive. Plans for monitoring will need to take into account the effects of substantial annual variation in numbers, which may be associated with large fluctuations in cormorants' prey base, short-term cycles of drought and flood, shifts of nesting cormorants into or out of the interior of California, and the expectation of greater environmental fluctuations with continuing climate change. The factors most likely to limit the number of cormorants breeding in the interior of the

*This paper is dedicated to the memory of the late Harry R. Carter, whose outstanding work on coastal seabirds and, particularly, his generous support, mentorship, and humanity inspired Shuford's studies of colonial waterbirds in the interior of California.

 Western Birds 51:270–292, 2020; doi 10.21199/WB51.4.1

state are habitat loss or alteration (particularly from reallocation of water for human needs), disease, human disturbance, and the long-term effects of climate change.

In North America, the Double-crested Cormorant (*Phalacrocorax auritus*) is currently widespread and often perceived as overabundant when viewed through the lens of fisheries and aquaculture conflicts. Yet a review of historical and current records indicates that the species was likely more abundant during initial European settlement than it is today, suggesting the perception of current overabundance rests on socio-political rather than biological or ecological factors. Continent-wide, cormorant numbers had sharply declined by the late 1800s and early 1900s, partially recovered between the 1920s and 1940s, declined sharply again from the late 1940s to 1970s, and rebounded again from the late 1970s through the end of the 20th century (Wires and Cuthbert 2006).

Along the Pacific coast of western North America, from southern British Columbia to northwestern Mexico and in the adjacent interior states, the Double-crested Cormorant was far more abundant in the 19th century than it is today, but by the late 1800s and early 1900s it had declined substantially (Wires and Cuthbert 2006). Populations in western North America (at least exclusive of Alaska and northwestern Mexico) subsequently increased from the mid-1900s to circa 2009, though at a rate lower than the exponential expansion documented east of the continental divide (Carter et al. 1995, Adkins et al. 2014). From 2014 to 2018 numbers in the region were relatively stable (USFWS 2019). Despite these broad patterns, trends in the West have varied by country, subregion, and state or province, and in the interior status and trends are less certain, owing to inadequate surveys.

Initiatives to promote the conservation of waterbirds throughout North America recognize the importance of inventorying and monitoring for determining conservation status, detecting population trends, assessing habitat health, and evaluating whether management and environmental change are affecting waterbirds (Kushlan et al. 2002). But to date a paucity of adequate data on the sizes and trends of waterbird populations has hampered efforts to conserve these birds in California (Shuford 2014b, Shuford and Dybala 2017) and the interior West (Seto 2008). Although there are extensive data on colonies of species such as the Double-crested Cormorant along the entire California coast from periodic broad-scale inventories (Sowls et al. 1980, Carter et al. 1992, Capitolo et al. 2004) and, since 1993, annual monitoring with aerial photographs (see Capitolo et al. 2019), there is much less information on this cormorant's populations in the interior of California and other western states.

To help fulfill these needs, from 2009 to 2012 the U.S. Fish and Wildlife Service coordinated the Western Colonial Waterbird Survey, a broad-scale inventory of 19 species of colonial waterbirds in 11 western states (www.fws.gov/mountain-prairie/migbirds/species/birds/western_colonial/index.html). Its goals were to document the species composition, size, and location of colonies; estimate minimum regional population sizes for each breeding species; produce an atlas of colonies; and establish a baseline for the development of a long-term monitoring program.

To ensure adequate coverage of the vast expanse of the West, regional experts organized and implemented the surveys at the state level. In California, Point Blue Conservation Science and its collaborators coordinated surveys of 15 primary species of colonial waterbirds (Shuford 2014a). Results of those surveys from 2009 to 2012, and comparisons to prior surveys, have been published for three species of terns, two of gulls (Shuford et al. 2016, Doster and Shuford 2018), and five of ardeids surveyed statewide (Shuford et al. 2020). Here we report on the distribution, number of colonies, and number of pairs of Double-crested Cormorants nesting in the interior of California from 2009 to 2012, and compare our results to those of surveys in 1998 and 1999 (Shuford 2010). We also compare the trends of the populations in the interior with those along the coast, interpret results on the basis of environmental conditions and prey dynamics, discuss current and future threats to cormorants breeding in the interior of California, and consider how recent and future surveys can aid in development of a strategy for monitoring colonial waterbirds throughout the western United States.

STUDY AREA AND METHODS

In organizing statewide surveys, we based the timing and extent of field work on a combination of extensive information gathered on the locations of historical and recent colonies, broad personal knowledge of wetlands and other potential foraging and nesting habitats since the 1980s, and discussions with a large network of collaborators developed over the years and expanded during the 2009–2012 surveys. These efforts were greatly enhanced by biologists who shared survey data from local or regional monitoring projects.

Because it was not feasible to survey all 15 target species statewide in the same year under the same environmental conditions, we surveyed the Double-crested Cormorant along with other species of colonial waterbirds by region. Consequently, surveys for the cormorant took three years and included only the interior of California (Shuford 2014a). To avoid or minimize overlap with efforts focused on coastal seabirds, our "interior" survey area for the cormorant included all of the state except for colonies on offshore islands or rocks, coastal bluffs, within estuaries, or otherwise within 10 km of the ocean or estuarine shoreline. We excluded all of the San Francisco Bay estuary west of the Carquinez Strait at Interstate 80.

We surveyed for breeding colonies of the Double-crested Cormorant in northeastern California in 2009; in the Sacramento Valley, Sacramento–San Joaquin River delta, and the northern and central coastal slope in 2011; and the San Joaquin Valley, coastal slope of southern California, the Salton Sea and Imperial Valley, and the Owens, Mojave, and lower Colorado River valleys in 2012. In 2012, we also surveyed the very limited potential habitat for nesting cormorants in the Klamath River country of northwestern California in Shasta, (mainly) western Siskiyou, and northern Humboldt counties. Descriptions of these study regions and the survey methods used in each are detailed in Shuford et al. (2020); the methods and areas surveyed were very similar to those used in a comparable statewide survey for cormorants in the interior from 1997 to 1999 (Shuford 2010).

Observers generally followed the protocols of the Western Colonial Waterbird Survey (Jones 2008), whether from the ground, aircraft (visually or with photographs), or boat. Methods varied by species, colony site, and region, depending on the species' nesting habits and local conditions, such as variation in nest substrates, proximity of other nesting species, and accessibility of colony sites (Shuford 2014a, Shuford et al. 2020). Aerial surveys were particularly valuable for photographing some large or remote cormorant colonies and for visually covering large areas, such as the Central Valley, that would have been impossible to survey adequately by other methods alone.

At each colony, observers tried to count or estimate the number of active nests or nesting pairs by species. Active nests were defined as those that, at the time of the survey, were attended by an adult(s), held eggs or young, or showed signs of occupancy (e.g., extensive guano) earlier in the current breeding season. As much as possible, surveys were timed around peak nesting, which varied by species. So, in some cases, follow-up surveys on one or more dates were needed to accommodate colonies with both early- and late-nesting species. Complicating matters further, within colonies of some species, including the Double-crested Cormorant, breeding may be asynchronous. The timing of breeding may vary from year to year and from site to site within a year. This sometimes required multiple surveys at a site to ensure a count close to or at the peak of nesting. Hence, at some multi-species colonies, we counted cormorants more frequently than if we had been surveying just for them alone.

To estimate the number of breeding pairs of the Double-crested Cormorant in the interior of California, we summed the regional estimates. This introduced an unknown degree of sampling variation, amplifying uncertainty in the total estimate because we could not gauge how much regional populations varied or shifted over the four years of the study in response to variation in precipitation, prey populations, or other factors.

Comparison with Previous Surveys

To consider possible change over time, we compared the results for 2009–2012 to comparable data from 1997 to 1999, also recorded regionally Shuford (2010). For the Double-crested Cormorant, however, almost all interior colonies were covered in 1999. For comparisons, we used the 1999 data, augmented by data for a few sites covered in 1998 but not in 1999 (derived from Table 2 in Shuford 2010).

Despite the considerable limits of the data, as described above and in Table 1, we conducted an analysis of variance (ANOVA) to determine if any of the differences between 1998–1999 and 2009–2012 were significant ($P < 0.05$). We designed the ANOVA as a three-way test for differences in abundance between survey periods, among ecoregions, and their interactions, against the random variation among colonies nested within ecoregions.

Climatic Conditions

Patterns of annual precipitation varied before and through the study but included several years of drought preceding survey years in most regions of the state (Shuford et al. 2020, which see for details of rainfall history by ecoregion). Of particular relevance to the cormorant, our surveys of northeastern and east-central California in 2009 followed 3 years of drought that left some terminal lakes, reservoirs, and wetlands dry or with atypically low

Table 1 Estimated Numbers of Pairs of Double-crested Cormorants at Colonies in the Interior[a] of California by Ecoregion[b] and County, 1998–1999 and 2009–2012

Site	Elevation (ft)	Latitude	Longitude	Estimated pairs 1998–1999[c]	Estimated pairs 2009–2012
NORTHWESTERN CALIFORNIA					
Lake County					
Clear Lake					
Mouth of Holiday Cove	1333	39.0286	−122.8800	25	0
Long Tule Point	1332	39.0242	−122.8586	57	0
East of Quercus Point	1332	39.0231	−122.8283	175[d]	0
Slater Island, Anderson Marsh	1334	38.9311	−122.6319	15	0
Upper Rodman Slough	1326	39.1366	−122.9021	0	53
Indian Valley Reservoir	1478	39.1530	−122.5360	0	3
Sonoma County (part)					
Delta Pond	55	38.4467	−122.8344	0	27
Laguna de Santa Rosa, Alpha Farms	75	38.3886	−122.8011	59	0
Napa County					
Lake Hennessey, Chiles Creek	355	38.4911	−122.3494	0	10
Ecoregion total				***331***	***93***
CENTRAL WESTERN CALIFORNIA					
Sonoma County (part)					
Petaluma wastewater plant	14	38.2222	−122.5804	6	4
San Benito County					
San Felipe Lake	138	36.9817	−121.4603	11[e]	0
San Luis Obispo County					
Twitchell Reservoir	750	35.0084	−120.3338	—[f]	30
Ecoregion total				***17***	***34***
SOUTHWESTERN CALIFORNIA					
Los Angeles County[g]					
San Gabriel River, Pico Rivera	154	33.9842	−118.0787	~6	0
Sepulveda Basin WA	690	34.1755	−118.4725	0	12
Legg Lake	217	34.0347	−118.0620	0	30
Orange County					
Orange Co. Water District, Anaheim Lake	239	33.8622	−117.8457	105	168
Riverside County (part)					
Prado Basin near dam	488	33.8942	−117.6434	30+	55
Mystic Lake	1428	33.8808	−117.0792	64	0
San Diego County					
Sweetwater Reservoir	237	32.7076	−116.9761	28	0
Ecoregion total				***233***	***265***
SACRAMENTO VALLEY					
Glenn County					
Howard Slough, at Butte Creek	62	39.3994	−121.8896	0	5
Butte County					
Sacramento River, Mile 188 (W of Murphy's Slough)	123	39.6662	−121.9823	—	1
Sacramento River, Mile 180.5-1 (Llano Seco)	99	39.5813	−121.9932	15	33
Gray Lodge WA, Colony 1	57	39.3153	−121.8619	0	19
Colusa County					
Butte Sink, nr. confluence Butte Creek and Angel Slough	54	39.3419	−121.8952	0	100

(*Continued*)

Site	Elevation (ft)	Latitude	Longitude	Estimated pairs 1998–1999[c]	Estimated pairs 2009–2012
Colusa NWR, T14.4	42	39.1530	−122.0319	0	3
Sutter County					
North Butte Country Club, Butte Sink	52	39.2728	−121.8964	65	0
Sutter Bypass W, N of Nelson Slough	27	38.9016	−121.6369	0	1
Sutter Bypass W, E of Knight's Landing	18	38.8249	−121.6613	0	15
Sutter Bypass, ~8 km NE of Knights Landing	30	38.8394	−121.6578	12	0
Yolo County					
Sacramento River, Mile 102.5 (Beaver Lake)	32	38.8876	−121.8124	16	44
Knights Landing Ridge Cut	27	38.7615	−121.6974	—	2
Port of Sacramento	8	38.5644	−121.5554	0	1
Solano County					
Bohannon	6	38.1827	−121.9565	0	158
Wheeler	4	38.0786	−121.9659	110	80
Spoonbill	3	38.0547	−121.8934	0	25
Hass Slough	−2	38.3020	−121.7289	—	4
Prospect Slough	−2	38.2855	−121.6641	—	6
Sacramento County					
American River, Mississippi Bar	135	38.6480	−121.1948	—	37
Stone Lakes NWR					
North Stone Lake	7	38.3865	−121.4877	154	26
Sun River	7	38.3374	−121.4981	0	30
SRCSD Bufferlands, Morrison Creek #1	6	38.4472	−121.4815	0	53
Cosumnes River Preserve, Horseshoe Lake	35	38.3430	−121.3243	3	17
Pellandini Ranch, W of Twin Cities	18	38.2843	−121.3672	29	0
Ecoregion total				***404***	***660***
SAN JOAQUIN VALLEY					
Contra Costa County					
Eucalyptus Island	11	37.8589	−121.5755	0	27
Alameda County					
Arroyo del Valle, Shadow Cliffs Regional Park	357	37.6652	−121.8324	1[h]	23
San Joaquin County					
Potato Slough	17	38.0833	−121.5571	0	20
Venice Tip (#1 and #2)	20	38.0450	−121.5306	9	210
Stanislaus County					
San Joaquin River NWR, Christman Island	33	37.6323	−121.1995	12	0
Merced County					
San Joaquin River, Mile 121 (SE of Hills Ferry)	58	37.3348	−120.9509	0	20
San Luis NWR					
Colony 8 (FT-1A)	67	37.2984	−120.8876	0	1
Colony 1, San Joaquin River	71	37.2696	−120.8301	0	10
Colony 5 (WB-3)	78	37.2516	−120.8149	22	5
Eastside Canal 1	91	37.2746	−120.7458	0	7
San Joaquin River, Turner Island	92	37.1549	−120.7426	0	60
Madera County					
San Joaquin River, Sycamore Island	263	36.8520	−119.8270	0	6
Fresno County					
San Joaquin River, Mile 242.5	224	36.8356	−119.9387	—	1

(*Continued*)

Site	Elevation (ft)	Latitude	Longitude	Estimated pairs 1998–1999[c]	Estimated pairs 2009–2012
San Joaquin River, Milburn Unit, SJR Ecological Reserve	240	36.8522	–119.8735	9	52
Leaky Acres	333	36.7912	–119.7352	—	5
Kings County					
South Wilbur Flood Area, Tulare Lake Drainage District	195	35.8748	–119.6570	119	90
East Hacienda Ranch Flood Basin, Tulare Lake Drainage District	206	35.8253	–119.6086	6	0
Tulare County					
Alpaugh Irrigation Reservoir	208	35.8958	–119.4115	0	6
Kern County					
Kern County Water Agency	409	35.3974	–119.0371	—	10
Costerisan Farms Lake	329	35.2334	–118.9826	—	10
Ecoregion total				***178***	***563***
CASCADE RANGE					
Siskiyou County (part)					
Lake Shastina (north)	2809	41.5156	–122.3922	8[i]	41
Lassen County					
Eagle Lake					
Pelican Point	5122	40.6333	–120.7459	118	0
Island between Buck Pt. and Little Troxel Pt.	5111	40.6594	–120.7147	0	2
Plumas County (part)					
Lake Almanor, Almanor Peninsula	4529	40.2641	–121.1571	—	15
Ecoregion total				***126***	***58***
SIERRA NEVADA					
Plumas County (part)					
Butt Valley Reservoir	4145	40.1458	–121.1836	24	11
Yuba County					
Yuba River, above Daguerra Point Dam	132	39.2167	–121.4363	0	1
Ecoregion total				***24***	***12***
MODOC PLATEAU					
Siskiyou County (part)					
Butte Valley WA (Meiss Lake)	4241	41.8559	–122.0620	84	0
Lower Klamath NWR (Sheepy Lake)	4083	41.9697	–121.7875	62	79
Modoc County					
Tule Lake NWR (lower) Sump 1-B	4040	41.8396	–121.4477	172	0
Clear Lake NWR	4484	41.8722	–121.0922	114	126
Ecoregion total				***432***	***205***
SONORAN DESERT					
Riverside County (part)					
Salton Sea					
76th Ave.	–233	33.5018	–116.0745	0	1
Johnson Street	–233	33.5183	–116.0594	(2)	0
Imperial County					
Salton Sea					
East side Poe Road	–233	33.1006	–115.7342	(13)	0
New River mouth	–233	33.1336	–115.6947	(30)	0
Alamo River delta	–230	33.2083	–115.6169	(106)	0
Mallard Road duck club	–214	33.3179	–115.6155	0	1

(*Continued*)

Site	Elevation (ft)	Latitude	Longitude	Estimated pairs 1998–1999[c]	Estimated pairs 2009–2012
Mullet Island	–200	33.2252	–115.6086	**5425[j]**	6594
Ramer Lake, Imperial WA	–174	33.0777	–115.5129	(18)	305
Ecoregion total				***5425***	***6901***
Grand total				**7170[k]**	**8791**

[a]The "interior" survey area excludes coastal colonies on offshore islands or rocks, coastal bluffs, within estuaries, or otherwise within 10 km of the ocean or estuarine shoreline; in the San Francisco Bay estuary, only colonies inland of the Carquinez Strait at Interstate 80 are included. Data for 1999, or referred to for that year, from Shuford (2010) unless otherwise noted. —, no survey made.

[b]Ecoregions used here are a subset of those defined in the Jepson manual (Hickman 1993): Northwestern California, Central Western California, Southwestern California, Sacramento Valley, San Joaquin Valley, Cascade Ranges, Sierra Nevada, Modoc Plateau, and Sonoran Desert (Figure 2 in Shuford et al. 2020).

[c]Pairs estimated from direct count of nests (1 nest = 1 pair) unless otherwise noted. All counts in 1999, except for four in 1998, as noted.

[d]Not checked in 1999, but 175 pairs in 1998.

[e]Not checked in 1999, but 11 pairs in 1998.

[f]Unclear if active in 1999. As of 2014, it had been active irregularly (depending on water levels) for about 15 years (W. Fritz pers. comm.). First available count is of 23 active nests in two sycamores on 18 June 2011 (inactive in 2014; T. Edell pers. comm.).

[g]Between the two survey periods, a colony at the Rio Hondo Spreading Grounds had 10 occupied nests on 10 June 2002 (ebird.org/checklist/S52704335).

[h]Not checked in 1999, but 1 pair in 1998.

[i]Not checked in 1999, but 8 pairs in 1998.

[j]In 1999, circumstances warranted treating the entire Salton Sea area (both north and south ends) as a single site. The estimate of nesting pairs for the entire Salton Sea is from the peak single-day (19 February) count of nests on Mullet Island, given that the relatively small number of nests established elsewhere at the Salton Sea after late February may have represented the relocation of adults that failed earlier at Mullet (see methods in Shuford 2010).

[k]The discrepancy between the 6865 pairs reported in Shuford (2010) for the 1999 survey and the 7170 reported here for 1998–1999 reflects (a) a slight enlargement of the interior survey area in 2009–2012, to include Suisun Marsh, and a comparable retrospective enlargement of the 1999 survey area, leading to the addition of a count of 110 pairs at one site in Suisun Marsh in 1999 that was not included in the prior total, and (b) the inclusion of data on four colonies counted in 1998 but not 1999.

water levels. In the San Joaquin Valley, our surveys in 2012 followed a very dry winter, and since 2006–07 drought had been broken only in 2010–11. Overall, water levels were below average in 2012, but some flood-storage basins periodically important to nesting cormorants (e.g., South Wilbur Flood Area) had extensive water remaining from the wet winter of 2010–11. In other ecoregions, the effects, if any, of drought on the cormorant's nesting or foraging habitats were not obvious but may have been subtle (see discussion for herons and egrets in Shuford et al. 2020).

DATA SUMMARY AND PRESENTATION

Ecoregions

We summarize the distribution of colonies of cormorants by 11 ecoregions defined in the Jepson manual (Hickman 1993) and described in Shuford et al. (2020): Northwestern California, Central Western California, Southwestern California, Sacramento Valley, San Joaquin Valley, Cascade Ranges, Sierra Nevada, Modoc Plateau, East of Sierra Nevada, Mojave Desert, and Sonoran Desert (Figure 2 in Shuford et al. 2020). In the Jepson system, the Sacramento–San Joaquin River delta is not a distinct subregion but parts are included in both the Sacramento Valley and San Joaquin Valley subregions.

Mapping

The maps showing the distribution and relative size of cormorant colonies in 1998–1999 and 2009–2012 were created in ArcMap version 10.5.1 (ESRI, Inc.); values for categories of relative abundance were based on natural breaks in the data pooled over both periods. The Mullet Island colony at the Salton Sea, by far the largest colony recorded, represents the highest abundance category for each survey period.

RESULTS

Abundance and Distribution

We estimate that 8791 pairs of Double-crested Cormorants nested in the interior of California from 2009 to 2012 (Table 1). Though this number exceeds the 7170 pairs estimated during the comparable survey in 1998 and 1999, according to the ANOVA these numbers do not differ significantly ($F_{8,\,62}$ = 0.003, P = 0.96). Within an ecoregion, cormorant numbers were generally consistent, on average, between survey periods ($F_{8,\,62}$ = 0.012, P = 0.99). Not surprisingly, the totals differed significantly by ecoregion because of substantially more cormorants nesting in the Sonoran Desert than in other ecoregions ($F_{8,\,8}$ = 57.0, P < 0.001). Among other ecoregions, abundance did not differ significantly ($F_{7,\,7}$ = 57.0, P = 0.10; Table 1). The average size of a cormorant colony, however, did not differ significantly by ecoregion, between the survey periods ($F_{8,\,62}$ = 0.99, P = 0.45), or within either the 1998–1999 ($F_{8,\,53}$ = 0.81, P = 0.60) or 2009–2012 ($F_{8,\,62}$ = 1.02, P = 0.43) rounds of surveys. Removing the Mullet Island colony from the analysis did not significantly alter these results. Although our analyses found no clear underlying differences between survey periods, we strongly caution against concluding there was no change because the substantial practical limits and constraints of the available data suggest that they may lack the precision needed to confirm a trend.

From 2009 to 2012, cormorants were breeding in 9 of the 11 ecoregions (Table 2, Figure 1), but 75% of the pairs were concentrated at one site—Mullet Island, Imperial County, at the south end of the Salton Sea in the Sonoran Desert ecoregion (79% of statewide total; Tables 1 and 2). Notably, the total of 6901 pairs for the Sonoran Desert ecoregion (including Mullet Island and other sites at the Salton Sea and adjacent Imperial Valley) was just 289 pairs fewer than the estimated total for the entire interior of California in 1998 and 1999. The ecoregions with the next highest proportions were the Sacramento Valley and San Joaquin Valley with about 8% and 6% of the total, respectively (Table 2). In 1998 and 1999, cormorants also bred in the same 9 ecoregions, and the Salton Sea/Sonoran Desert ecoregion similarly accounted for 76% of the statewide interior total; the Sacramento Valley and Modoc Plateau ecoregions each held 6% (Tables 1 and 2, Figure 2).

Table 2 Percentage of Nesting Pairs (and Number of Colonies) of Double-crested Cormorants by Ecoregion from Statewide Surveys of the Interior of California, 1998–1999 and 2009–2012

Ecoregion[a]	1998–1999	2009–2012
Northwestern California	5 (5)	1 (4)
Central Western California	<1 (2)	<1 (2)
Southwestern California	3 (5)	3 (4)
Sacramento Valley	6 (8)	8 (21)
San Joaquin Valley	2 (7)	6 (18)
Cascade Ranges	2 (2)	<1 (3)
Sierra Nevada	<1 (1)	<1 (2)
Modoc Plateau	6 (4)	2 (2)
East of Sierra Nevada	0	0
Mojave Desert	0	0
Sonoran Desert	76 (1)[b]	79 (4)

[a]As defined in the Jepson Manual: Higher Plants of California (Hickman 1993; Figure 2 in Shuford et al. 2020).

[b]Number of colonies in this ecoregion does not include five colonies at the Salton Sea that may have represented the relocation of adults that failed earlier at the large colony at Mullet Island (Table 1; Methods in Shuford 2010).

From 2009 to 2012, cormorants nested in at least 60 colonies. In 1998 and 1999, when coverage was less extensive, colonies numbered 35 (Table 1). The total for 1998–1999, however, does not include five colonies at the Salton Sea that may have represented birds that relocated after an early-season abandonment of the large Mullet Island colony. The Sacramento Valley and San Joaquin Valley ecoregions accounted for 35% and 30%, respectively, of the total number of colony sites from 2009 to 2012; colony sites were more evenly distributed among ecoregions in 1998 and 1999 (Tables 1 and 2, Figures 1 and 2).

DISCUSSION

Population Trends in California

Grinnell and Miller (1944) described the Double-crested Cormorant as resident and "locally common" in California, with a "marked reduction in numbers of individuals and breeding colonies noted in recent years." With continued declines through the 1970s from habitat loss, human disturbance, and contaminants this cormorant was designated a species of special concern in California (Remsen 1978). But after population increases in subsequent decades this designation was dropped (Shuford and Gardali 2008).

Carter et al. (1995) concluded that historic declines and extirpations at coastal colonies in northern and central California probably paralleled declines that began in the mid- to late 1880s at the South Farallon Islands, where numbers remained low until the 1970s. Numbers of breeding Double-crested Cormorants began to expand elsewhere in northern California in the 1960s and at the Farallons in the 1970s. The species colonized San Francisco

Bay in the late 1970s, subsequently breeding mainly on artificial structures such as bridges, and has since increased to nearly 3500 pairs in peak years (Rauzon et al. 2019).

Colonies in southern California declined from the early 1900s through the 1970s, then increased (Carter et al. 1995). Total numbers of nests on the California coast increased from <1000 per year (1975–1980) to about 4400 (1989–1991) to about 6600 (2001–2003), then decreased to about 5000 in 2008 (Hunt et al. 1979, Sowls et al. 1980, Carter et al. 1992, 1995, Capitolo et al. 2004, Adkins et al. 2014, as summarized in Capitolo et al. 2019). The lower total in 2008 likely reflected a temporary reduction in prey (not associated with El Niño), particularly a decrease in the number and size of the Northern Anchovy (*Engraulis mordax*) in central California (Capitolo et al. 2019).

In the interior, the Double-crested Cormorant has bred widely. Although there are few data on historic colony sizes, some sites held hundreds and perhaps thousands of nesting pairs (Remsen 1978, Shuford 2010:44–53 and Appendix 6). Massive loss of wetlands and alteration of the state's natural hydrology earlier in the 20th century for agricultural and urban needs (see Shuford et al. 2001, Garone 2011) caused marked reductions in cormorant numbers and colonies (Grinnell and Miller 1944, Carter et al. 1995, Shuford 2010: Appendix 6). The loss of large lakes (e.g., Tulare and Buena Vista lakes) and the diminution of the size or quality of others (e.g., Tule and Eagle lakes) have had the greatest long-term effect on interior populations. It is unknown to what degree these losses were offset (or exceeded?) by the subsequent creation of reservoirs or human-altered sites such as the Salton Sea, where numbers have spiked, then abruptly declined, in recent years as outlined below. In the interior of southern California away from the Salton Trough, cormorants formerly may not have bred until the creation of reservoirs (with introduced or invasive non-native fish) supplied foraging habitat and the planting of large non-native trees supplied nest substrate.

The only interior cormorant colonies with a fairly continuous record of numbers since the early 1950s are Tule Lake, Lower Klamath, and Clear Lake national wildlife refuges (NWR) (Shuford 2010, Table 3). Although numbers at these sites show no clear trends, they appear not to be representative of the increase for California as a whole. Carter et al. (1995) estimated that at least 2806 individuals bred at inland colonies in the early 1990s but acknowledged that the interior had not been surveyed adequately. As the two comprehensive surveys of breeding cormorants in the interior yielded 7170 and 8791 pairs, the total for the interior may be about a third greater than the total for the California coast, in favorable years. But when conditions at the Salton Sea are poor (i.e., Mullet Island is unavailable, prey is scarce) the interior total may be one half or less of the coastal total.

Although the Double-crested Cormorant's history of breeding in the interior of California is fragmentary, it appears that total numbers at inland colonies have increased since the 1970s, as they have on the coast (Carter et al. 1995). Limitations of the surveys, dynamic conditions, and large and rapid population changes at some key sites make assessing trends difficult, however. For example, a drop in numbers at the Sheepy Lake colony at Lower Klamath NWR from 978 pairs in 1997 to 62 pairs in 1999 apparently resulted from water levels being kept too high in 1999, with the result that many of the tulemat islands on which the cormorants nested were inundated and saturated (D. Mauser pers. comm.). Cormorant numbers can vary widely at the local and regional level between periods of flood and drought. For example, in 2009, when we surveyed the three ecoregions of northeastern California during an extended drought, numbers there were lower than in 1999, following a very wet period. Specifically, though an estimated 118, 84, and 172 pairs of cormorants nested at Eagle Lake, Butte Valley Wildlife Area (Meiss Lake), and Tule Lake NWR, respectively, in 1999, none used those sites in 2009, when falling water levels eliminated all potential nesting habitat.

The cormorant population at the Salton Sea has been particularly dynamic (Molina and Sturm 2004, Hurlbert et al. 2007, Shuford 2010). After estimates of up to 500 nesting pairs in the early 20th century, through the late 1980s numbers rarely exceeded 100 pairs (Shuford 2010). Cormorants did not nest at the Salton Sea from 1989 to 1994 (Molina and Sturm 2004), and only 56 pairs nested in 1995 (Hurlbert et al. 2007, Shuford 2010). After colonization of Mullet Island in 1996, cormorants reached a peak of about 5425 pairs in 1999 (Table 2 in Shuford et al. 2002), but none were observed nesting there from 2001 to 2003 (Molina and Sturm 2004, D. Anderson in litt.). Following recolonization in 2004 (Molina pers. obs.), the number nesting on Mullet reached an estimated 6594 pairs in 2012 (this study). Despite a steady decline in water levels that left only shallow water between the island and the mainland, aerial photos taken on 12 March 2013 showed many hundreds of active nests on Mullet Island [K. Riesz and S. Przeklasa née Haynes, Calif. Dept. Fish and Wildlife (CDFW)]. With a continuing decline in water levels that enabled land predators and vehicles to reach the island easily, the colony was abandoned in 2014 and has remained inactive through 2020 (T. Anderson, Salton Sea NWR, and S. Przeklasa née Haynes in litt.).

Most prior fluctuations in cormorant populations at the Salton Sea appear to reflect changes in local prey populations. Hurlbert et al. (2007) assessed variation in the numbers of waterbirds at the Salton Sea on the basis of data from local surveys of colonial waterbirds (1987–1999), the two local Christmas Bird Counts (CBCs) (mainly 1968–2004), and the Breeding Bird Survey (BBS) for the western United States (1968–2002). Fluctuations in fish-eating waterbirds, including the Double-crested Cormorant, closely tracked fish populations over their two cycles of boom and bust from the 1970s to the early 2000s. Molina and Sturm (2004) concluded that because potentially suitable habitat for waterbird colonies had remained constant from the mid-1980s to late 1990s, rapid increases in some species, including the cormorant, in the mid- to late 1990s were best explained by changes in the availability of food rather than of nest sites. These large changes over a few years suggest that patterns supported only by sporadic anecdotal data should be interpreted very cautiously.

The apparent increase in the numbers of breeding pairs and colonies of the Double-crested Cormorant in the interior of California since 1998–1999 reflects primarily the (short-lived) increase in numbers at the Salton Sea, an increasing number of colonies and breeding pairs in the Central Valley, and, to a lesser degree, better coverage on the recent surveys. Despite a lack of a statistically significant population trend from 1998–1999 to 2009–2012, given the limitations of the data, the pattern of greater numbers in the interior of

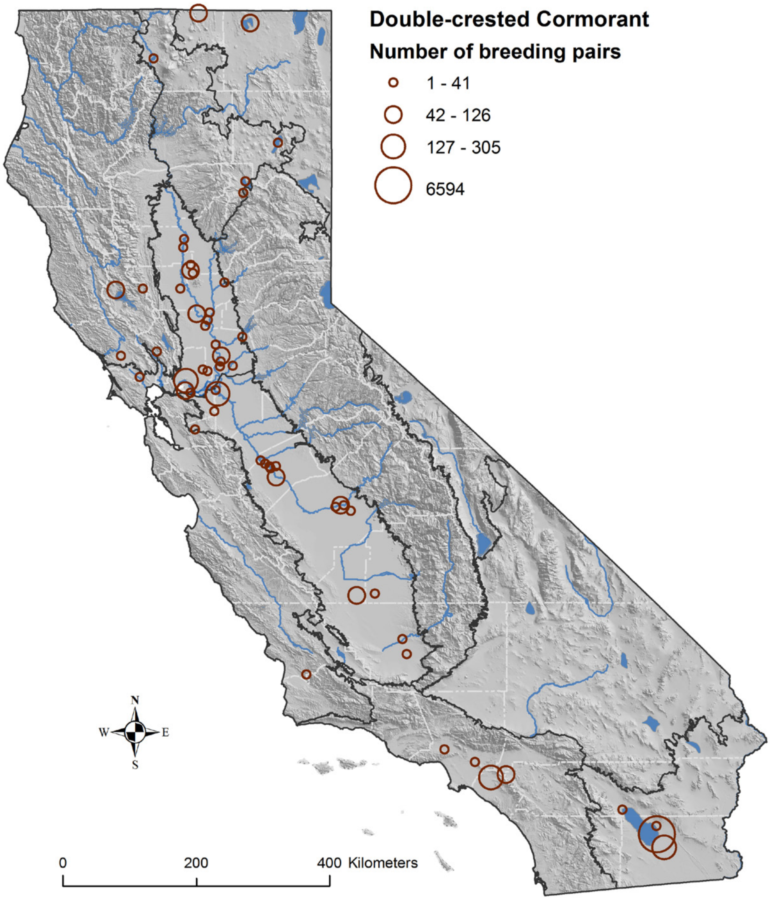

Figure 1. Distribution and relative size of Double-crested Cormorant colonies in the interior of California from statewide surveys, 2009–2012 (see Table 1).

California is consistent with an increase in the overall breeding population along the Pacific coast and over much of western North America through the early 2000s (Carter et al. 1995, Adkins et al. 2014), followed since by a leveling off in both regions (Capitolo 2019, Rauzon et al. 2019, USFWS 2019). The colony at Mullet Island at the Salton Sea was the second largest colony in western North America from at least the late 1990s to 2012, exceeded in size by only East Sand Island at the mouth of the Columbia River, Oregon. In fact, the count of 6594 pairs at Mullet Island in 2012, two years before its abandonment, was equivalent to about 21% of the approximately 31,200 pairs Adkins et al. (2014) estimated for western North America (exclusive of Alaska and northwestern Mexico) circa 2009.

Other sources provide data on cormorant numbers away from colonies

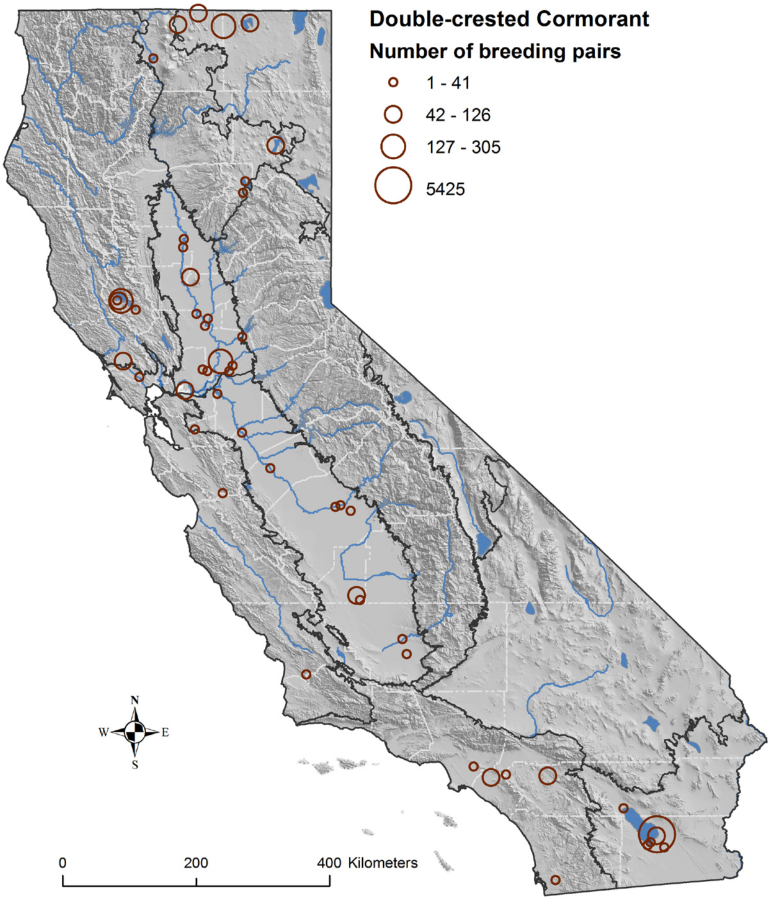

FIGURE 2. Distribution and relative size of Double-crested Cormorant colonies in the interior of California from statewide surveys, 1998–1999 (see Table 1). Includes five colonies at the Salton Sea and Imperial Valley (not included in calculation of total breeding pairs) that may have represented birds that relocated after an early-season abandonment of the large Mullet Island colony.

but have their limitations. Although the Double-crested Cormorant occurs in California year round, it is not clear if numbers in winter are augmented substantially by influxes of birds from elsewhere or how well-suited the CBC is to tracking trends in these waterbirds. The BBS records data on many species of birds, including this cormorant, but the methods generally are inadequate for colonial waterbirds and tend to undersample marshes (Bystrak 1981, Robbins et al. 1986).

For the periods 1968–2012 and 2002–2012 (i.e., through the last year of our surveys), BBS data for the Double-crested Cormorant showed a significant increase for California but no significant trend for the Western BBS Region as a whole (Sauer et al. 2014). For the period 1978–2014, Pandolfino and Handel (2018) found a significant increase in numbers of the Double-crested Cormorant on CBCs in California's Central Valley. Even with the limitations of all these studies, it is still clear that the Double-crested Cormorant has increased greatly as a breeder in the interior of California in the last 40 to 50 years. This trend, however, may now be reversed with the abandonment of the former premier colony at Mullet Island at the Salton Sea.

Population Shifts

Presumably the large number of cormorants that last nested at Mullet Island in 2013 have shifted elsewhere to breed. Nevertheless, this loss has been only partly offset by an increase in the numbers of cormorants nesting at Finney and Ramer lakes in the Imperial Valley and a short-lived colony on islands in pond 513A of the Wister Unit of Imperial Wildlife Area adjacent to the Salton Sea, which had a peak of 75 nests when established in 2014 (Molina unpubl. data). In 2015, an estimated 60, 467, and 725 pairs nested at these three sites, respectively. Subsequently, numbers have decreased, with totals for these sites ranging from 9 to 118 nests from 2017 to 2019 (S. Przeklasa née Haynes in litt.). Previously, large numbers nested at Ramer Lake, e.g., 925 nests estimated on 17 May 2011 (D. Anderson in litt.). Regardless, the total of 1252 nests for the three other active colonies in 2015, when the Mullet colony was inactive, represents only 18% of the combined numbers of nesting pairs at Mullet Island (6594) and Ramer Lake (305) in 2012.

Despite the sharp drop in the number of cormorants breeding at the Salton Sea after the abandonment of Mullet Island in 2014, there is no evidence of a sharp spike in numbers breeding in 2014 or subsequently on islands along the Pacific coast of the Baja California peninsula (Bedolla-Guzmán et al. 2019), in the Gulf of California (including at the largest known colony there at Isla Alcatraz; D. Anderson, E. Clark, J. Martínez Reyes in litt.), or on California's coast or islands (P. Capitolo in litt.). It is possible, however, that large numbers of Double-crested Cormorants may have shifted from the Salton Sea to colonies in mangroves on the west coast of mainland Mexico (south to about 28° N), where there are (or have been) seemingly large numbers nesting but no adequate data from multi-year surveys. Given the difficulty of identification at a distance in the mangroves, it is also possible that many of these birds are Neotropical Cormorants (*Phalacrocorax brasilianus*) (D. W. Anderson and E. W. Clark in litt.), which are expanding their range northward (Telfair and Morrison 2020). It is also possible that the large numbers of cormorants that abandoned the Salton Sea after 2013 may have spread so widely among colonies over so large a region that no influx to any one colony has been large enough to attract biologists' attention.

Band recoveries, satellite tagging, and genetic studies provide evidence that some cormorants wintering (October–March) at the Salton Sea come from distant colonies to the north, but local breeders may have strong connectivity with northwestern Mexico. Banded or tagged juveniles and adults dispersing or migrating from breeding sites in the Columbia River estuary move both north and south, but just a few have reached the Salton Sea and mouth of the Colorado River in the upper Gulf of California (Clark et al.

2006, Courtot et al. 2012). The genetic diversity of cormorants from coastal southern California and the Salton Sea/Imperial Valley is high, suggesting that lineages of multiple origins may converge in these areas. Haplotypes found in southern California that are unique within the U.S. and Canada may be derived from cormorants from northwestern Mexico, and thus represent northward movement and introgression between previously isolated lineages (Mercer et al. 2013).

Climatic Variation

Over the last 20 years, climatic conditions in California have been highly variable, ranging from very wet to extremely dry. Statewide surveys of the Double-crested Cormorant and other colonial waterbirds in the interior of California from 1997 to 1999 took place during a period of precipitation well above average (Shuford 2010), whereas comparable surveys from 2009 to 2012 overlapped with the extended drought that began in winter 2006–07. Despite being interrupted by one wet year (129% of long-term mean in 2010–11), this dry period persisted four years beyond the completion of our surveys in 2012 (Shuford et al. 2020). The dry period from 2011–12 to 2015–16, alone, is considered the most severe statewide drought in the historical record (Swain 2015, Wang et al. 2017). Furthermore, the 2000–2018 drought in southwestern North America, including California—driven by natural variability superimposed on drying from anthropogenic warming—was the second driest 19-year period since 800 CE (Williams et al. 2020).

The lack of long-term monitoring of the populations of colonial waterbirds in the interior of California limits the conclusions we can draw on the drought's effects. But the regional data for the species inventoried both 1997–1999 (wet period) and 2009–2012 (dry period) provide some valuable insights (Shuford 2014a, Shuford et al. 2016, Doster and Shuford 2018). In the drought years, breeding populations of two gull species and three tern species were greatly reduced throughout the inland portion of their California breeding ranges (i.e., the Central Valley and/or northeastern California). In recent decades, drought has affected the Double-crested Cormorant mainly in northeastern California (e.g., in 2009). Conversely, cormorants may nest in trees in some areas in the closed Tulare Basin of the southern San Joaquin Valley only in very wet years, when excess flows are stored in large flood basins such as the South Wilbur Flood Area. In most other inland areas of California cormorants nest in trees and forage in large rivers, lakes, reservoirs, or other bodies of deep water that are available continuously, which insulates them more from the cycles of drought and flood. Regardless, effects on most species, whether monitored or not, undoubtedly intensified after 2012, as the drought continued four more years. Furthermore, future effects may be even greater or more widespread, given projections of 21st-century increases in the frequency of wet extremes and smaller increases in dry extremes (Swain et al. 2018).

Accuracy and Challenges of Nest Counts

Shuford et al. (2020) discussed the difficulty of determining how closely counts or estimates of nests or breeding pairs of ardeids represent the actual number present and outlined factors influencing the accuracy of counts. Although surveys of Double-crested Cormorants, both 1998–1999 and 2009–2012, followed the same methods used for ardeids in the latter period, the counts for the cormorant in the interior of California are likely more accurate than those for ardeids because a large proportion of cormorants were nesting on the ground on open islands and were counted from aerial photographs. By contrast, most ardeids were nesting in trees or marshes where direct aerial and ground counts were hindered by screening vegetation. The smaller number of cormorants nesting in trees were generally more visible than ardeids, as most were in snags or sparsely foliaged trees, presumably chosen because of the cormorants' limited maneuverability when landing.

Many of the recommendations for censusing breeding ardeids in California (Shuford et al. 2020) also apply to the Double-crested Cormorant. Ideally all surveys should be conducted in a single year as colonies' locations and size can change as water levels and the availability of nest sites or foraging areas fluctuates, or as these or other factors affect the abundance of prey. Evidence continues to accumulate for other species, at least, indicating that what may appear to be a population increase or decrease in one area may simply reflect a shift in concentration of birds within the broader range (Bart et al. 2007, Wilson et al. 2013, Paprocki et al. 2014, Fleskes et al. 2018).

Regardless, summing counts taken over more than one year, as we have done, is often the only feasible way to obtain an overall population estimate of multiple species spread among many colonies over a broad area (e.g., see Carter et al. 1992 for California seabirds). Timing the counts to the peak of nesting is always desirable, but this peak can vary substantially by region. For example, counts of Double-crested Cormorants in May work well in many parts of California, but at the Salton Sea cormorants may begin laying eggs in December or January and the number of nests may peak in mid-February (Shuford 2010, 2014a).

Future Monitoring

Additional regional and statewide surveys will be necessary for the long-term status of the Double-crested Cormorant in California to be assessed confidently. Seto (2008) proposed a baseline inventory as a step toward a long-term monitoring program for colonial waterbirds throughout the western United States, a program following standardized protocols and methods (e.g., Steinkamp et al. 2003, Jones 2008). For future inventories, census methods should be selected to provide the most accurate results for the particular species, nest substrate, and time of the season. To facilitate comparisons, repeating the protocols and methods used from 2009 to 2012 would be desirable. But modifications might be needed or desirable, as conditions change or knowledge and technology advance. For example, the use of drones (e.g., Ogden 2013) may ultimately improve surveys' accuracy, facilitate logistics, or reduce costs. Shuford et al. (2020) summarized other factors that apply to monitoring waterbirds, including the Double-crested Cormorant, such as the geographic scale and objectives, and coordination with collaborators working at various scales so status and trends can be accurately assessed for the range of scales important to partners. The lack of evidence on where the ~6600 pairs of cormorants that had abandoned Mullet Island by 2014 may have nested in subsequent years emphasizes the need for future surveys to be coordinated over much broader areas of coastal and interior western North America, including northwestern Mexico, and the need for further studies of the cormorant's movements and the connectivity of its populations.

In California, decisions on the frequency of monitoring should take into account the state's great annual variation in precipitation and wide fluctuations in the size of some colonies, the substrates available for nests, foraging areas, and prey abundance. The intervals between surveys should be short, as precipitation may become more variable with climate change (Swain et al. 2018). While the desired levels of precision and ability to detect trends should strongly influence sampling effort, particularly as annual variation in a colony or subregion can be high (Shuford 2010, Capitolo et al. 2019, Rauzon et al. 2019, this study), resource limitations may limit the surveys' frequency. With such limitations it may be necessary to focus on a statistically robust sampling framework that takes into account spatial variation in waterbirds' densities, temporal variability in colony attendance by the stage of the nesting cycle, and differences in the probability of detecting birds that vary by species, habitats, and over time (Steinkamp et al. 2003). The Pacific Flyway Council (2013) considered such factors when it prioritized monitoring of the western population of the Double-crested Cormorant in response to the species' predation on fish of conservation, economic, or social value. Surveys were initially planned for every three years from 2014 to at least 2023. But, by partnering with the U.S. Army Corps of Engineers, from 2014 to 2018 the USFWS (2019) estimated the population annually from surveys of a sample of both coastal and interior colonies in this region. They suggested using caution, however, in comparison of these estimates to prior ones from comprehensive surveys spread over multiple years. Also, because their sampling focuses on monitoring the western population as a whole it may not produce robust results at other scales, given small sample sizes at the subregional level. Hence, we also recommend comprehensive surveys of all known and potential sites in the interior of California, and elsewhere, once per decade.

Threats and Limiting Factors

In western North America, Double-crested Cormorants have faced varied threats, including unauthorized and regulated shooting, nest destruction, introduction of mammalian predators on islands, organochlorine pollutants, oil spills, gill-net fishing, climatic changes, and habitat loss in the interior from agriculture and water development (Carter et al. 1995). Adkins et al. (2014) concluded that the main factors limiting the western Double-crested Cormorant population currently are predation by the increasing numbers of Bald Eagles (*Haliaeetus leucocephalus*), human disturbance at colonies, and climatic variation. Along the coast the availability of prey for cormorants may be affected by changes in ocean conditions (e.g., the timing of the onset of upwelling) or climatic cycles (e.g., El Niño–Southern Oscillation). Inland, cormorants face less stable and predictable food resources and nesting sites during periods of severe drought or flooding.

Other important continuing or new threats, at least in the interior of California, include habitat loss and degradation (particularly from over- or reallocation of water), disease, and the long-term effects of climate change

(Shuford 2010, 2014b). The recent unprecedented California drought emphasizes the importance of reliable water supplies for all waterbirds nesting inland. Beyond desiccation of foraging habitats when water is scarce, water diversions for human uses may facilitate predators' access to nesting islands and emergent trees and snags as water levels drop or sites dry up entirely. Competition for water will only increase as the human population expands unless water-conservation efforts are redoubled.

Areas of California where overallocation of water has been a particular problem in recent years include the Klamath Basin, Central Valley, and Salton Sea (summaries in Shuford 2010). The greatest threat realized, as noted above, was the loss of the huge colony of Double-crested Cormorants on Mullet Island at the Salton Sea in 2014 when the steady decline in water levels (from reallocation of water to coastal cities) gave terrestrial predators access to the colony, forcing its abandonment. Similarly, some snags in which cormorants formerly nested near the shore of the Salton Sea were out of the water in 2012 and no longer suitable for nesting. As of 2020, many snags have fallen, and the remaining ones are subject to disturbance as water levels have receded further (Shuford et al. 2020). Also, the Salton Sea's increasing salinity as its water level drops will ultimately greatly reduce the fish prey crucial to nesting waterbirds. Furthermore, Newcastle disease caused the death of thousands of cormorants (mostly chicks and juveniles) and abandonment of the Mullet Island colony in 1997, 1998, and 2007 (Friend 2002, Hurlbert et al. 2007, T. Anderson/Salton Sea NWR in litt.). Although the California population of the Double-crested Cormorant has increased since the 1970s, with an expanding human population and changing climate such threats may increase.

By contrast, observations from elsewhere in North America suggest nesting cormorants may displace some species of ardeids locally, by competition for nest sites and, particularly, habitat degradation (e.g., defoliating and killing trees). But there appears to be no evidence of such effects at the regional or population level (Wires et al. 2001). If any such effects are occurring in California they likely are very limited, given that the populations of the five relevant species of herons and egrets appear to be either stable or increasing (Shuford et al. 2020).

ACKNOWLEDGMENTS

We are deeply indebted to the many individuals and organizations who helped this project in multiple capacities, without whom it would not have been feasible. The many contributors are listed in detail in Shuford (2014a) and Shuford et al. (2020). The scope of the survey effort was greatly expanded by in-kind contributions from collaborating agencies and nonprofit organizations, including Audubon California, Audubon Canyon Ranch, CDFW, Los Angeles Department of Water and Power, Natural History Museum of Los Angeles County, other projects and divisions of Point Blue Conservation Science, San Francisco Bay Bird Observatory, The Nature Conservancy, and U.S. Fish and Wildlife Service. Crucial administrative, logistical, and funding support was provided or facilitated by Bob Altman, Lance Benner, Esther Burkett, Paul Buttner, Neil Clipperton, Lyann Comrack, Rob Doster, Catherine Hickey, Rob Holbrook, Bob Shaffer, Dale Steele, Marie Strassburger, and Bruce Wilcox. We especially thank Lyann Comrack and Rob Doster for their unwavering support and encouragement of this project, which ensured its success. The manuscript was substantially improved by comments from Daniel W. Anderson, Phillip J.

Capitolo, Emily W. Clark, Mark J. Rauzon, Christopher W. Swarth, and Philip Unitt. Funding for this work was provided by the CDFW (Wildlife Branch—Nongame Wildlife Program), California Rice Commission, Imperial Irrigation District, Pasadena Audubon Society, S. D. Bechtel, Jr. Foundation, U.S. Fish and Wildlife Service's Migratory Bird Program (Region 8) and State Wildlife Grant F10AF00647 to CDFW, and individual contributions to Point Blue Conservation Science. ArcGIS software was generously provided through ESRI's program for nonprofit organizations. This is Point Blue contribution 2297.

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Accepted 1 June 2020