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NUMBERS OF TERNS BREEDING INLAND IN CALIFORNIA: TRENDS OR TRIBULATIONS?

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ABSTRACT: Broad-scale surveys or monitoring of the distribution and abundance of waterbirds in the interior of the American West have been limited despite great losses of waterbirds' historic foraging and nesting habitats. Yet such work is crucial for assessing conservation status, population trends, habitat health, and the effects of management and environmental change on waterbirds. As part of the Western Colonial Waterbird Survey—an inventory of 19 species across 11 western states—we focused on three species of terns with conservation concern and assessed their distribution and numbers throughout their inland breeding ranges in California from 2009 to 2012. We compare these numbers to data from comparable surveys from 1997 to 1999. Climatic conditions strongly influenced the distribution and abundance of all three species, especially precipitation, which was below the long-term mean in relevant regions of the state for 3–4 years preceding the second round of surveys, greatly reducing foraging and nesting habitat. For the Black Tern (*Chlidonias niger*) and Forster's Tern (*Sterna forsteri*), respectively, statewide inland totals in 2009–2012 were about 49% and 26% of those in 1997–1999. Similarly, the numbers of breeding sites for those species were greatly reduced, particularly in northeastern California and the San Joaquin Valley. Patterns were less clear and varied regionally for the Caspian Tern (*Hydroprogne caspia*), as totals were greatly affected in all years by generally high, but variable, numbers at the Salton Sea. In northeastern California, however, drought reduced numbers of breeding Caspian Terns at least 10-fold from 1999 to 2009, and that region's contribution to the statewide inland total dropped from 68% in 1999 to 1% in 2009. It is unclear if these patterns for the three tern species will prove to be part of a longer-term declining trend or just a tribulation the terns faced from short-term fluctuations in precipitation. The latter may be likely given California's pattern of drought recurring about every 15 years through the 20th century. However, the relatively benign climatic patterns during this century may not persist in the future, and any drought effects come on top of the loss of >90% of California's historic wetlands and a severe over-allocation of the state's water resources. Designs for long-term monitoring of inland tern populations should consider the state's highly variable annual precipitation and the possibility of some species shifting among coastal and inland breeding sites. Management in the face of such variability and the uncertainty of future climate may be difficult, but securing adequate water in both dry and wet periods will be important as competition for supplies increases.

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/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 development of a long-term monitoring program for colonial waterbirds in the West. Because of a prior census of gull and tern colonies in coastal Washington, Oregon, and California in 2006 and 2007, the more recent 11-state effort did not survey these species in coastal areas (Seto 2008). An atlas has been produced for the eight interior states (Cavitt et al. 2014), and another is in development for inland areas of the three coastal states (R. Doster pers. comm.).

Among the 19 species covered in the 2009 to 2012 inventory, as well as by a comprehensive survey of 7 species of colonial waterbirds in the interior of California from 1997 to 1999, were the Black Tern (*Chlidonias niger*), Forster's Tern (*Sterna forsteri*), and Caspian Tern (*Hydroprogne caspia*) (Shuford et al. 2001, Shuford 2010). The extent of habitat suitable for these species may vary greatly between cycles of precipitation, so this time series of data enabled an evaluation of terns' response to a fluctuating climate.

In California, the Black Tern breeds exclusively inland, mainly in low-stature wetlands in the northeastern portion of the state and in cultivated rice fields of the Sacramento Valley, but also locally and irregularly in the San Joaquin Valley (Shuford et al. 2001). By contrast, the Forster's Tern and Caspian Tern breed in the state both on the coast and inland. In estuarine environments both species breed mainly on islands or salt-pond levees in San Francisco Bay and along the southern coast. Inland, Forster's Terns breed primarily on islands or in marshes of wetlands, reservoirs, and large lakes. The state's primary inland nesting area for the Forster's Tern is northeastern California, but a few breed in the San Joaquin Valley and in southern California on the coastal slope and at the Salton Sea (Shuford 2010, 2014a). Most Caspian Tern colonies in the interior of the state occur in northeastern California, with a few in the southern San Joaquin Valley, in southern California on the coastal slope, and at the Salton Sea (Shuford and Craig 2002, Suryan et al. 2004, Shuford 2010, 2014a). Most Caspian Tern colonies in northeastern California are associated with colonies of the Ring-billed (*Larus delawarensis*) and California (*L. californicus*) gulls on islands in large lakes or reservoirs; elsewhere inland they breed on islands by themselves or with other ground-nesting colonial waterbirds.

The level of conservation concern for the three tern species varies. The North American Waterbird Conservation Plan ranks both the Black Tern and Forster's Tern as of moderate conservation concern at the continental level (Kushlan et al. 2002). In the Bird Conservation Regions (BCR) that encompass areas key to these species' breeding in California—BCR 9 (Great Basin) and BCR 32 (coastal California, including the Central Valley)—the Forster's Tern is considered of moderate concern in both, whereas the Black Tern is of high and moderate concern in these regions, respectively (Ivey and Herziger 2006, Shuford 2014b). The Black Tern is also designated a species of special concern in California (Shuford 2008). By contrast, with a history of recent population increase, the Caspian Tern is considered of low conservation concern at the continental level and in the BCRs mentioned above (prior references). Still, it has been of intense management concern in the Pacific coast states because of efforts to redistribute birds away from the colony at the Columbia River estuary, Oregon, the world's largest Caspian Tern colony (Cuthbert and Wires 1999), where they prey on juveniles of threatened and endangered salmonids (USFWS 2005, Collis et al. 2012).

Given these conservation concerns, information on numbers of these terns is needed to ensure that appropriate conservation actions can be taken in a timely manner. Similarly, the perceived vulnerability of these species to a changing climate (e.g., Gardali et al. 2012) illustrates the need to develop a better understanding of how climatic conditions influence their distribution and abundance.

Here we compare the abundance and distribution patterns of these three species during the two periods of comprehensive surveys, 1997–1999 (Shuford et al. 2001, Shuford 2010) and 2009–2012 (Shuford 2014a, this study). We also describe drought effects on numbers and habitat of nesting terns, future scenarios under climate change, and how our results may influence the development of future plans for monitoring these or other species of colonial waterbirds in California and the West.

STUDY AREA AND METHODS

We censused the breeding populations of the three tern species as part of a broader survey of 15 species of colonial waterbirds in the interior of California from 2009 to 2012 (Shuford 2014a). Lacking the resources to cover this vast area in one year, we took a regional approach that enabled us to survey the entirety, or key portions, of each species' range in a single year, e.g., the Caspian Tern in 2009 and Black and Forster's terns in 2010 (see exceptions below). In 2012, we surveyed inland areas of southern California that in recent years have held a few colonies of these terns. In all years, we varied field survey methods by region, to match local logistical constraints, and timed surveys to follow the passage of most migrants and begin with the initiation of nesting.

For many species of waterbirds it is difficult to determine how close counts or estimates of nests or breeding pairs are to the actual number present at a site or in an entire region. A count's accuracy can be influenced by multiple factors (see Shuford 2014a), but we did not have the resources to quantify how these might have influenced our accuracy. Hence, we selected the census methods and protocols we judged would provide the most accurate estimates depending on the species involved and possible constraints, including colonies' accessibility, a need to minimize disturbance, and the difficulty of covering such a large state with varied habitats.

Northeastern California

Our study area included valleys of the Cascade Range, Klamath Mountains, and Sierra Nevada, the Modoc Plateau, and the Great Basin desert of all or portions of Siskiyou, Shasta, Modoc, Lassen, Plumas, Sierra, Nevada, Placer, and El Dorado counties. Tern habitat includes marshes, lakes, and reservoirs from 1220 to 1830 m (4000–6000 feet) elevation in intermountain valleys or in depressions on the Modoc Plateau.

Our surveys in northeastern California in 2009 and 2010 followed a 3-year period of drought with precipitation well below the long-term mean (Figure 1). Consequently some terminal lakes, reservoirs, or shallow wetlands in the region were dry or greatly reduced in extent (Shuford and Haines pers. obs.). By contrast, in the 3 years prior to comparable broad-scale tern surveys in northeastern California in 1997, precipitation was well above the

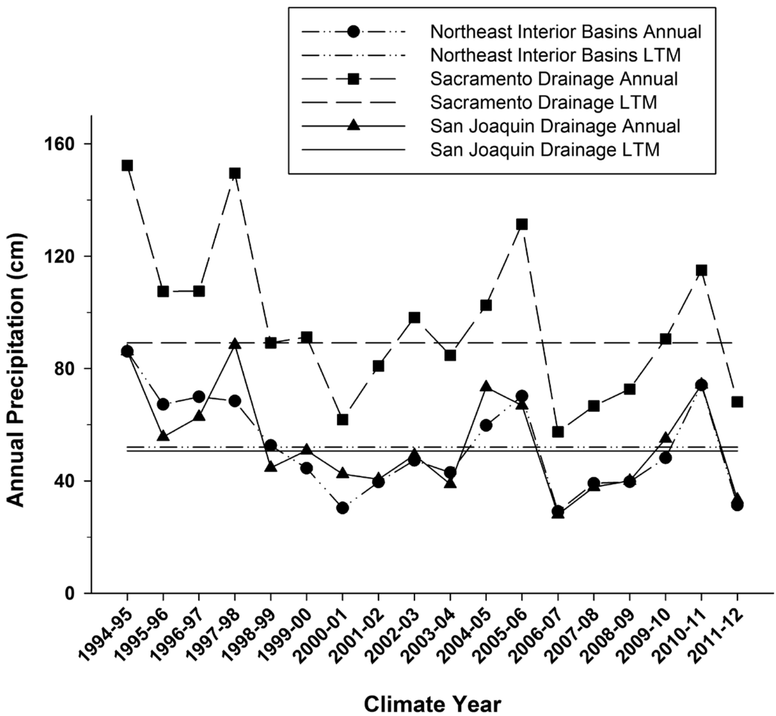

Figure 1. Annual (1 July–30 June) precipitation for the climate years 1994–95 to 2011–12, compared to the respective long-term means (LTM; n = 117 years; www.wrcc.dri.edu/divisional.html), for the Northeast Interior Basins, Sacramento Drainage, and San Joaquin Drainage climate divisions for California (www.wrcc.dri.edu/spi/divplot1map.html). The climate year captures the marked seasonality of precipitation in California (mainly October–April). The two former divisions together broadly overlap the area surveyed for terns in northeastern California; the latter two roughly match the areas surveyed for terns in the Sacramento and San Joaquin valleys.

long-term mean for the region (Figure 1). In the early part of the tern nesting season of 2010 it also was unusually cool, delaying nesting as described below. Mean temperatures for May–June for the Sacramento Drainage Division and Northeast Interior Basins Division (www.wrcc.dri.edu/spi/divplot1map.html) were 0.94° C and 1.77° C cooler than the long-term means (n = 116 years) for those regions, respectively (www.wrcc.dri.edu/divisional.html). By contrast, in 1997 mean May–June temperatures for these respective regions were 1.25° C and 0.9° C warmer than the long-term means.

Surveys in northeastern California in mid-May 2009 focused mainly on gulls and Caspian Terns (Shuford 2014a). From 2 June to 15 July 2010, Haines (assisted by Shuford for 2 weeks) surveyed the other colonial waterbirds in this region, including Black and Forster's terns. Sites surveyed included almost all those detailed in the appendices and tables in Shuford (2010), plus a few others not covered on comparable surveys in 1997. In 2010, as in 1997, surveys were not possible at a few areas of likely nesting because of physical barriers on public lands or lack of access to private property. Observers conducted most surveys on foot but occasionally used a kayak on larger or deeper water bodies. From 18 to 20 July and 1 to 2 August 2010, Shuford also completed ground-based surveys at reservoirs and wetlands in east-central California (Alpine and Mono counties).

Black Tern. Given the large number of scattered wetlands in this region it was impractical to count all Black Tern nests at each breeding site. So, depending on circumstances, we used three types of counts and corresponding methods to estimate numbers of breeding pairs of terns—total nests, total disturbed adults, and total visible undisturbed adults (see Shuford et al. 2001). Correction factors used to estimate breeding pairs for the latter two methods were derived in 1997. When data are available to make more than one estimate, we present only the method of apparent highest reliability.

The atypically cool spring in northeastern California in 2010 delayed nesting later than in 1997, a year with spring temperatures above average. By the end of May in 1997, most Black Tern nests had full clutches. In the first 10 days of June 2010, however, few birds were on full clutches and many appeared to be foraging away from breeding marshes (details in Shuford 2014a). Lacking confidence in interpreting numbers at individual marshes surveyed in early June, we resurveyed most of these sites again 7–10 days later.

Forster's Tern. To estimate numbers of breeding pairs of Forster's Tern we used the same three methods as for the Black Tern (details in Shuford 2010) but relied more on direct counts of nests. Similarly, we derived comparable correction factors in 1997 and present results of only the method of apparent highest reliability. All methods likely provide conservative estimates, particularly because the timing of nest initiation for Forster's Terns at a site can vary considerably by year or subcolony (Gould 1974, Shaw 1998), posing significant challenges to censusing. To address this, we visited important colonies at Lower Klamath National Wildlife Refuge (NWR), Siskiyou County, Tule Lake NWR, Siskiyou and Modoc counties, and Eagle Lake, Lassen County, repeatedly. Because Forster's Terns generally breed out in the open or in accessible areas at these sites, we had confidence in survey numbers as they changed with repeated visits over the season and used the highest seasonal counts.

Caspian Tern. From 12 to 22 May 2009, P. Henderson and Shuford, aided locally by collaborating biologists and volunteers, searched on foot and by boat for nesting Caspian Terns, which in this region typically nest in association with Ring-billed and California gulls (Shuford and Henderson 2010, Shuford 2014a). Observers made direct counts of nests or breeding adults, or documented a lack of tern nesting, at 13 sites. These included all sites where Caspian Terns had nested in recent years (Shuford and Craig 2002, USFWS unpubl. data) and other sites previously known just for gull nesting. During an aerial survey on 12 May 2009, we confirmed a lack of nesting gulls (or terns) at irregularly occupied colony sites at Sheepy Lake on Lower Klamath NWR and at Tule Lake NWR.

Surveys in May are not ideal for estimating breeding pairs of Caspian Terns, which typically delay nesting a few weeks later than gulls, but they usually are adequate to determine if the terns are on territory and beginning to nest. Consequently, from 16 to 19 June Henderson returned to count adults and nests at the one site where terns were present in May and made follow-up visits to five other sites to see if they might have been colonized since May (details in Shuford 2014a). In addition, P. Cherny (pers. comm.) confirmed a lack of tern nesting at Honey Lake Wildlife Area (WA) in 2009.

Central Valley

California's Central Valley, surrounded by mountains except at its western drainage into the San Francisco Bay estuary, is about 645 km long and 65 km wide. It encompasses the Sacramento Valley, draining southward, the San Joaquin Valley, draining northward, and the Sacramento–San Joaquin delta, where these rivers converge. The San Joaquin Valley can be further divided into the San Joaquin and (closed) Tulare basins (CVJV 2006). Over 90% of the Central Valley's historic wetlands have been lost (Frayer et al. 1989, Kempka et al. 1991), and habitat for breeding waterbirds is typically scarce. The dominant land use in the Central Valley is agriculture, with some irrigated crops providing habitat for nesting or foraging waterbirds. Large areas of cultivated rice (*Oryza sativa*) fields in the Sacramento Valley, and smaller areas in the delta and San Joaquin Basin, provide potential nesting habitat for Black Terns. Other habitats in the Central Valley sometimes suitable for breeding terns include managed wetlands on refuges and duck-hunting clubs (limited summer water), basins for flood-water storage or ground-water recharge, reservoirs, and agricultural lands flooded by spring runoff after exceptionally wet winters.

After 3 years of drought, precipitation in the Sacramento Drainage Division in the winter of 2009–10 was close to the long-term mean (Figure 1). Planting of rice in the Sacramento Valley was delayed in 2010 because of the cool and wet spring. In April and May 2010, the 20.7 cm of precipitation in the Sacramento Drainage Division was 183% of the long-term mean for that period and temperatures were 2.27° C cooler than the long-term mean (n = 116 years) for that region (www.wrcc.dri.edu/divisional.html). From weekly agricultural reports, we estimated that 93% of the rice was planted by the time of our surveys in 2010 (80% planted by 23 May, 90% by 30 May, 93% by 6 June, 97% by 13 June; U.S. Dept. Agric./National Agric. Statistics Service). Likewise, unseasonably cool weather slowed emergence and growth of the crop by about a week over normal (15% emerged by 23 May, 40% by 30 May, 55% by 6 June, 70% by 13 June; USDA/NASS Weekly Weather and Crop Bulletins), so visibility of terns in rice was good at the time of surveys.

The area surveyed for breeding Black Terns in the delta and northern San Joaquin Basin in 2010 falls within the northern portion of the San Joaquin Drainage Division (www.wrcc.dri.edu/spi/divplot1map.html), where the precipitation in the prior winter was slightly above the long-term mean but preceded by 3 years of drought (Figure 1). We surveyed the central and southern San Joaquin Valley in 2012, which was preceded by a very dry winter; since 2006–07 drought had been broken only in 2010–11 (Figure 1).

Black Tern. In recent decades, the vast majority of Black Terns nesting in the Central Valley did so in cultivated rice fields (Shuford et al. 2001). In 2010, there were 225,815 ha of planted rice in the Central Valley: 222,473 ha (98.5%) in the Sacramento Valley and 5342 ha (2.4%) in the delta and northern San Joaquin Valley. In contrast to its positive relationship with the extent of wetlands in northeastern California, under most circumstances precipitation in the previous winter has little effect on the amount of rice planted in the Sacramento Valley. The 222,000 ha of rice planted in 2010, when precipitation in the previous winter was about average following 3 years of drought, compares to ~187,000 ha planted at the time of the last comprehensive survey in 1998, when precipitation in the previous winter was very high following 3 years also above the long-term mean (Figure 1).

In the Sacramento Valley, we surveyed Black Terns from roadsides as detailed by Shuford et al. (2001). Strum, R. Doster, and seven other skilled volunteers covered multiple survey routes of varying lengths within eight counties from 27 May to 12 June 2010. They counted terns and recorded the extent of rice within an area 160 m wide on each side of the road. From these data we projected the mean density of terns per 100 ha for each county (or grouping of counties) by calculating the mean density for all of the county's routes weighted by habitat miles, i.e., the total number of miles of suitable habitat covered with both sides of the road tallied separately. We estimated the total number of breeding terns in each county by multiplying tern density per county times the number of hectares of planted rice per county (www.nass.usda.gov/Statistics_by_State/California/Publications/County_Estimates/index.asp), adjusted by a correction factor of 0.93, the estimated proportion of rice planted at the time of our surveys (see Shuford et al. 2001 for additional details). As in 1998, we estimated the number of breeding pairs in Sacramento Valley rice fields by dividing the estimated number of breeding terns (derived from density data) by 1.27, the mean ratio of the counts of undisturbed adults to that of nests in low-stature wetlands in northeastern California in 1997 (see Shuford et al. 2001).

By contrast, the limited extent of rice in the delta and northern San Joaquin Valley enables surveys of all potential habitat for nesting Black Terns. From 17 to 25 June 2010, J. Humphrey counted visible undisturbed adults in planted rice in the 647, 2590, 1012, and 1093 ha of planted rice in Stanislaus, San Joaquin, Merced, and Fresno counties, respectively (county agricultural commissioner reports). Although the potential to damage crops precluded her from entering fields, in a few cases she counted total nests or total disturbed adults when looking into fields from adjacent levees. Hence, we estimated numbers of pairs of Black Terns in these counties by all three methods outlined above for northeastern California (see Shuford et al. 2001).

In May and June 2012, Shuford, collaborating biologists, and volunteers surveyed various species of colonial waterbirds in the central and southern San Joaquin Valley (Shuford 2014a), where modest numbers of Black Terns bred in 1998 (Shuford et al. 2001). Because of drought (see Figure 1), wet habitats were much scarcer in 2012 than in 1998 (Shuford pers. obs.). From the ground, we surveyed all areas in the region we judged, from prior experience or local experts' current knowledge, might have habitat for nesting terns. We also scouted for additional tern habitat during aerial surveys for heron and egret colonies over four days from 8 to 16 May 2012; these surveys covered all substantial water bodies and the length of all major rivers and creeks in the San Joaquin Valley from Stanislaus County south through Kern County. Many reservoirs or flood-storage basins on the valley floor were dry (e.g., Kern Fan Element Water Bank), but a few had retained some storage from runoff in the winter of 2010–11 (e.g., South Wilbur Flood Area). Also, Shuford spent 24–27 June 2012 surveying nesting terns in all accessible shallow-water habitat that seemed suitable in Fresno, Kings, Tulare, and Kern counties. As these species can nest over a protracted period, these included many sites previously searched in May and various duck-hunting clubs in the Tulare Basin with summer water. Areas searched in 2012 included the sites where the three tern species nested in this region during prior broad-scale surveys in the late 1990s (Shuford 2010).

Forster's and Caspian Terns. In recent years, these species have nested in the Central Valley only very locally in the San Joaquin Valley (Shuford 2010). In 2012, we searched for these terns at the same time we surveyed for Black Terns and other colonial waterbirds, as described above.

Southern California

The 2012 surveys in this region focused on two subregions: the coastal slope of southern California north to southern Santa Barbara County, including the coastal plain, interior valleys, and some montane valleys or depressions, and the southern deserts, mainly at the Salton Sea and Imperial Valley. In southern California the winter of 2011–12 was very dry, preceded by two winters of above-average precipitation after three very dry ones starting in 2006–07 (Figure 2). The Black Tern has not previously been documented breeding in this region, and we did not observe it there in 2012.

Forster's and Caspian Terns. In 2012, D. S. Cooper coordinated surveys of multiple species of colonial waterbirds, primarily on the coastal slope of southern California. Surveys, from 10 January to 4 August (mostly March–June), focused mainly on colonies of tree-nesting herons, egrets, and cormorants but also covered areas of potential tern breeding. Observations at the only active colony of the Forster's Tern documented in the interior of southern California in 2012 were hampered by poor visibility of birds on a nesting island overgrown with weeds. D. Willick estimated the number of pairs of nesting terns roughly on the basis of observations of about 150–200 fledglings seen at any one time over the summer.

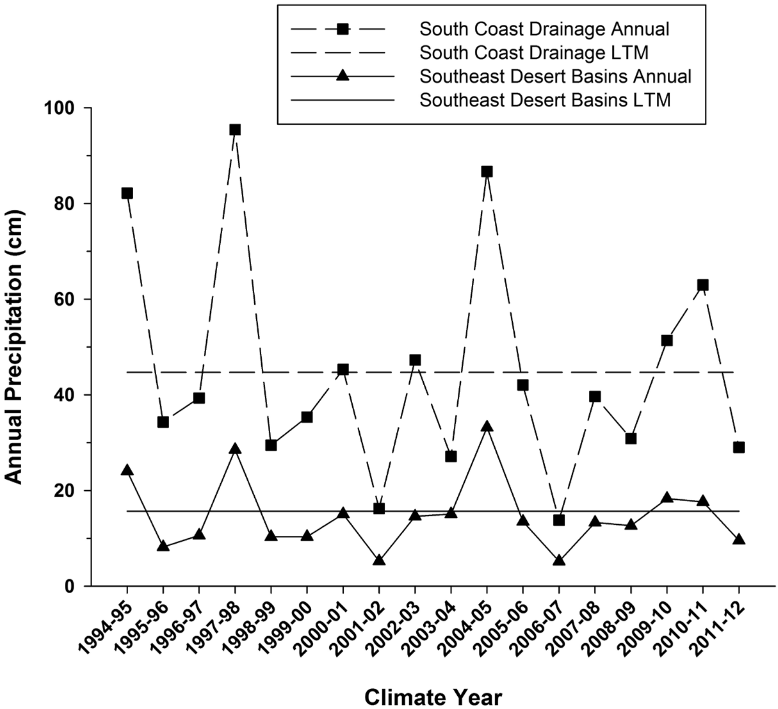

Figure 2. Annual (1 July–30 June) precipitation for the climate years 1994–95 to 2011–12, compared to the respective long-term means (LTM; *n* = 117 years; www.wrcc.dri.edu/divisional.html), for the South Coast Drainage and the Southeast Desert Basins climate divisions for California (www.wrcc.dri.edu/spi/divplot1map.html). The climate year captures the marked seasonality of precipitation in California (mainly October–April). These two climate divisions together broadly overlap the area surveyed for terns in southern California.

Various species of waterbirds were surveyed at the Salton Sea (Riverside and Imperial counties) in 2012 (Molina and Shuford 2013). Numbers we report for Caspian Terns nesting in 2012 (and 2009) are from long-term monitoring of larid populations at that site since 1992 (Molina 2004, K. Molina unpubl. data). No colonies of Forster's Terns were seen at the Salton Sea in 2012, and we know of no other potential nesting habitat for this species elsewhere in the deserts of southern California.

Data Summary and Mapping by Ecoregions

For summarizing and mapping patterns of colony occurrence, we use primarily the geographic subdivisions or ecoregions of California from Hickman et al. (1993), who defined three floristic provinces divided into 10 regions and 23 subregions. We followed Shuford's (2014a) recognition of 11 ecoregions, which include 9 of these regions plus the Sacramento Valley and San

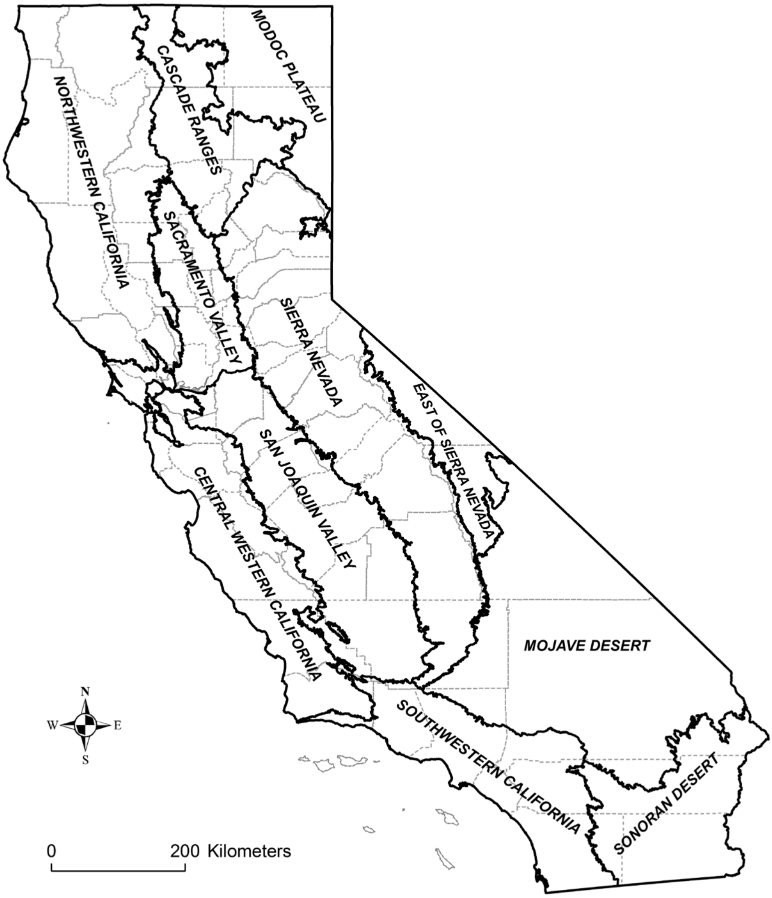

Figure 3. Ecoregions—based on the Jepson manual's geographic subdivisions of California (Hickman 1993)—used for mapping and summarizing data from statewide surveys of tern colonies, 2009–2012.

Joaquin Valley subregions of the Great Central Valley region (Figure 3). For descriptive ease, we equate the combined Cascade Ranges, Modoc Plateau, and (northern) Sierra Nevada ecoregions with "northeastern California," as widely used (e.g., Shuford et al. 2001, Shuford 2010). Similarly, we equate the combined Mojave Desert, Sonoran Desert, Southwestern California, and (southern) Central Western California ecoregions with "southern California."

D. Jongsomjit mapped colonies in California in 1997–1999 and 2009–2012 with ArcMap version 10.1 (ESRI, Inc.). Values for categories of relative abundance were based on natural breaks in the data for each species for the two survey periods combined, facilitating comparisons of colony size by period.

Table 1 Percentage of Nesting Pairs by Ecoregion[a] for Three Species of Terns from Statewide Surveys of the Interior of California, 2009–2012

	Southwestern California	Sacramento Valley	San Joaquin Valley	Cascade Ranges	Sierra Nevada	Modoc Plateau	Sonoran Desert
Caspian Tern	0	0	0	0	0	4	96
Black Tern	0	46	3	2	0	49	0
Forster's Tern	25	0	3	<1	8	64	0

[a]As defined by Hickman (1993), see Figure 3; during the survey period, terns occurred in seven of these.

RESULTS

Patterns of Distribution and Abundance

From 2009 to 2012, the three tern species combined bred in 7 of the 11 ecoregions in the interior of California: the Forster's Tern in 5, the Black Tern in 4, and the Caspian Tern in 2 (Table 1, Figure 3). Drought precluded nesting or reduced numbers nesting in some ecoregions below those of 1997–1998, when conditions were wetter (Figures 1 and 2) and suitable nesting and foraging habitat was more extensive. Patterns of distribution and abundance varied by species.

Black Tern

In 2010, we estimated 2029 pairs of Black Terns nested in the state: 51% in northeastern California and 49% in the Central Valley. The statewide total in 2010 was only 49% of the 4150 pairs estimated in 1997–1998, when numbers were higher in both regions (Tables 2 and 3; Figures 4 and 5).

Northeastern California. In 2010, an estimated 1033 pairs of Black Terns nested at 36 scattered sites, versus 1940 pairs at 60 sites in 1997 (Table 2, Figures 4 and 5). These figures, from four ecoregions, represent only 53% of the total breeding pairs and 60% of the number of nesting sites for northeastern California in 1997 (Tables 2). Drought had greatly reduced the number of sites and extent of habitat at those that remained in 2010 (Haines and Shuford pers. obs.). The Modoc Plateau ecoregion accounted for 97% and 88% of the Black Terns breeding in northeastern California in 2010 and 1997, respectively. In 2010, about 82%, 11%, 6%, and <1% of the total were in Modoc, Siskiyou, Lassen, and Shasta counties, respectively. Five sites had >50 pairs of terns: Lower Klamath NWR, Siskiyou County; Weed Valley, Fletcher Creek Reservoir, and Lookout Ranch, Modoc County; and Ash Creek WA, Modoc and Lassen counties.

Central Valley. We estimated 1198 (range 888–1508) adult terns, or 943 (range 699–1187) pairs, bred in Sacramento Valley rice fields in 2010 (Table 3), 47% of the estimate for that region in 1998. Densities were highest in Yuba and Glenn counties in 2010 versus in Colusa and Glenn counties in 1998 (Table 3). In the San Joaquin Valley in 2010, 22 pairs bred at 1 site in rice fields southwest of the city of Merced, Merced County, and 31 pairs

Table 2 Estimated Numbers of Pairs of Black Terns at Colonies in Northeastern California by Ecoregion[a], 1997 and 2010

Site	Estimated pairs[b] 1997	Estimated pairs[b] 2010	Survey date 2010
Cascade Ranges			
Siskiyou County (part)			
Grass Lake	22[3]	14[2]	13 June
Lassen County (part)			
Mosquito Flat	0	2[2]	2 July
Poison Lake	38[2]	9[2]	4 July
Ashurst Lake	2[3]	7[2]	2 July
Dry Lake, Grass Valley	5[3]	0	4 July
Straylor Lake	9[3]	0	2 July
Long Lake	5[3]	0	2 July
Gordon Lake	9[3]	0	2 July
Pine Creek wetlands	7[3]	0	4 July
McCoy waterpit	9[3]	0	5 July
Eagle Lake			
Spaulding	73[3]	0	5 July
North Basin	17[3]	3[2]	6 July
Troxel	22[3]	0	6 July
Ecoregion total	***218***	***35***	
Sierra Nevada			
Lassen County (part)			
Mountain Meadows Reservoir	11[2]	0	14 July
Ecoregion total	***11***	***0***	
Modoc Plateau			
Siskiyou County (part)			
Butte Valley WA, Unit 7C	11[2]	0	30 June
Butte Valley National Grasslands	2[3]	0	30 June
Orr Lake	6[3]	0	17 June
Dry Lake	3[3]	0	17 June
Lower Klamath NWR			
Unit 4D	12[1]	0	15 June
Unit 4E	37[2]	0	15 June
Unit 6A	0	1[1]	17 June
Unit 6C	0	94[3]	15 June
Tule Lake NWR, Sump 1-B	0	2[1]	29 June
Barnum Flat Reservoir	54[3]	2[2]	28 June
Modoc County			
Dry Lake	9[3]	1[1]	13 June
Fourmile Valley	27[1]	28[3]	12 June
Wild Horse Valley	3[1]	11[3]	12 June
Buchanan Flat	21[1]	16[3]	11 June
Weed Valley	160[3]	237[3]	11 June
Baseball Reservoir	42[1]	14[3]	11 June
Dry Valley Reservoir	30[1]	28[3]	22 June
Hager Basin North	14[1]	0	2 June
Hager Basin South	18[1]	0	2 June

(*continued*)

Table 2 (*continued*)

Site	Estimated pairs[b] 1997	Estimated pairs[b] 2010	Survey date 2010
Telephone Flat Reservoir	7[1]	0	9 June
South Mountain Reservoir	2[1]	11[3]	9 June
Pease Flat	47[3]	20[2]	10 June
Mud Lake	16[1]	0	11 June
Crowder Mountain Reservoir	40[1]	0	9 June
Whitney Reservoir	5[2]	0	4 June
Stovepipe Flat Tank	—	10[3]	5 June
Hackamore Reservoir	10[2]	9[3]	4 June
Henski/Spaulding Reservoir	20[2]	34[3]	13 June
Beeler Reservoir	13[2]	0	13 June
Pinky's Pond	7[2]	31[3]	13 June
Widow Valley	64[3]	0	5 June
Bucher Swamp	96[3]	0	5 June
Williams Reservoir	—	15[3]	5 June
Six Shooter Tank	9[2]	7[1]	4 June
Deadhorse Flat Reservoir	35[3]	0	7 June
Surveyors Valley	28[3]	0	6 June
Boles Meadow (marsh)	166[3]	25[3]	7 June
Fletcher Creek Reservoir	31[1]	131[3]	22 June
Reservoir N	0	13[3]	23 June
Jacks Swamp	26[1]	0	8 June
Dead Horse Reservoir	11[1]	0	8 June
Jesse Valley	10[3]	6[3]	24 June
Mosquito Lake	0	7[2]	28 June
Whitehorse Flat Reservoir	29[3]	0	28 June
Egg Lake	270[3]	41[3]	28 June
Taylor Creek wetlands	101[3]	0	27 June
Lookout Ranch	—	56[3]	13 July
Ash Creek WA 1 (part)	0	37[3]	27 June
Ash Creek WA 2 (part)	0	14[3]	27 June
Warm Springs Valley	—	16[3]	26 June
Wild rice fields, Rd. 54	—	33[3]	26 June
Shasta County			
Bald Mountain Reservoir	0	5[2]	3 July
Lassen County (part)			
Ash Creek WA (part)	0	4[2]	27 June
Muck Valley	42[3]	0	1 July
Hoover Flat Reservoir	6[3]	0	1 July
Moll Reservoir	17[2]	0	2 July
Oxendine Spring	5[2]	0	2 July
Ash Valley (main)	52[3]	0	2 July
Ash Valley (southeast)	7[3]	0	2 July
Red Rock Lakes complex	57[3]	0	24 June
Boot Lake	12[3]	8[3]	25 June
Willow Creek WA			
Pond 5	0	7[3]	8 July
Pond 13	0	12[3]	7 July

(*continued*)

Table 2 (*continued*)

Site	Estimated pairs[b] 1997	Estimated pairs[b] 2010	Survey date 2010
Pond 14	0	6[3]	7 July
Pond 16	10[3]	0	7 July
Pond 18	0	6[3]	7 July
Horse Lake	8[2]	0	7 July
Honey Lake N, private	3[2]	0	5 July
Ecoregion total	***1711***	***998***	
Grand total	**1940**	**1033**	

[a]The three relevant ecoregions used here are a subset of those defined for all of California by Hickman (1993); see Figure 3.

[b]Numbers of pairs estimated by three methods, listed here in order of apparent reliability, on the basis of [1]numbers of total nests, [2]counts of total disturbed adults, and [3]counts of total undisturbed adults (see Methods in Shuford et al. 2001). When data enable more than one type of estimate, the estimate presented is from the method of highest apparent reliability. Numbers for 1997 from Shuford et al. (2001).

bred at 6 scattered sites in rice fields in northern Fresno County southeast of the town of South Dos Palos, Merced County. The estimate of 53 pairs for the San Joaquin Basin in 2010 was 71% of the total for that region in 1998. There was no evidence of any Black Terns breeding in the Tulare Basin in 2012, in contrast to the 151 pairs estimated there in 1998. Hence, the number of pairs of nesting Black Terns estimated for the entire San Joaquin Valley in 2010–2012 was only 23% of the total for that region in 1998.

Forster's Tern

For 2010 to 2012, we estimated 610 pairs of Forster's Terns nested at 11 inland sites in the state versus 2357 pairs at 31 sites in 1997 and 1998 (Table 4). From 2010 to 2012, 73% of the breeding birds were in northeastern California, 3% in the Central Valley, and 24% on the coastal slope of southern California. Two sites in the Klamath Basin NWR Complex on the Modoc Plateau accounted for ~57% of this total, and one site in southwestern California accounted for 25% (Tables 1 and 4). Overall inland totals for 2010–2012 represented only 26% of the breeding pairs and 35% of the number of sites recorded in 1997–1998 (Table 4, Figures 6 and 7).

Northeastern California. In 2010 an estimated 444 pairs of Forster's Terns nested at 8 sites in this region versus 1816 pairs at 21 sites in 1997 (Table 4, Figures 6 and 7). Total breeding pairs and nesting sites in 2010 were, respectively, only 24% and 38% of those in 1997. Of the 2010 total, 78%, 15%, and 6% were in Siskiyou, Lassen, and Modoc counties, respectively. Only three sites held >50 pairs: Lower Klamath NWR and Tule Lake NWR, Siskiyou County, and Mountain Meadows Reservoir, Lassen County.

Central Valley. In 2012, we estimated a total of 16 pairs of Forster's Terns were nesting at 2 sites in the San Joaquin Valley versus 541 pairs at 10 sites there in 1997–1998 (Table 4, Figures 6 and 7). In 2012, eight pairs nested on the edge of an island at Leaky Acres, a water-recharge basin

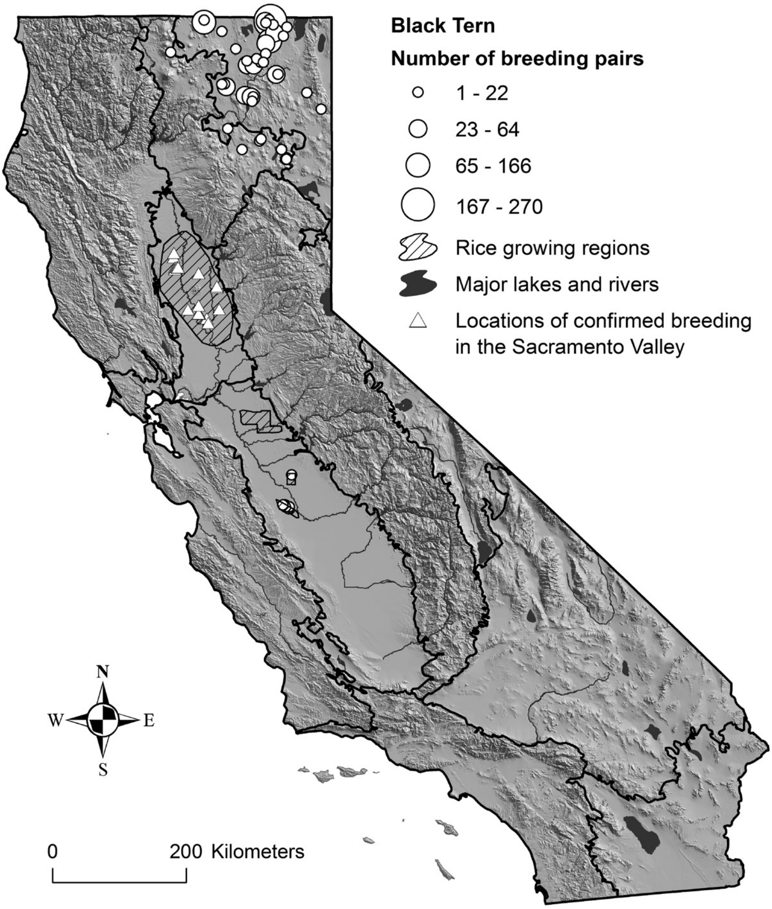

Figure 4. Distribution and relative size of Black Tern colonies in northeastern California and in the northern San Joaquin Valley from surveys in 2010 (see Table 2); surveys in the southern San Joaquin Valley in 2012 did not locate any colonies of this species. Triangles in the area of Sacramento Valley rice fields represent locations of breeding confirmed in 2010 during roadside surveys by which we sampled this extensive habitat, where limited access precludes locating all colonies (see Table 3).

of 26 ponds covering 81 ha operated by the city of Fresno, Fresno County (J. Seay in litt., Shuford pers. obs.). An estimated eight pairs nested at a traditionally used island in Turlock Lake, a large reservoir in southeastern Stanislaus County, on the basis of observations of 15 adults near the island on 23 June and a nest with eggshell fragments on the island on 14 July (H. and S. Reeve in litt.). In 2012, numbers of breeding pairs and nesting sites in the San Joaquin Valley were, respectively, only about 3% and 20% of those in 1997–1998 (Table 4).

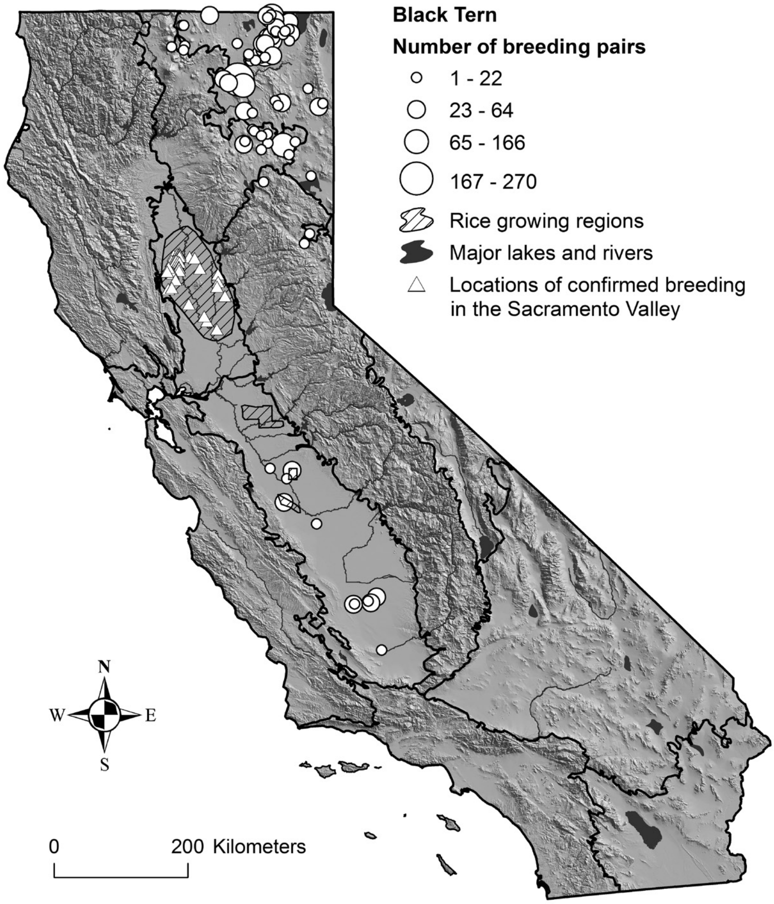

Figure 5. Distribution and relative size of Black Tern colonies in California from statewide surveys, 1997–1999 (Shuford et al. 2001; map revised from Shuford 2010). Triangles in the area of Sacramento Valley rice fields represent locations of breeding confirmed in 1998 during roadside surveys by which we sampled this extensive habitat, where limited access precludes locating all colonies (see Table 3).

Southern California. The only inland site in this region where we documented breeding by Forster's Terns in 2012 (Table 4) was on the coastal slope about 22.5 km from the ocean. Roughly 150 pairs nested in Anaheim at the Orange County Water District's Burris Basin 2, a water-recharge basin adjacent to the Santa Ana River (formerly known as "Burris Pit"). The terns were nesting on a weedy island, originally built for California Least Terns (*Sternula antillarum browni*).

Table 3 Numbers of Black Terns Estimated in the Sacramento Valley from Roadside Surveys of Rice Fields, 29 May–10 June 1998 and 1–11 June 2010[a]

	Hectares planted rice[b]		Survey routes (n)		Distance surveyed (km)[c]		Terns per 100 ha (± SE)[d]		Terns estimated ± (SE)[e]	
County	1998	2010	1998	2010	1998	2010	1998	2010	1998	2010
Colusa	36,637	57,583	38	30	370	453	2.67 (0.67)	0.37 (0.13)	978 (245)	215 (75)
Sutter–Yolo–Sacramento[f]	36,485	60,293	26	36	285	611	0.70 (0.23)	0.32 (0.11)	225 (84)	191 (66)
Sutter	27,553	43,658	15	24	204	474	—	0.41 (0.15)	—	178 (65)
Butte	26,645	35,302	10	7	235	166	0.85 (0.31)	0.72 (0.43)	226 (82)	253 (150)
Glenn	25,131	32,216	44	26	353	362	3.68 (1.56)	1.12 (0.29)	925 (392)	362 (94)
Yuba	11,294	14,565	16	9	122	100	1.22 (0.44)	1.25 (0.71)	138 (50)	182 (103)
Yolo	6177	15,431	10	12	69	137	—	0 (0)	—	0 (0)
Placer	4239	6234	4	4	47	61	0 (0)	0 (0)	0	0
Sacramento	2755	1204	1	0	11	0	—	—	—	—
Tehama	363	405[g]	0	0	0	0	—	—	—	—
Total	140,794	206,570	138	112	1411	1752	1.80 (0.54)[h]	0.58 (0.15)[h]	2523 (754)	1198 (310)

[a]Data for 1998 from Shuford et al. (2001).

[b]Planted rice acreage adjusted to account for estimate that only 75% (1998) and 93% (2010) of the total for the year had been planted at the time of our surveys (see Methods).

[c]Each side of road tallied separately.

[d]Density estimates for each county are means (± standard error) of survey routes, weighted by distance surveyed.

[e]Tern numbers estimated by multiplying densities on roadside surveys times acreage of available rice fields. Standard errors represent variation in densities of terns on survey routes but do not account for possible error in the estimate of the amount of planted rice at the time of tern surveys.

[f]Data for these counties pooled for density estimates and analyses because of small sample sizes for Yolo and Sacramento counties.

[g]Amount of rice in Tehama County estimated in 2010. Although we surveyed no routes in Tehama Co. in either 1998 or 2010, prior evidence suggests that terns do not breed in that area. If they do now, numbers would be very small, given the limited rice acreage, and insignificant relative to totals for the entire Sacramento Valley.

[h]Mean of county density estimates, weighted by hectares of rice.

Table 4 Estimated Numbers of Pairs of Forster's Terns at Colonies in the Interior of California by Ecoregion, 2010–2012 and 1997–1998[a]

Site	Estimated pairs[b] 1997–1998	Estimated pairs[b] 2010–2012	Survey date 2010–2012
Southwestern California			
Orange County			
Orange County Water District, Burris Basin 2	0	150[c]	4 August 2012
Ecoregion total	***0***	***150***	
San Joaquin Valley			
Stanislaus County			
Turlock Lake	75[2]	8[3]	14 July 2012
Fresno County			
Leaky Acres	—	8[1]	30 May 2012
Kings County			
Corcoran Irrigation District, Resv. #1	51[2]	0	24 June 2012
Corcoran Irrigation District, Resv. #2	3[1]	0	19 May 2012
Lost Hills Water District and Rainbow Ranch compensation wetland	4[1]	0	dry in 2012
S of Hacienda Ranch Flood Basin #1	134[1]	0	9 May 2012
S of Hacienda Ranch Flood Basin #2	74[1]	0	9 May 2012
Tulare Lake Drainage District, South Evaporation Basin	1[1]	0	multiple visits in 2012
Tulare County			
Alpaugh Irrigation District Reservoir lands	38[2]	0	25 June 2012
~2 km W of Road 40, ~6 km S of Alpaugh	128[2]	0	9 May 2012
Kern County			
Kern Fan Element Water Bank (Pond W-2)	33[2]	0	9 May 2012
Ecoregion total	***541***	***16***	
Cascade Ranges			
Lassen County (part)			
Eagle Lake[d]	86[3]	3[2]	6 July 2010
Ecoregion total	***86***	***3***	
Sierra Nevada			
Lassen County (part)			
Mountain Meadows Reservoir	38[3]	52[2]	14 July 2010
El Dorado County			
Pope Marsh, South Lake Tahoe	16[1]	0	4 July 2010
Ecoregion total	***54***	***52***	
Modoc Plateau			
Siskiyou County			

(continued)

Table 4 (*continued*)

Site	Estimated pairs[b] 1997–1998	Estimated pairs[b] 2010–2012	Survey date 2010–2012
Prather Ranch north	8[3]	0	30 June 2010
Butte Valley WA (Meiss Lake)	98[3]	0	30 June 2010
Lower Klamath NWR			
Unit 3A	29[3]	0	15 June 2010
Unit 4D	18[1]	0	15 June 2010
Unit 4E	46[1]	0	15 June 2010
Unit 6A	0	248[1]	16 June 2010
Unit 11B	63[1]	0	16 June 2010
Tule Lake NWR			
Sump 1-A	226[3]	63[1]	12 July 2010
Sump 1-B	0	37[1]	29 June 2010
Shasta County			
Horr Pond	4[3]	0	3 July 2010
Modoc County			
Whitehorse Flat Reservoir	0	28[2]	28 June 2010
Egg Lake	22[3]	0	28 June 2010
Boles Meadow (islands)	443[1]	0	7 June 2010
Fairchild Swamp	116[3]	0	6 June 2010
Lookout Ranch	—	1[2]	13 July 2010
Raker and Thomas Reservoir	8[1]	0	23 June 2010
Goose Lake	458[2]	0	24 June 2010
Lassen County (part)			
Ash Creek WA	~14[2]	7[3]	27 June 2010
Boot Lake	0	5[2]	25 June 2010
Grasshopper Valley	54[3]	0	6 July 2010
Horse Lake	19[3]	0	7 July 2010
Red Rock Lakes complex	4[3]	0	24 June 2010
Leavitt Lake	31[1]	0	6 &15 July 2010
Honey Lake WA, Fleming Unit (Pond 15)	7[1]	0	5 July 2010
Honey Lake North, private	2[1]	0	5 July 2010
Plumas County			
Sierra Valley (S of steel bridge)	6[2]	0	25 June 2010
Ecoregion total	***1676***	***389***	
Grand total	**2357**	**610**	

[a]The "interior" survey area excludes coastal tern colonies within or adjacent to estuaries. The five ecoregions used here are a subset of those for all of California in Hickman (1993); see Figure 3. Data for 1997–1999 are from Shuford (2010) unless otherwise noted.

[b]Number of pairs estimated by three methods listed here in order of apparent reliability, on the basis of [1]numbers of total nests, [2]best counts of total undisturbed adults, or [3]best counts of disturbed adults (see Methods in Shuford 2010). When data enable more than one type of estimate, the estimate presented is from the method of highest apparent reliability. Dash denotes no data available.

[c]Island was overgrown with weeds, hence viewing nesting activity was difficult. On the basis of 150–200 fledglings seen at one time over the summer, a rough estimate of 150 nesting pairs.

[d]In 2010, all nesting was in the marsh in the North Basin. Of 123 Forster's Terns counted from 8–9 July 1997 (representing an estimated 86 pairs), 14 were along the southwest shore from south of Pelican Point south to cove near Eagle Lake Resort, 90 at Spaulding, 4 in Delta Bay, 1 in Buck Bay, 11 in North Basin, 2 at Troxel, and 1 in Duck Island Bay.

Table 5 Estimated Numbers of Pairs of Caspian Terns at Colonies in the Interior[a] of California by Ecoregion[b], 2009–2012 and 1999

Site	Estimated pairs[c] 1999	Estimated pairs[c] 2009–2012	Survey date 2009–2012
Southwestern California			
Riverside County			
Lake Elsinore	14	—	—
Ecoregion total	***14***	—	
San Joaquin Valley			
Kings County			
Lemoore NAS sewage ponds	0	—	—
South Evaporation Basin, Westlake Farms	0	0	multiple dates 2012
Tulare lakebed, ~14 km E of Kettleman City	0	0	9 May 2012
South Wilbur Flood Area, Tulare Lake Drainage District	27	0	6 June 2012
South Evaporation Basin, Tulare Lake Drainage District	0	0	multiple dates 2012
Ecoregion total	***27***	***0***	
Modoc Plateau			
Siskiyou County			
Butte Valley WA (Meiss Lake)	27	0	16 June 2009
Modoc County			
Clear Lake NWR	118	44[d]	17 June 2009
Goose Lake	310	0	19 June 2009
Big Sage Reservoir	0	0	19 June 2009
Lassen County			
Dakin Unit (Hartson Reservoir), Honey Lake WA	87+	0[e]	June 2009
Ecoregion total	***542***	***44***	
Sonoran Desert			
Imperial County			
South end Salton Sea, Salton Sea NWR HQ, Pond D	211	1177	7 May 2012
Ecoregion total	***211***	***1177***	
Grand total	**794**	**1221**	

[a]The "interior" survey area excludes coastal tern colonies within or adjacent to estuaries; for the San Francisco Bay estuary, the Carquinez Strait at Interstate-80 is considered the boundary between coastal and interior. Data for 1999 are from Shuford (2010) unless otherwise noted. Dash denotes no survey made.

[b]The four ecoregions used here are a subset of those for all of California in Hickman (1993); see Figure 3.

[c]Pairs estimated from direct count of nests (1 nest = 1 pair) unless otherwise noted.

[d]Observers recorded 71 adult Caspian Terns on territory in mid-June, nestled within a large colony of Ring-billed Gulls on a rocky islet on the east lobe of the lake. Only a few of these birds were sitting down as if on nests, so it was difficult to estimate the number of breeding pairs at this site. To do so (see Shuford 2010), we multiplied the number of adults counted by 0.62 to approximate the number of breeding pairs on the basis of the average ratio of nests to adults at sites on the California coast (0.625, Carter et al. 1992:I-45) and the California interior (0.61, Shuford unpubl. data).

[e]On 14 May 2009 visit, no terns were nesting at Hartson Reservoir or the adjacent pond 5A on the Dakin Unit of Honey Lake WA; suitable islands were lacking at Hartson, and the water surrounding the few islands at 5A was very shallow. P. Cherny confirmed that no tern colony was active in June 2009.

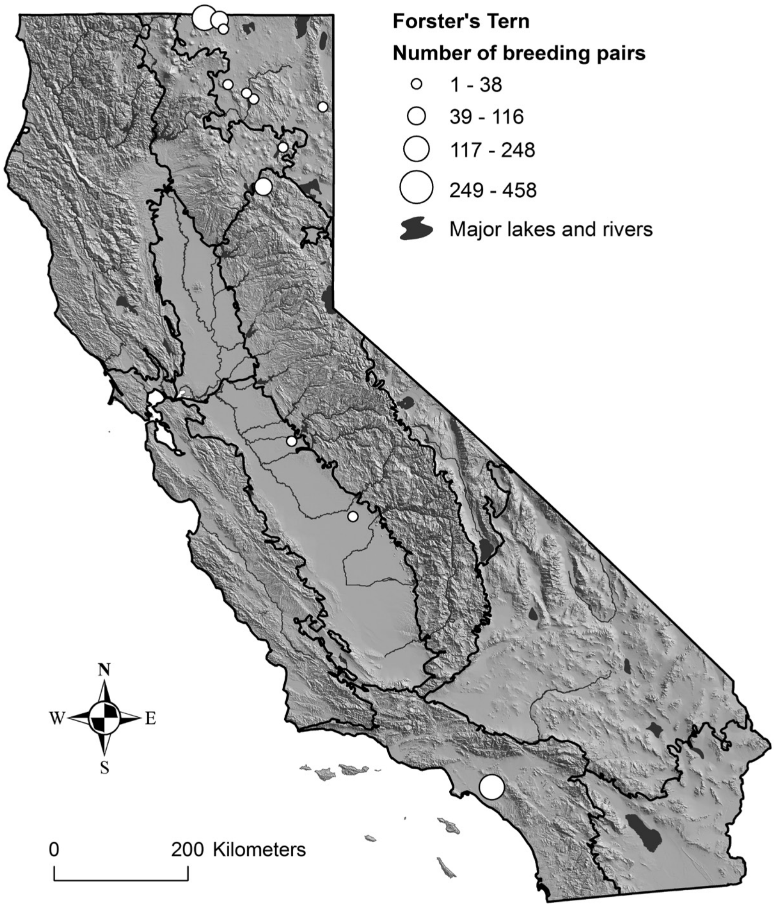

Figure 6. Distribution and relative size of Forster's Tern colonies inland in California from statewide surveys, 2009–2012 (see Table 4).

Caspian Tern

During our surveys Caspian Terns nested at two sites in the interior of California: Clear Lake NWR on the Modoc Plateau and the Salton Sea. In 2009, 44 pairs nested at the former and at least 3000 pairs nested at the latter (K. Molina pers. comm.), but in 2012 the number for the Salton Sea dropped to 1177 (Table 5, Figure 8). By contrast, an estimated 1762 pairs nested at 8 interior sites (3 at the Salton Sea) in 1997 and about 794 pairs nested at 7 sites in 1999 (Shuford 2010; Figure 9), when coverage was slightly better than in 1997. The 2009 inland total represents 173% and 383% of the totals for 1997 and 1999, respectively. Also, in 1998 Caspian Terns nested at several sites in the Tulare Basin where they did not in either

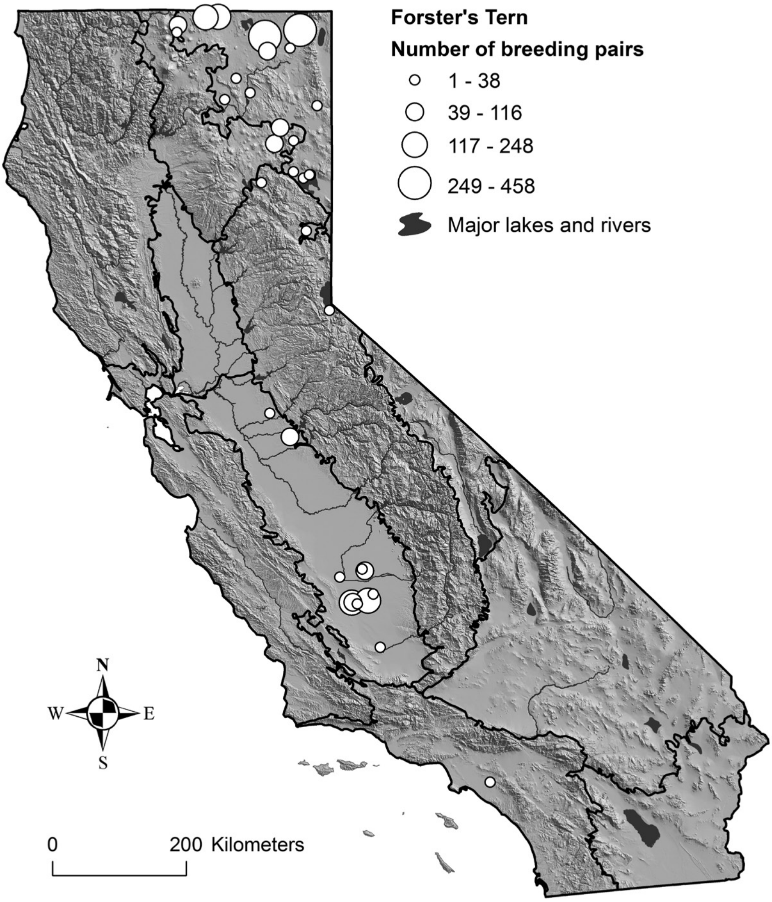

Figure 7. Distribution and relative size of Forster's Tern colonies inland in California from statewide surveys, 1997–1999 (see Table 4; map revised from Shuford 2010).

1997 or 1999 (Shuford 2010). In these years, the inland total was greatly influenced by the wide variation in the number of pairs nesting at the Salton Sea (~1200 in 1997, ~800 in 1998, 211 in 1999; Molina 2004).

The very limited nesting of Caspian Terns in northeastern California in 2009 paralleled the pattern of the Ring-billed and California gulls (Shuford 2014a). Except for a small Caspian Tern colony at Clear Lake NWR, other traditional colonies on the Modoc Plateau were inactive in 2009. At Meiss Lake (Butte Valley WA), Goose Lake, Big Sage Reservoir, and Hartson Reservoir (Honey Lake WA) drought left water levels so low that all islands where terns might nest had become accessible to terrestrial predators. In combination with the Clear Lake colony, these Modoc Plateau colonies col-

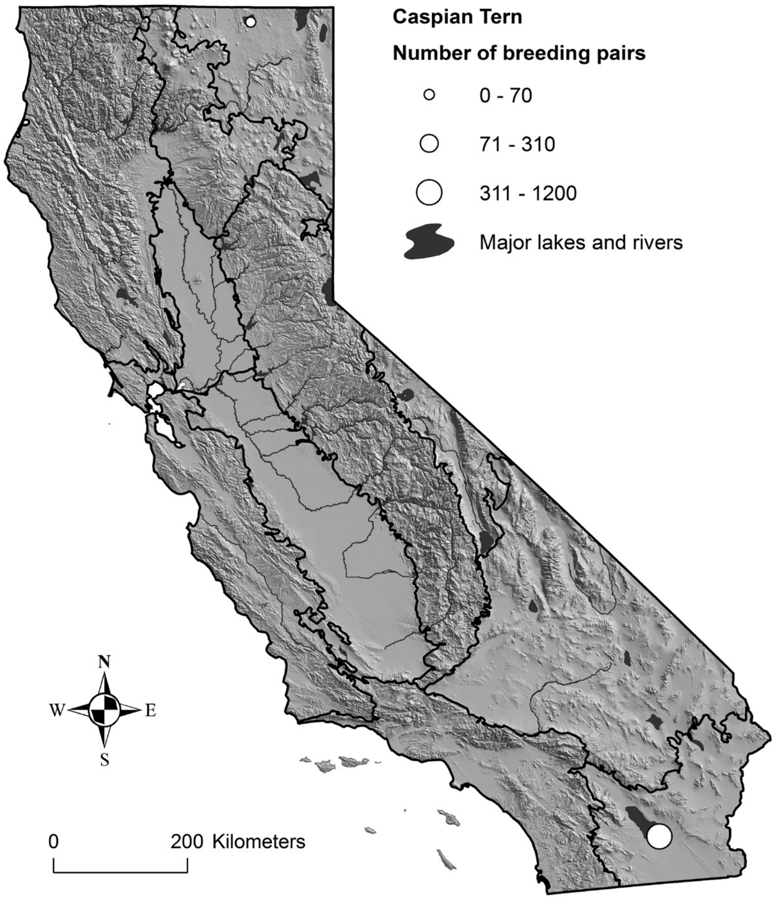

Figure 8. Distribution and relative size of Caspian Tern colonies inland in California from statewide surveys, 2009–2012 (see Table 5).

lectively held over 400 nesting pairs of Caspian Terns when all were surveyed in 1997 and 1999 (Shuford 2010). Except at Clear Lake NWR in 2011 (12 pairs) and 2012 (~60 pairs), all the traditional Modoc Plateau colonies were inactive from 2010 to 2013 (BRNW 2011–2014). The low numbers at traditional sites were offset, however, by nesting on newly constructed artificial islands in the Klamath Basin beginning in 2010. In 2011, 236 pairs bred at four sites in the Klamath Basin, including three of these artificial islands, contributing to an estimate of 1350 pairs for inland California that year (Collis et al. 2012).

In the San Joaquin Valley, there were no known active colonies from 2009 to 2012 (J. Seay pers. comm.).

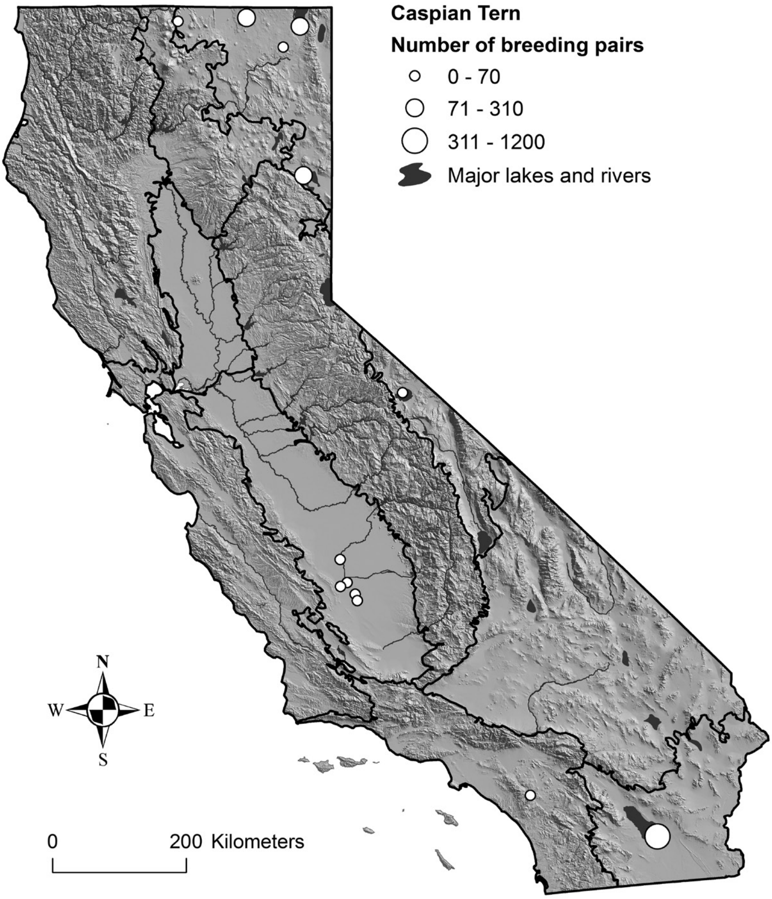

Figure 9. Distribution and relative size of Caspian Tern colonies inland in California from statewide surveys, 1997–1999 (See Table 5; map revised from Shuford 2010).

DISCUSSION

Numbers of breeding terns in the interior of California declined steeply from 1997–1999 to 2009–2012. Precipitation was below the long-term mean in the regions where terns nest for 3–4 years preceding the latter period, greatly reducing terns' foraging and nesting habitat. For the Black Tern and Forster's Tern, respectively, statewide inland totals for 2009–2012 were about 49% and 26% of those for 1997–1999. Similarly, the numbers of sites where those species bred were greatly reduced, particularly in northeastern California and the San Joaquin Valley. Because the Salton Sea accounted for such a large fraction of California's inland population, annual totals for the Caspian Tern were greatly affected by the wide variation there.

Still, drought in northeastern California reduced numbers of Caspian Terns breeding in that region at least 10-fold from 1999 to 2009 and, in part, its contribution to the statewide inland total from 68% in 1999 to 1% in 2009.

Continuing or Future Drought Effects

California's current severe drought emphasizes the importance of reliable water supplies for wetlands and flood-irrigated crops that are terns' prime foraging habitats in the interior of the state. Although waterbirds are adapted to periodic droughts, if these are prolonged, populations may drop below some critical threshold. Drought-induced bottlenecks in resources are a serious threat to waterbirds, particularly as overallocation of water and climate change combine to impose longer dry periods (Kingsford et al. 2010, Kingsford 2014). Diversions of water for human use may not only eliminate or lower the quality of foraging habitat when water is scarce but also reduce nesting sites or facilitate predators' access to nesting islands that become connected to the mainland (e.g., Shuford and Ryan 2000). Competition for water will only increase as the human population grows unless water conservation accelerates (MAS 2005).

Since the mid-1990s California's annual precipitation has fluctuated widely, from very wet to extremely dry (Figure 10). Statewide surveys of seven species of colonial waterbirds in the interior of California from 1997 to 1999 (Shuford 2010) took place during a period of well above-average precipitation, whereas the 2009–2012 surveys overlapped with an extended drought that began in 2006–07 (Figure 10). Despite being interrupted in 2010–11 (precipitation 129% of long-term mean), this dry period has so far persisted 4 years beyond the completion of waterbird surveys in 2012 (Figure 10), likely with intensified effects on terns.

The current drought is exceptional from both a short- and long-term perspective. Cumulative statewide precipitation in California during the three winters starting in 2011–12 ranked the second lowest of any 3-year period since records began in 1895 (Seager et al. 2014). Paleoclimate reconstructions, however, indicate the current drought is the most severe in the last 1200 years with severe moisture deficits driven by a combination of reduced precipitation and record high temperatures (Griffin and Anchukaitis 2014). Still, the current drought is not part of a long-term change in California precipitation. Despite a drying trend in California since the late 1970s, there is no appreciable trend to either wetter or drier winters over the full record since 1895 (Funk et al. 2014, Seager et al. 2014).

A lack of long-term data for most populations of waterbirds in the interior of California limits conclusions on the drought's effects, but breeding populations of the three species of terns were greatly reduced from 1997–1999 to 2009–2012. Effects on the Black Tern and Forster's Tern, in particular, likely have been even more severe since 2012 as the extent of shallow-water wetlands and irrigated agriculture used by these terns has continued to shrink. It is unclear, however, if this decrease will prove to be part of a longer-term decline or just a tribulation arising from short-term fluctuations in climate. The latter may be more likely given that over the last 100 years California droughts have recurred on a cycle of about 15 years (St. George

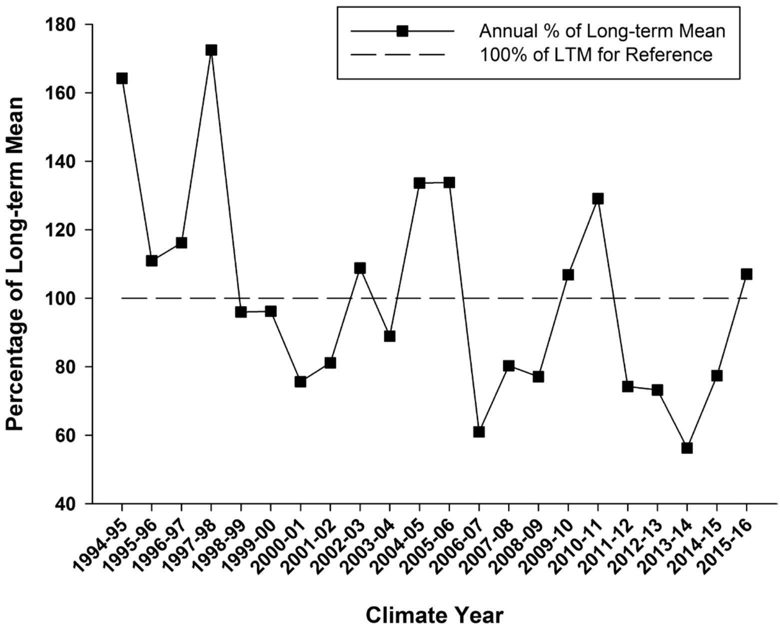

Figure 10. Annual precipitation for the entire state of California, as a percentage of the long-term mean (LTM; n = 121 years), for the climate years (1 July–30 June) 1994–95 to 2015–16. Data from the Western Regional Climate Center (www.wrcc.dri.edu/divisional.html).

and Ault 2011, Dettinger and Cayan 2014, Meko et al. 2014), and waterbird numbers often rebound rapidly (e.g., Earnst et al. 1998). Still, in the 20th century California's climate was more benign than that in almost any comparable period in the last two millennia (Ingram and Malamud–Roam 2013), and patterns of the last century may not persist. Any drought effects compound the loss of >90% of California's historic wetlands (Dahl 1990) and the present severe over-allocation of the state's water resources—current allocations total about five times the state's mean annual runoff (Grantham and Viers 2014).

On the Modoc Plateau, the drought's effects on the Caspian Tern have been offset by the attraction of terns to artificial islands at two sites in the California portion of the Klamath Basin NWR Complex (Sheepy Lake, Lower Klamath NWR; Sump 1-B, Tule Lake NWR); from 2010 to 2014, an average of 385 pairs (range 222–629) nested on them (BRNW 2011–14). This provision of nest sites is part of a much broader effort to redistribute Caspian Terns away from the colony at the Columbia River estuary to other coastal and interior sites in the Pacific states to reduce tern predation on the river's threatened and endangered salmonids (USFWS 2005, Collis et al. 2012). Nesting success at the Klamath Basin sites has been mixed during the recent drought (D. Roby pers. comm.), and it remains to be seen if the artificial islands will increase the tern population of the Modoc Plateau once wet conditions return and islands again become available at other traditional breeding sites. Even if artificial islands boost the regional population, they may not offset an anticipated decline at the Salton Sea, where a decline in water level and increase in salinity are projected to accelerate rapidly after 2017 so that in 5–7 years the sea will no longer sustain fish and the birds, such as the Caspian Tern, that depend on them (Cohen 2014).

Logistical Challenges

Obtaining accurate and repeatable counts of terns and other colonial waterbirds requires survey methods tailored to the species, region, habitat, or site; adjusting methods for variation in habitat with the climate cycle; repeating counts when unfavorable weather delays the onset of nesting; or counting repeatedly through the season for species whose timing of peak nesting varies by year or site (see examples above).

For future statewide inventories, to facilitate comparisons, we recommend using the method of counting most accurate for the species, nest substrate, and time of the season and replicating, as closely as possible, the methods used in 2009–2012. Flexibility is important, however, as modifications may be needed or desirable depending on conditions at the time of an inventory or advances in knowledge or technology that may improve survey accuracy over what is possible currently.

Long-Term Monitoring

Monitoring of waterbirds is crucial for determining their conservation status, detecting population trends, assessing habitat health, and evaluating whether management and environmental change are affecting waterbirds (Kushlan et al. 2002). Frequent or comprehensive monitoring, of terns or other waterbirds, over large regions is often not feasible because of the time and resources required. Therefore any future long-term program for monitoring these birds in California likely will rely on sampling a subset of colonies or habitats. Monitoring breeding waterbirds associated with interior wetlands confronts additional problems, even if only a subset of sites is sampled, because the habitats are ephemeral. This may lead to substantial short-term variation in the number of active colonies, the birds' distribution among the colonies, and overall population sizes, compounding the difficulty of sampling patchily distributed species.

For species breeding both inland and on the coast, monitoring both regions simultaneously would be ideal. If just one of these is monitored (e.g., Strong et al. 2004, this study) it may be unclear whether apparent trends reflect patterns for the entire population or shifts between the coast and interior. Demographic monitoring also may be important to evaluating the factors driving population changes. For example, numbers of Black Terns in Sacramento Valley rice fields were lower in 2010 than in 1998, despite a larger area planted in rice in 2010. Was this because the overall population had been depleted by low reproductive success in prior drought years?

Future Scenarios

It is unclear what effect a changing climate will have on populations of terns breeding in the interior. California's remarkable variation in precipitation (annual totals routinely vary from 50% to >200% of long-term averages) arises from the small number of storms that provide most of the state's precipitation each year (Dettinger et al. 2011, Dettinger and Cayan 2014). To date, evidence for anthropogenic influence on rainfall and atmospheric circulation patterns during the current California drought is equivocal (Funk et al. 2014, Seager et al. 2014, Swain et al. 2014, Wang and Schubert 2014). Likewise, expectations of future precipitation patterns in California remain unclear given differences in climate models and high natural variability (e.g., Deser et al. 2012, Pierce et al. 2012). Such natural fluctuations will intensify or mute the magnitude of effects caused by human actions. Projections are robust, however, for a continued trend toward higher temperatures, expected to increase evaporation and reduce runoff and recharge from precipitation (Cayan et al. 2010) and so further limit the water available for wetlands or flood-irrigated agriculture during droughts. Regardless, given the high level of uncertainty in precipitation projections it may be prudent to hope for the best but plan for the worst. We recommend trying to secure reliable water supplies whenever and wherever possible if these can be used to manage habitats or crops to benefit breeding terns and other waterbirds in both wet and, especially, dry periods. Such planning seems judicious given the relatively high probability of a future multi-decade megadrought (Ault et al. 2014) and that even droughts as long (>200 years), severe, and widespread as those from A.D. 900 to 1350 (Stine 1994, Woodhouse et al. 2010) may recur.

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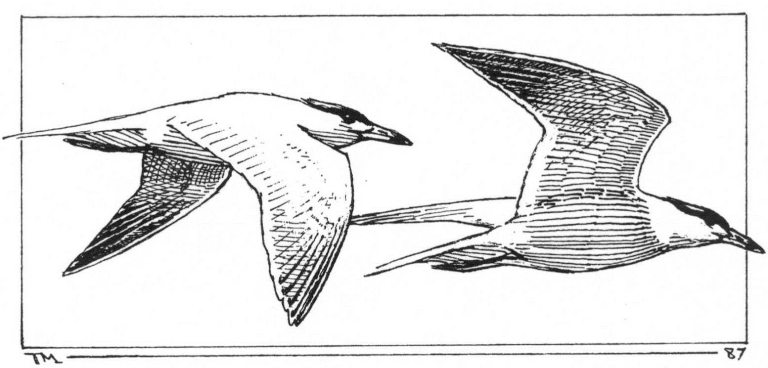

Caspian Terns

Sketch by Tim Manolis