

OSPREY POPULATION INCREASE AND NESTING SUCCESS OVER FIVE YEARS IN CENTRAL INTERIOR CALIFORNIA

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ABSTRACT: From 2020 to 2024 the population of the Osprey (*Pandion haliaetus*) nesting in seven counties in central interior California increased at an average annual rate of 4.5%. Of the 13 to 51 nests adequately monitored annually, the percentage that successfully fledged young (nest success) ranged from 69% to 100% per year, while productivity (number of young fledged per occupied nest) ranged from 1.13 to 1.85. Average annual storage levels at the five major reservoirs were roughly associated with Osprey nesting success and productivity over the five-year period, although the relationship was not statistically significant. The rates of reproductive success and productivity we observed are similar to those since 1975 elsewhere in northern California, where success has remained consistently high. The rate of increase of the central interior population is lower than for most other areas studied since 1975, suggesting that the population, although reproducing at or above a sustainable level, may be reaching a habitat-limited carrying capacity. A rapid recent increase in the Bald Eagle (*Haliaeetus leucocephalus*) population in this region poses a potential threat, but no detrimental effects on the Osprey have been documented yet.

Since the 1980s, the Osprey (*Pandion haliaetus*) has extended its breeding range into the central portion of California's Central Valley and Sierra Nevada foothills ("central interior California"; Airola and Pandolfino 2022). In 2021 and 2022, we located nests in this region, monitored their success and productivity, and described the nesting habitat (Airola and Estep 2022, 2023). Annual nesting success (percent of occupied nests that fledged young) averaged 71% and 76% in those two years, and productivity averaged 1.27 and 1.44 young fledged per occupied nest, which are above rates sufficient to maintain or increase Osprey populations (Henny and Wight 1969, Spitzer and Poole 1980).

The Osprey is widely recognized as an indicator of environmental health, especially with respect to the prevalence and effects of pesticides and other organic chemicals (Ames and Mersereau 1964, Henny 1983, Grove et al. 2008, Lazarus et al. 2015). Since 1972, when the insecticide DDT was banned in the U. S., the species has recovered and increased in California (Gould and Jurek 1988, Brake et al. 2014, Airola and Pandolfino 2022) and elsewhere (Henny 1983, Bierregaard et al. 2016). Nonetheless, some problems with chemical contaminants persist locally (e.g., in Chesapeake Bay; Rattner and McGowan 2007), and continued monitoring of Osprey populations has been recommended as an indicator of environmental health (Henny et al. 2010). In addition, the hypothesis suggested by our previous results, of an effect of climate on water storage and thus on the Osprey's habitat and reproductive health (Airola and Estep 2022, 2023), warrants testing.

For a fuller indication of population status in this region, we acquired additional data on changes in the number of Osprey territories and on

reproduction in central interior California in 2023 and 2024 and compiled unpublished information from our study area from 2020. Here, we report on population changes and reproduction over the full 2020–2024 study period and compare them to those previously described in the smaller dataset from 2021 and 2022. In our 2021 and 2022 studies, we showed that reproductive success and productivity varied with the type of water body in the territory. At reservoirs, these measures differed by year. From 2021 to 2022, the reservoirs' levels changed, as affected by annual precipitation and water management. Presumably, these changes influenced Osprey reproduction through their effects on the extent of foraging habitat, prey populations, or travel distances to nests (Airola and Estep 2022, 2023). Therefore, with five years of data, we also evaluated success at different water-body types and at reservoirs whose storage level varied from year to year.

METHODS

Study Area

In 2023 and 2024 we surveyed Ospreys in the same 30,000-km² area in central interior California covered in 2021 and 2022 (Airola and Estep 2022, 2023). The area includes lands along the Sacramento River, port of West Sacramento, and Sacramento Ship Channel within Sutter, Yolo, Sacramento counties, and in the foothills on the western side of the Sierra Nevada within Amador, San Joaquin, Calaveras, and Tuolumne counties (Figure 1). In the foothills, we monitored Ospreys at Camanche, Pardee, New Hogan, New Melones, and Tulloch reservoirs. Other nests were associated with smaller ponds storing water for livestock and irrigation.

Data Acquisition

Our methods followed previous monitoring of this population (Airola and Estep 2022, 2023). We identified nests year round, but especially from February to July when adults were attending. We found Osprey nests while driving roads during extensive field work on other species in this region, as well as by searching for them from roads near rivers, reservoirs, and areas with stock ponds, and scanning inaccessible shorelines with a scope. We queried resource managers at reservoirs, and searched reports at <https://eBird.org>. Detection was facilitated by most nests being situated on utility poles and other artificial structures, often near roads. Despite extensive effort, we almost surely did not identify all nests in our study area because of lack of access to private lands, lack of road access, and vegetative and topographic screening.

We checked nests known within our study area 2–5 times annually over the nesting season to verify occupancy, search for new or previously undetected nests, and determine nesting stage and reproductive success. In some portions of the study area, our search area and efforts varied slightly from year to year. Therefore, we quantified annual changes in numbers of nesting territories by carefully identifying which newly discovered nests were newly established (i.e., appeared in areas carefully searched in past years) versus those which may have been older nests that had been located only as a result of changes in the area surveyed.

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FIGURE 1. Osprey study area in central interior California showing major water bodies surveyed.

To avoid bias (Steenhof 1987), we calculated reproductive success only on the basis of nests that we or others (e.g., ebird.org) observed adults attending before the end of April (“adequately monitored”). We considered nests successful in fledging young when we estimated that young were >80% of adult size (roughly 6–7 weeks from hatching).

Analysis

To determine the rate of population change, in each year we counted territories that we verified to be newly established (i.e., at sites that had been previously surveyed but lacked nests) versus abandoned (where previous nest sites were not used, and no new nests were established within several hundred meters. Thus newly discovered nests at sites that we had overlooked or not previously surveyed were not incorporated into the trend analysis. Next, we subtracted the total number of abandoned territories from the number of newly established territories to determine the net change in the number of territories each year. We then divided the net change in number of territories by the number of territories found in the previous year in the same surveyed

area, to calculate a percent change in the breeding population, and calculated the average annual rate of change across all years. We believe that this method is not materially confounded by shifts to alternative nests in portions of the territory not visible to us because, within a territory, Ospreys used the same nest site during 142 (97%) of 146 nesting attempts in consecutive years.

We compared measures of reproductive success (nest success and productivity) with reservoir levels (percent of average annual storage on 1 May) to test the hypothesis that higher reservoir levels should increase reproductive success. The underlying rationale for this hypothesis is that lower reservoir levels reduce the extent of foraging habitat, increase travel distances between nests and foraging areas, and may affect prey populations, thereby reducing provisioning efficiency (Airola and Estep 2022, 2023). For each of the five major reservoirs (Pardee, Camanche, New Hogan, New Melones, and Tulloch), we calculated each year's storage (available at <https://cdec.water.ca.gov/reportapp/javareports?name=RES>) as a percentage of average annual storage. We used GraphPad (<https://www.graphpad.com/quickcalcs/linear1>) to calculate regression statistics to test for significance of the relationships (slopes), using the *F* statistic at a *P* value of 0.05.

RESULTS

Population Change

We recorded 24 occupied nesting territories in a limited survey in 2020. With increased effort, these numbers grew to 39 in 2021 and 42 in 2022, respectively (Airola and Estep 2022, 2023), 48 in 2023, and 62 in 2024 (Table 1). Most of the increase resulted from discovering nests in portions of the study area that were not surveyed in previous years. In 2024, the year in which we found the most occupied nests (62), 56% (35) were at reservoirs, 29% (18) were along the Sacramento River and the adjacent port of Sacramento and ship channel, and 15% (9) were at stock ponds.

The number of territories that we verified to be newly established (i.e., nests constructed at sites that were unoccupied during previous surveys) varied from one to six annually, while the number of territories that were

TABLE 1 Annual Change in Osprey Population in Central Interior California, 2020–2024

Territories	Year				Annual average
	2020–2021	2021–2022	2022–2023	2023–2024	
Total located and resurveyed in subsequent year	24	37 ^a	42	48	42
Verified as new in subsequent year	1	1	6	6	3.5
Verified as abandoned in subsequent year	0	1	4	2	1.8
Net annual increase	1	0	2	4	1.8
Percent increase	4.2	0.0	4.8	8.3	4.5

^aTwo of 39 nests monitored in 2021 were not monitored in 2022.

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TABLE 2 Osprey Nest Success and Productivity in Central Interior California, 2020–2024

Nest category and results	Year					Total
	2020	2021	2022	2023	2024	
Total occupied	24	39	42	48	62	215
Occupied, adequately monitored	13	34	37	46	51	181
Successful	13	24	28	32	35	132
No. young fledged	24	42	52	52	69	239
Percent nests successful	100	71	76	70	69	73
No. young/monitored nest	1.85	1.27	1.41	1.13	1.35	1.32

abandoned varied annually from zero to four (Table 1). Overall, the Osprey population increased from 2020 to 2024 by up to four territories annually, equating to an average population increase of 4.5% (Table 1).

Reproductive Success

Over the five years we monitored reproductive success, nest success averaged 73% and ranged from 69% to 100% (Table 2). Productivity averaged 1.33 and ranged from 1.13 to 1.85 young per occupied nest. Over the five years of our study, average nest success and productivity were highest at nests along the Sacramento River and port of West Sacramento, intermediate for nests at reservoirs, and lowest for nests at smaller ponds (Table 3). Reservoirs, however, were more successful and productive than river and port nests in 2023 and 2024. Success and productivity declined dramatically at nests near ponds during the drought year of 2021, and nests at ponds were the least productive during each of the study’s five years. The relative reproductive success at various water-body types corresponded to net changes in numbers of territories over the five years, with more territories gained along the Sacramento River (+5), fewer at reservoirs (+3), and a slight loss at ponds (–1).

Regression analysis suggested that the success and productivity of nests at the five major reservoirs were generally associated with average annual storage levels (Figure 2). The relationship between storage and percent nesting success approached significance (slope = 0.46, $R^2 = 0.63$, $F = 5.17$, $P = 0.11$),

TABLE 3 Osprey Reproductive Success at Three Types of Water Bodies in Central Interior California

Reproduction metric	Water-body type	Year					Annual average ^a
		2020	2021	2022	2023	2024	
Nest success (%)	River/port	100	89	100	69	61	77
	Reservoir	100	72	56	71	80	73
	Pond	100	33	71	56	50	54
Productivity (no. young/occupied nest)	River/port	2.0	1.7	2.0	1.1	1.3	1.45
	Reservoir	1.7	1.3	1.3	1.3	1.5	1.37
	Pond	1.0	0.3	1.0	0.9	1.1	0.81

^aAverage weighted by number of nests monitored each year: river/port = 4, 6, 10, 18, 18 nests; reservoir = 7, 18, 16, 21, 25 nests; pond = 2, 10, 8, 9, 8 nests.

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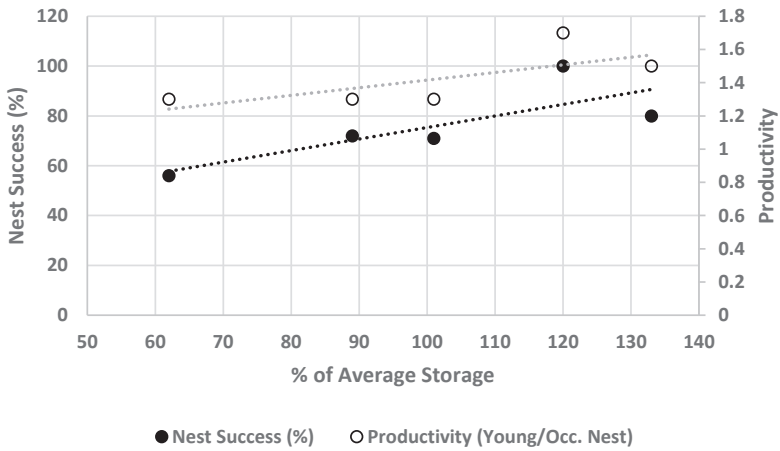


FIGURE 2. General relationship between reservoir storage (percent of average annual storage on 1 May) and Osprey nesting success and productivity at the five major reservoirs in central interior California. Results are suggestive but not statistically significant.

while the relationship with productivity was suggestive but not significant (slope = 0.0046, $R^2 = 0.50$, $F = 3.025$, $P = 0.18$).

DISCUSSION

Results from three additional years of monitoring (2020, 2023, 2024) are largely consistent with results we previously reported for 2021 and 2022 (Table 2; Airola and Estep 2022, 2023). Nest success was near or above 70%, productivity was consistently at or above levels associated with a healthy population (i.e., 0.8–1.1 young per occupied nest; Henny and Wight 1969, Spitzer and Poole 1980), and the population increased by an average of 4.5% annually (Table 2). Thus our 2020–2024 results confirm earlier conclusions (Airola and Estep 2022, 2023, Airola and Pandolfino 2022) that the Osprey population in central interior California is reproducing at a sustainable rate.

The modest rate of increase in the Osprey population in central interior California, while productivity averaged 1.33 young per occupied nest, may indicate that relatively high reproductive rates are required to maintain a stable Osprey population in this region, or it could indicate that this region is providing emigrants to populate surrounding areas. Average distances of the Osprey's dispersal from natal sites to breeding sites have been reported as 14 km in Michigan (Postupalsky 1989) and 47 km in Finland (Saurola 1995). Our results also confirmed our observations from 2021 and 2022 that nest success and productivity at stock ponds were below those of reservoirs and the Sacramento River and port.

Information on the Osprey's reproductive success, productivity, and population trends in northern California since the 1960s (Table 4) provides context for interpreting our results. From 1969 to 1975, around the time DDT use was

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TABLE 4 Reproductive Success and Population Trends for Ospreys Monitored at Various Sites in Northern California, 1969–2024

Location	Years	Average nest success	Average productivity	Average annual population trend (%)	Sources
Lassen and Plumas counties	1969–1971	54%	1.02	15%	Kahl 1972, Henny et al. 1978, Airola and Shubert 1981
Klamath National Forest	1969–1974	61%	1.03		Gale and Forbis 1974, Henny et al. 1978
North Coast, Humboldt and Del Norte counties	1971–1972	65%	1.19		French 1972, Henny et al. 1978
Usal Creek, Mendocino Co.	1971	43%	0.50		French 1972, Henny et al. 1978
Shasta Lake, Shasta Co.	1969–1975		0.82		Henny et al. 1978
Trinity (Clair Engle) Lake, Trinity Co.	1972–1975		0.50		Henny et al. 1978
Lake Almanor, Plumas Co.	1975–1980	59%	1.35	+11%	Airola and Shubert 1981
Kent Lake, Marin Co.	1981–2000 2004–2021		1.40	+10% –8%	Evens and Brake 2022
Clear Lake, Lake Co.	1992–2001		1.44	+7%	Anderson et al. 2008
Mare Island, Napa and Solano counties	1999–2007 2008–2013			+16% +23%	Brake et al. 2014 Brake et al. 2014
San Francisco Bay area ^a	2013	65%	1.70	+31%	Brake et al. 2014
San Francisco Bay area ^a	2014–2021			+11%	Evens and Brake 2022
Mono Lake, Mono Co.	2004–2012	73%	1.32	+33%	Fields and Pagel 2016
Central interior California	2020–2024	73%	1.33	+4.5%	Airola and Estep 2022, 2023; this study

^aSolano, Contra Costa, Alameda, and San Francisco counties.

banned, the Osprey’s reproductive rates and population increases in northern California were lower than in subsequent years, with one exception. Along the north coast, reproduction during this period remained high (French 1972, Henny et al. 1978), presumably because lower amounts of pesticides were used in this forest-dominated region with a sparse human population.

The high reproductive success we documented in central interior California is consistent with the results of other studies in northern California

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since 1975 (Table 4). Measures of reproductive success within central interior California are higher than in most areas studied before 1975 and have been associated with a gradual population increase and range expansion over the succeeding decades (Airola and Pandolfino 2022). The only reported exception since 1975 is at Kent Lake, where the Osprey population increased through about 2000, but then declined after a pair of Bald Eagles (*Haliaeetus leucocephalus*) began nesting there in 2004 and interfered with Osprey nesting (Evens and Brake 2022; Table 4). The 4.5% rate of population growth in central interior California is low compared to other populations studied from the 1990s to the 2020s (Table 4), suggesting that the species may be reaching habitat saturation in this region, and that further growth will be modest.

Despite the recent population increase and high reproductive success of central interior California's Osprey population, several potential threats persist. A recent and continuing increase in the Bald Eagle population in this same region (Airola et al. in press) may portend conflicts between the two species and possible declines in the Osprey population, as Evens and Brake (2022) noted at Kent Lake (Table 4). To date, we have observed minor conflicts between the species during our brief surveys within the study area, but no displacement of Ospreys from nesting territories. In our study region, both species nest at similar distances from waters suitable for foraging (averages of 0.56 km for the Osprey, $n = 33$, Airola and Estep 2022; 0.37 km for the Bald Eagle; $n = 39$; Airola et al. in press). Ospreys are generally more tolerant of human activity than are eagles (Gerrard et al. 1976, Washburn 2014), and in central interior California Ospreys tend to nest closer to roads than do Bald Eagles ($\bar{x} = 0.1$ km and 1.2 km, respectively; Airola and Estep 2022, Airola et al. in press). This difference may contribute to the species' coexistence, although in some areas eagles are known to have adapted to tolerate increased levels of human disturbance (Newbrey et al. 2005, Airola 2007).

The general (although not statistically significant) relationship between reservoir levels and reproductive success may indicate some sensitivity to the warming and drying climate (Kadir et al. 2013). The high proportion of nests found at reservoirs and stock ponds (85%), which are susceptible to drought, reduction of the snowpack in the Sierra Nevada, and a resulting change in the timing of runoff (Diffenbaugh et al. 2015), combined with the dramatic drop in productivity at ponds during the drought year of 2021 (Airola and Estep 2022, 2023), warrants concern regarding potential effects of climate change.

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