Habitat use and reproductive success of ospreys in central interior California

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FULL RESEARCH ARTICLE

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Abstract

The osprey (*Pandion halieatus*) declined globally in the mid-late 20th century due primarily to pesticide contamination that reduced reproduction. The species has recovered through much of its range, and its range in California has increased. The species has received limited attention in recent decades, despite recommendations that it be monitored as an environmental indicator. In 2021, we located a sample of 39 osprey occupied nests near the Sacramento River and at reservoirs and small ponds in central interior California and determined habitats used and reproductive success. Nearly one-third of nests were located within 100 m of waterbodies and 88% were within 1000 m. The median distance of nests from roads was 51 m. Thirty-four (87%) of occupied nests were on anthropogenic sites, including utility poles, poles erected for ospreys, transmission towers, light poles, and port structures. Only five nests (13%) were in trees and snags. Nearly half (48%) of nests were on platforms constructed on utility poles and on poles erected for ospreys, both placed to protect electrical systems. Water levels in reservoirs, and some small farm ponds, were lower than average in 2021 due to drought, while the Sacramento River and Port were less affected. Twenty-four (71%) of 34 adequately monitored nests were successful in fledging at least one young. Productivity averaged 1.27 young/occupied nest, suggesting a healthy population. Reproductive success differed significantly among nests at different water body types, with river-port, reservoir, and pond sites exhibiting high, moderate, and low productivity, respectively. Our results document a range expansion into central interior California, presumably in response to reduced pesticide levels, reservoir creation, and availability of anthropogenic nest sites. Results also suggest that drought, and thus predicted warming and drier climate, may disproportionately affect populations nesting at non-riverine habitats by reducing the amount foraging area and increasing the distance from nest sites to foraging areas.

Key words: California, drought, habitat use, nest site, nest platform, osprey, *Pandion halieatus*, reproductive success, reservoir

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Introduction

The osprey (*Pandion halieatus*), a widely distributed fish-eating raptor, suffered substantial population declines through much of its range during the 1960s and early 1970s as a result of organic pesticide accumulation (Ames and Mersereau 1964; Henny 1983; Bierregaard et al. 2016). Population recovery began following the banning of dichlorodiphenyltrichloroethane (DDT) in 1972 (Spitzer and Poole 1980; Henny 1987; White 1994; Monson 1996; Bierregaard et al. 2016). Increases in population size and geographic range continued in response to reduced human persecution, adoption of human structures as nesting sites, and creation of new aquatic habitat through reservoir construction (Henny et al. 2010). The species remains susceptible to declines in some areas from toxins, reduction in food availability, and drought (Bierregaard et al. 2016).

The population history of osprey in California generally follows the pattern elsewhere. Little detailed information exists on population sizes prior to and during the DDT-era. Due largely to persecution from fishermen, the nesting osprey population on the southern California mainland was eliminated by the 1910s and was nearly eliminated from the Channel Islands by the 1930s (Kiff 1980). Grinnell and Miller (1944) described the species as “originally common and widespread” in the state, but “reduced in number, and known nesting stations few,” without suggesting a cause for the decline. In the late 1970s and 1980s, the species distribution was limited to the coastal area north of San Francisco Bay and interior rivers and lakes in the Cascades region (e.g., Kamath River, Shasta and Eagle Lakes, Lake Almanor, and nearby waterbodies), with only a handful of records for the rest of the state (Henny 1983; Evens 1992).

Surveys conducted after the DDT-era in California documented improved reproductive success, increased populations at known breeding locations, and expansion of breeding to areas outside the previous geographic range (Henny et al. 1978; Airola and Shubert 1981; Gould and Jurek 1988; Anderson et al. 2008; Fields and Pagel 2016). Despite the species’ low dispersal distance from existing nesting areas (Poole 1989; Postupalsky 1989), range expansion has continued to occur, with the species occupying extensive areas that were formerly unoccupied or supported few breeding ospreys, including San Francisco Bay and nearby reservoirs, the central and southern coast region, the Coast Range, and Sierra Nevada (Gould and Jurek 1988; Evens 1992; Unitt 2004; Kerr 2007; Brake 2018; eBird 2021). Other than colonization of Sacramento County since the 1980s (Pandolfino et al. 2021) and eBird records, there is no documentation of the colonization of the Central Valley and adjacent Sierra Nevada foothills, which may contribute to under-reporting of the breeding range in this area (e.g., Wheeler 2018).

Monitoring of osprey populations, including apparently healthy ones, has been recommended to serve as a baseline indicator of environmental contamination and health (Henny et al. 2010). The apparent health of the osprey population since the DDT era, however, has reduced research and management attention in many areas, including California. Published studies on sizes and reproductive rates of populations in California since the 1980s are lacking, except at Clear Lake, Lake County (Anderson et al. 2008) and for recently established populations at Mono Lake, Mono County (Fields and Pagel 2016) and San Francisco Bay (Brake et al. 2014; Brake 2018). Documentation of reproductive rates and nest site characteristics of ospreys in the expanded portion of their range is needed for management purposes, including understanding the potential effects of climate change and addressing conflicts with the nesting use of structures erected for electrical transmission and distribution and for communications.

Study objectives were to locate a sample of osprey breeding sites in central interior California, describe nesting and foraging habitat characteristics, and evaluate reproductive success of the population as a whole and those at different water body types.

Methods

Study Area

We conducted osprey surveys in central California along the Sacramento River and at the nearby Port of Sacramento and in the foothills on the western side of the Sierra Nevada on lands at 10–450 m elevation (**Fig. 1**). The survey area encompassed an 82-km river section of the Sacramento River (river miles 50–132[1]) in Sacramento, Yolo, and Sutter counties and the Port of Sacramento in West Sacramento, Yolo County. In the Sierra foothills, surveyed areas included public roads and public recreation areas within Amador, Calaveras, San Joaquin, and Tuolumne counties, especially areas near major water supply reservoirs and scattered smaller water impoundments. Major reservoirs in the Sierra foothills portion of the study area were Camanche Reservoir in San Joaquin and Calaveras counties, New Hogan Reservoir in Calaveras County, and New Melones and Tulloch reservoirs, both of which are in Calaveras and Tuolumne counties.

Figure 1. Nest locations and major water bodies within Sacramento River and central Sierra Nevada foothills study area.

Land cover along the Sacramento River consists of sparse to dense cottonwood-dominated (*Populus* spp.) riparian woodland on the waterside of levees surrounded by agriculture and commercial and residential development (Estep 2020). Foothill areas support primarily Mediterranean annual grassland and oak woodland (*Quercus* spp.), with lesser amounts of chaparral, agricultural lands (irrigated pasture, vineyards), wetlands, and rural residential properties (Airola et al. 2015). Much of the land surrounding Tulloch Reservoir is densely developed for residential and recreational use.

Survey Methods

We located nests while driving public roads and walking short distances from roads in public use areas near rivers, reservoirs, and ponds during April through mid-July in 2021. Roads and survey areas were selected non-randomly based on previous knowledge of nest locations and the presence of different types of suitable aquatic habitat (rivers, reservoirs, farm ponds). Some nests were identified from eBird records (**eBird** 2021) and then surveyed. We surveyed by scanning for nests on utility poles and towers, snags (i.e., standing dead trees), and live trees. We monitored nests from the best available vantage points using 8x binoculars and a 15–60x spotting scope. Nests reported do not represent complete surveys of the entire region or any one area but rather a sample of nests from throughout the region.

We described nests based on their primary characteristics: live trees, snags, electrical transmission line towers, wooden utility poles, poles erected for ospreys (often near utility poles to discourage nesting there), and other human structures (cranes; port facilities; and cell, television, and weather towers). We also noted if the site supported a man-made nest platform (i.e., a structure erected to contain and support the nest).

We described water conditions during the 2021 drought at the four major reservoirs by characterizing the percent of average reservoir storage volume during late July and early August (**CDWR** 2021; J. Jones, pers. comm.). We measured the distance from the nest to the nearest water body >2 ha in size (considered a minimum size that could support a nesting osprey) and to the nearest paved public road from Google Earth Pro. This imagery was taken during 2018–2020, so distances to water during 2021 for nests located near reservoirs were underestimated because reservoirs were at lower elevations due to drought conditions (see **Results**).

We detected most nests by directly observing them rather than from the presence of ospreys in an area. We characterized nests that were discovered after 20 June, the approximate date when the first young fledged from a nest in the study area, as occupied if their condition indicated that they had been repaired during the season. We excluded these late-discovered nests in calculating nesting success, due to uncertainty as to whether the nest had failed or successfully fledged young. This method avoids overestimating reproductive success that may result from excluding nests that failed before they were detected (Brown et al. 2013).

We monitored nests from when they were discovered at least until young were estimated to be at least 80% grown (and thus assumed to have fledged successfully) or until nests failed. We recorded activity of adults (standing on nest or adjacent trees, in incubation or brooding posture, shading young) to interpret the nest stage before young were visible in the nest. We counted the number of nestlings and characterized their ages based on their size (% fully grown) and plumage characteristics (Bierregaard et al. 2016).

We use standard terminology for various nest stages and to describe reproductive success (Postupalsky 1977; Steenhof and Newton 2007). An *occupied nest* had adults attending it, including nest-building and nest defense. An *active nest* progressed to the egg-laying stage. Because we were never able to see eggs in the nest, we considered nests active if adults were seen in the brood position or young were present. Nests were *successful* if they fledged at least one young. Reproduction was characterized as the number of young per occupied and successful nests. We use the terms *nesting success* to describe the percent of nests that were successful and *productivity* to describe the number of young produced per occupied nest.

At some nests, we could only acquire partial information on occupancy, activity, nesting success, and numbers of young fledged due to timing of first surveys and visibility limitations. Therefore, sample sizes differ for reporting of various parameters. We attempted to ascribe the causes of failure for unsuccessful nests. In addition to nest collapse, we assumed that disappearance of young from nests was a result of predation, and observation of all young dead in the nest was a result of exposure or starvation.

We assigned nests to three water body classes to test for difference in nesting success and productivity: 1) the Sacramento River and Port, 2) reservoirs, and 3) smaller ranch and farm ponds. We used the Social Sciences Statistics (**https://www.socscistatistics.com/**) to test for differences in nest success using the chi-square (χ^2) test statistic and for differences in productivity using the Kruskal-Wallis statistic (H). Differences were considered statistically significant at $P < 0.05$.

Results

We located 41 nests in the 2021 breeding season (**Fig. 1**), 39 of which were verified to be occupied and 37 of which were determined to be active. Most occupied nests were associated with reservoirs, including Comanche (8 nests), New Hogan (2), New Melones (7), and Tulloch (4), although river, streams, and small ponds also occurred near some of these nests. Other nests were at widely scattered small ponds (7), the Sacramento River in Yolo, Sacramento, and Sutter counties (10), and the Port of Sacramento and associated Deep Water Ship Channel (2). Nest distance to a water body >2 ha in size averaged 562 m (median = 182 m), with 34% of nests within 100 m and 88% of nests within 1,000 m of water, and the farthest nest 6,170 m away (**Fig. 2**). Nests were located an average of 108 m from a public road (median = 51 m).

Figure 2. Nest support structures used by ospreys in central interior California in 2021.

Thirty-four (87%) of the 39 occupied nests were on anthropogenic sites (**Fig. 3**). Nearly half of nests (45%) were on utility poles (**Fig. 4**) and 15% were on "osprey poles" placed specifically as nest supports, mostly to discourage use of utility poles (P. Sanders, pers. comm.). The five metal communications towers included two cellular telephone towers, two television transmission towers, and one weather station. The transmission towers supported high voltage electrical lines. Light poles were at a baseball field and rodeo arena at the Calaveras County Fairgrounds. The structures at the Port of Sacramento include an apparently abandoned crane and a steel structure. Two nests were in live blue oaks (*Quercus douglasii*) at the Glory Hole Recreation Area adjacent to New Melones Reservoir, and three were in snags, including a gray pine (*Pinus sabiniana*) at Glory Hole, and one each were in a Fremont cottonwood (*Populus fremontii*) and western sycamore (*Plantanus racemosa*) along the Sacramento River in Yolo County.

Figure 3. Numbers of osprey nests at various distances from a waterbody larger than 2 ha within

central interior California.

Figure 4. Osprey nest on electrical distribution pole at the I Street Bridge along the Sacramento River in Sacramento, CA. Photo Credit: © Lisa C. Alvarez

Nineteen nests (48%) were placed on artificial platforms specifically designed to support a nest, including 12 nests on raised platforms constructed on modified utility poles and one on a transmission tower that were installed by Pacific Gas and Electric Company to protect the electrical lines after nests were established there (M. Best, pers comm.). All six osprey poles with nests also had nest platforms. Most nest platforms consisted of plastic tubs; one was a flat plastic plate, and several were wooden platforms.

Water conditions at reservoirs were lower than the seasonal average (**Table 1**), reflecting the 2021 drought condition in which only 45% of average annual precipitation occurred in central California (CDWR 2021). Although some smaller stock ponds used by ospreys were substantially diminished in size during 2021, presumably by drought, the majority of ponds remained full, likely from irrigation deliveries or pumping (D. Airola, personal observation). Water elevations on the Sacramento River and Port of Sacramento are generally stable from year-to-year because of releases from upstream storage to manage flows and maintain water quality in the Sacramento-San Joaquin Delta and because of tidal influence at least as far upstream as the City of Sacramento (CSWRCB 2021; NOAA 2021).

Table 1. Water storage conditions at four reservoirs surveyed for ospreys in late July and early August 2021 compared to average storage.

Reservoir	Annual average	2021	% Annual average
Camanche	301,660	177,420	59%
New Hogan	151,492	113,619	75%
New Melones	1,656,004	1,242,003	75%
Tulloch	65,157	65,157	100%

Reproductive success could be determined for 34 of 39 occupied nests (although number of young produced could only be determined for 33 nests). Across all sites, 24 (71%) of monitored nests successfully fledged at least one fledgling (**Table 2**). Nesting success was highest at sites near the Sacramento River and the Port of Sacramento, intermediate at sites near reservoirs, and substantially lower at sites near smaller farm ponds (**Table 2**). The 33 adequately monitored nests produced a total of 42 young, for an average reproductive rate of 1.27 young per occupied nest and 1.75 young per successful nest (i.e., 42 young/24 successful nests). Productivity also varied substantially at different water body types, with high, moderate, and low production at river/port, reservoirs, and ponds, respectively (**Table 1**). Differences among water body types were significant for the number of young produced ($H_{2d.f.} = 6.164$, $P = 0.046$) and slightly below statistical significance for nesting success ($\square_{2d.f.} = 5.26$, $P = 0.072$).

Table 2. Reproductive success and productivity at osprey nests near different water body types in central California, 2021.

Water body type	No. nests where success determined	No. nests successful	% of nests successful	No. nests where young counted	Young produced	Average no. young/nest
Ponds	6	2	33%	6	2	0.33
Reservoirs	18	13	72%	17	23	1.35
River/Port	10	9	89%	10	17	1.70
All sites	34	24	71%	33	42	1.27

Causes of nest failure were evident or inferred for six of 10 failed sites. Nest collapse killed nestlings in two nests, one in a live tree and one in a snag, both at Glory Hole Recreation Area, New Melones Reservoir. In both cases, a major branch supporting the nest broke, and most of the nest and its contents fell to the ground. Single nestlings were found dead in the fallen debris at each nest, and one injured nestling died at a rehabilitation facility (P. Sanders, pers comm.). Two additional nesting failures were attributed to nest predation, and two to exposure or starvation. Potential predators seen or known to occur near sites where predation occurred include the bald eagle (*Haliaeetus leucocephalus*), great horned owl (*Bubo virginianus*), common raven (*Corvus corax*), and raccoon (*Procyon lotor)*.

The 30 nests on anthropogenic sites were significantly more successful (80%) than on the four adequately surveyed sites on natural snags and trees, all of which failed ($\chi^2_{1d.f.}$ = 10.20, P = 0.001). Nests on platforms constructed on osprey poles and utility poles had slightly lower nesting success (67%, n =12) than those on other anthropogenic sites (88%, n = 17), but this difference was not statistically significant ($\chi^2_{1d.f.}$ = 1.17, P = 0.28). Similarly, productivity on platforms (mean = 1.08) was lower than at other anthropogenic sites (mean = 1.71), but this difference was not statistically significant ($H_{1d.f.}$ = 2.33, P = 0.13).

Discussion

Although our surveys were not comprehensive, they document that ospreys have widely colonized and increased in abundance in the central portion of the Central Valley and Sierra foothills, where they were largely absent as recently as the 1980s. Colonization there appears to be tied to the presence of water bodies and availability and adoption of a wide variety of anthropogenic nesting substrates, as has been widely noted for the species (Henny and Kaiser 1996; Anderson et al. 2008; Bierregaard et al. 2016). Although nests on utility and osprey poles are likely slightly more visible than those in live trees, the preponderant use of these anthropogenic sites among nests we located (87% of all nests) nonetheless attests to their importance in the region. The program to modify electrical poles and towers and install osprey poles to protect transmission and accommodate osprey nests appears to have been highly successful in maintaining osprey use and likely has contributed to osprey increase in the region, as was noted at Clear Lake (Anderson et al. 2008).
Data showing higher reproductive success on nests on anthropogenic structures than on those in live

trees or snags in this region (notwithstanding the low sample size of only four adequately monitored natural sites) are consistent with findings generally (Bierregaard et al. 2016; but see Airola and Shubert 1981). Lower nest success in trees and snags is generally attributable to higher rates of nest loss (as we found), wind, or falling of the nest tree. The lack of significant differences between reproductive success and productivity at nesting platforms installed for ospreys and other anthropogenic sites indicates that platforms are not directly enhancing reproduction. Nonetheless, they are likely to be beneficial by reducing conflicts with electrical transmission, which otherwise would require other measures to eliminate osprey nesting at these sites.

Population modeling from band return data of ospreys banded in the northeastern U. S. determined that reproductive rates of 0.95–1.30 young per breeding female were required to maintain a stable population (Henny and Wight 1969). More recent data over 1992–2006 from California showed that production of an average of 1.44 young/occupied nest was associated with an average annual 7% increase in the nesting population at Clear Lake (Anderson et al. 2008). Average annual productivity was 1.45 young/occupied nest in an increasing population in northern San Francisco Bay over 2012–2018 (Brake 2018) and 1.42 young/occupied nest over 2004–2012 at a stable or increasing population of 4–8 pairs at Mono Lake (Fields and Pagel 2016).

The 2021 average productivity of 1.27 young per occupied nest within the central interior California study area suggests a generally healthy level of reproduction, especially in a drought year with lower-than-average water levels in reservoirs and in some ponds. Results from a single year, however, provide an incomplete basis from which to assess population health, as fluctuation in reproductive rates is typical in osprey populations (Airola and Shubert 1981; Anderson et al. 2008; Bierregaard et al. 2016; Fields and Pagel 2016; Brake 2018). Thus, data are needed for additional years to fully determine population health. The species' expansion into the region over the last 40 years and its relative abundance, however, suggests that the population has been healthy overall during this period.

The gradient of reproductive success—high at riverine and port nests, moderate at interior reservoirs, and low at areas with smaller ponds—suggests a possible drought effect, as reservoirs and ponds are more affected by drought than the Sacramento River and Port. This effect could result from reduction in available foraging habitat or increased travel distance from nests to drawn-down foraging areas. Reproductive data from average and wet years would help clarify whether drought has a substantial effect on reproduction at reservoirs and ponds. The results suggest the possibility that the expected increase in drought conditions under climate change (Diffenbaugh et al. 2015) could pose a threat to the osprey population, especially in more susceptible non-riverine areas.

The potential effect of increased spring and summer temperature on food provisioning and resulting reproductive success deserves exploration. Peak daily temperatures are trending upward since the mid-1980s (Kadir et al. 2013) which is likely to continue (Diffenbaugh et al. 2015). Although we did not rigorously monitor nest behavior, adults were frequently seen shading nestlings on hot days, especially at interior (non-riverine) sites. Although ospreys regularly shade young in nests (Levenson 1979), if hotter temperatures require adults to spend more time shading nestlings, the reduced time for provisioning young could affect reproductive success.

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