REPRODUCTIVE SUCCESS OF OSPREY *PANDION HALIAETUS CAROLINENSIS* IN AN URBAN NESTING AREA IN KINO BAY, SONORA, MEXICO

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ABSTRACT

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The Osprey *Pandion haliaetus* is a cosmopolitan species, with both migratory and resident populations. Its reproductive success helps us identify environmental changes in its habitat. Therefore, this study evaluated this species' reproductive success in the urban setting of Kino Bay and Laguna La Cruz, Sonora, Mexico, over four breeding seasons (2017–2020). A total of 33 nests were monitored, of which 22 were active for at least one season. All active nests occurred on anthropogenic structures, such as power line poles. Data, including egg, chick, and fledgling counts, and mortality, hatching, nesting, and reproductive success rates, were recorded. During the four seasons, a total of 56 nest clutches, 164 eggs, 121 chicks, and 91 fledglings were recorded. Results indicated that artificial structures did not negatively impact reproductive success. The most common clutch size was three eggs, and larger clutches (three or four eggs) showed higher success rates for hatching and nesting. Higher productivity was observed during the 2018 and 2019 seasons, with 2.07 and 2.00 fledglings per active nest, respectively. These records coincide with seasons when the average maximum temperature was lower during the incubation and chick-rearing period (February to May). Variations in reproductive parameters across seasons suggest that average maximum temperature during incubation and chick-rearing influences hatching success and chick mortality. Nesting on urban infrastructure was not found to directly affect Osprey reproductive success.

Key words: Pandionidae, fecundity, survivorship, anthropogenic structures

RESUMEN

El águila pescadora (*Pandion haliaetus*) es una especie cosmopolita, con poblaciones migratorias y residentes. Su éxito reproductivo nos ayuda a identificar cambios ambientales en su hábitat. Por lo tanto, este estudio evaluó el éxito reproductivo de esta especie en Bahía Kino y Laguna La Cruz, Sonora, México, durante cuatro temporadas de reproducción (2017–2020). Se monitorearon un total de 33 nidos, de los cuales 22 estuvieron activos durante al menos una temporada. Todos los nidos activos se registraron sobre estructuras antropogénicas como postes de líneas eléctricas. Se registraron datos, incluidos el número de huevos, polluelos y volantones, así como las tasas de mortalidad, eclosión, anidación y éxito reproductivo. Durante las cuatro estaciones, se registraron un total de 56 eventos de nidación, 164 huevos, 121 polluelos y 91 volantones. Los resultados indicaron que los nidos en estructuras artificiales se utilizaron con frecuencia y no tuvieron un impacto negativo en el éxito reproductivo. El tamaño de puesta más común fue de tres huevos, y las nidadas más numerosas (tres o cuatro huevos) mostraron mayores tasas de eclosión y éxito en la anidación. Se observó una mayor productividad en las temporadas 2018 y 2019, con 2.07 y 2.00 volantones por nido activo, respectivamente. Estos registros coinciden con las estaciones en las que la temperatura máxima promedio registró valores más bajos durante el período de incubación y cuidado de los polluelos (de febrero a mayo). Las variaciones en los parámetros reproductivos a través de las estaciones sugieren que la temperatura máxima promedio durante esos meses, influye en la eclosión y la mortalidad de los polluelos. No se encontraron efectos negativos directos sobre la reproducción de la especie por la anidación en infraestructura urbana.

Palabras clave: Pandionidae, fecundidad, sobrevivencia, estructuras antropogénicas

INTRODUCTION

The Osprey *Pandion haliaetus*, also known as the sea hawk or fish hawk, is among the world's most widely distributed raptors (BirdLife International, 2021). As a reliable indicator of local environmental conditions (Daniel-Denemann, 1994), it functions as a sentinel species (Grove et al., 2009). Environmental factors, including habitat quality and anthropogenic disturbances, directly influence reproductive success, population stability, and colonization capacity.

Osprey populations may be migratory or resident, with residents being less well studied. Migratory populations breed synchronously from April to May, while residents breed asynchronously from December to July (Judge, 1983). They typically produce one clutch per season, most commonly three eggs, occasionally two, and rarely

four. Average lifespan is approximately 25 y, with females reaching sexual maturity at age 5 y (Bent, 1937; Edwards & Collopy, 1988).

Breeding success varies annually and geographically, influenced primarily by nesting site characteristics and demographic rates (Luevano-Esparza et al., 2015). Studies in northwestern Mexico demonstrate both positive and negative impacts of artificial nesting platforms, particularly those on powerline poles (Castellanos-Vera & Ortega-Rubio, 1995; Castellanos-Vera & Rivera, 2007; Daniel-Danemann, 1994; Luevano-Esparza et al., 2015). Such platforms represent important conservation measures (Ewins, 1996; Postupalsky & Stackpole, 1974).

At Ojo de Liebre and Guerrero Negro lagoons in Baja California Sur, breeding pairs increased 366% from 27 in 1946 to 126 in 1993 (Castellanos-Vera & Ortega-Rubio, 1995). Between 1980 and 1990, average productivity was 0.69 juveniles per active nest, with higher success at artificial sites. By 1993, productivity had reached 1.28 juveniles per active nest, alongside increased breeding pairs and nests (Castellanos-Vera & Ortega-Rubio, 1995).

Daniel-Denemann (1994) studied Ballena Island in San Ignacio Lagoon, Baja California Sur, Mexico—the world's densest Osprey breeding colony. During 1988–1989, average density reached 99.23 active nests/km^2, with a productivity of 0.96 juveniles per active nest.

Luevano-Esparza et al. (2015) investigated breeding at La Pinta estuary near Puerto Peñasco, Sonora, where artificial saguaro-shaped platforms were installed. Over eight breeding seasons (2006–2013), 17 pairs constructed nests, producing 55 eggs from which 53 chicks hatched and fledged.

The coastal zone of Kino Bay and Laguna La Cruz Ramsar Site provides natural Osprey habitat, primarily during the breeding season. However, no data exist on population performance in this area. This study aims to (1) address this gap by monitoring reproductive activity over four breeding seasons and (2) test whether artificial structures negatively affect reproductive output at individual nests. Such research enhances species understanding while providing valuable information on the Ramsar site's ecological condition, supporting future conservation and management strategies.

METHODS

Study Area

Kino Bay and Laguna La Cruz are located on the eastern coast of the Gulf of California in northwest Mexico, within the municipality of Hermosillo, Sonora (28°47′58″N, 111°54′55″W). The study included two areas: (a) the coastline of Kino Bay, covering 54 km^2 and comprising 14 km of sandy beaches, and (b) Laguna La Cruz,



Fig. 1. Geographic location of the Osprey *Pandion haliaetus carolinensis* study area in Kino Bay and Laguna La Cruz, Sonora, Mexico.

covering 57 km^2 of primary floodplain and with a coastal perimeter of approximately 40 km (Fig. 1). Both water bodies form part of a coastal-lagoon wetlands system, where Laguna La Cruz is constantly flooded exclusively by tidal currents from Kino Bay. Therefore, the entry and availability of aquatic species in Laguna La Cruz (e.g., fish, crustaceans, reptiles, and marine mammals) are modulated by the tides. The regional climate is classified as hot-arid (BWh) with average annual temperatures ranging from 22 °C to 33 °C and annual precipitation between 150 and 200 mm (Fig. 2). Laguna La Cruz is listed as a Wetland of International Importance by the Ramsar Convention (Site number 2154), designated on 02 February 2013, under the name of "Wetlands of Laguna La Cruz" (https://rsis.ramsar.org/ris/2154).

Monitoring of Reproductive Performance

An inventory of active and inactive nests was conducted, and the geographic location of each nest was recorded using a Garmin eTrex 10 Global Positioning System (GPS) unit.

Nests were monitored weekly during four reproductive seasons (2017–2020), documenting courtship and nest building or rebuilding, copulation, nesting initiation, number of eggs, number of hatched eggs, clutch size, and chick and fledgling development. Mortality events were also recorded at various stages of nestling development.

The development of eggs and chicks was monitored through observations of the nest's interior and video recordings obtained using a camera mounted on a 5-m-long fiberglass pole. Because the nests were built on energized power lines, safety equipment was worn to prevent electrical hazards while operating the pole. Additionally, photographs were taken from ground level with a Canon PowerShot G12 semi-professional camera to document fledglings.

Reproductive Success Parameters

To evaluate the success parameters of breeding pairs, formulas proposed by Mayfield (1975), Postupalsky (1977), Erwin and Custer (1982), Daniel-Danemann (1994), and SEMARNAT-CONANP (2010) were applied. By using the observational data, the following parameters were estimated:

- Average clutch size = [Total eggs/Total active nests]
- Mortality = [Total dead chicks/Total chicks] × 100
- Productivity = [Total fledglings/Total active nests]
- Hatching success = [Total hatched eggs/Total eggs] × 100
- Fledgling success = [Total fledglings/Total chicks] × 100
- Nesting success = [Total nests with at least one fledgling/Total active nests] × 100
- Reproductive success = [Total fledglings/Total eggs] × 100

Data Analysis

A two-way analysis of variance (ANOVA) ($p < .05$), followed by Tukey's comparison test, was performed using GraphPad

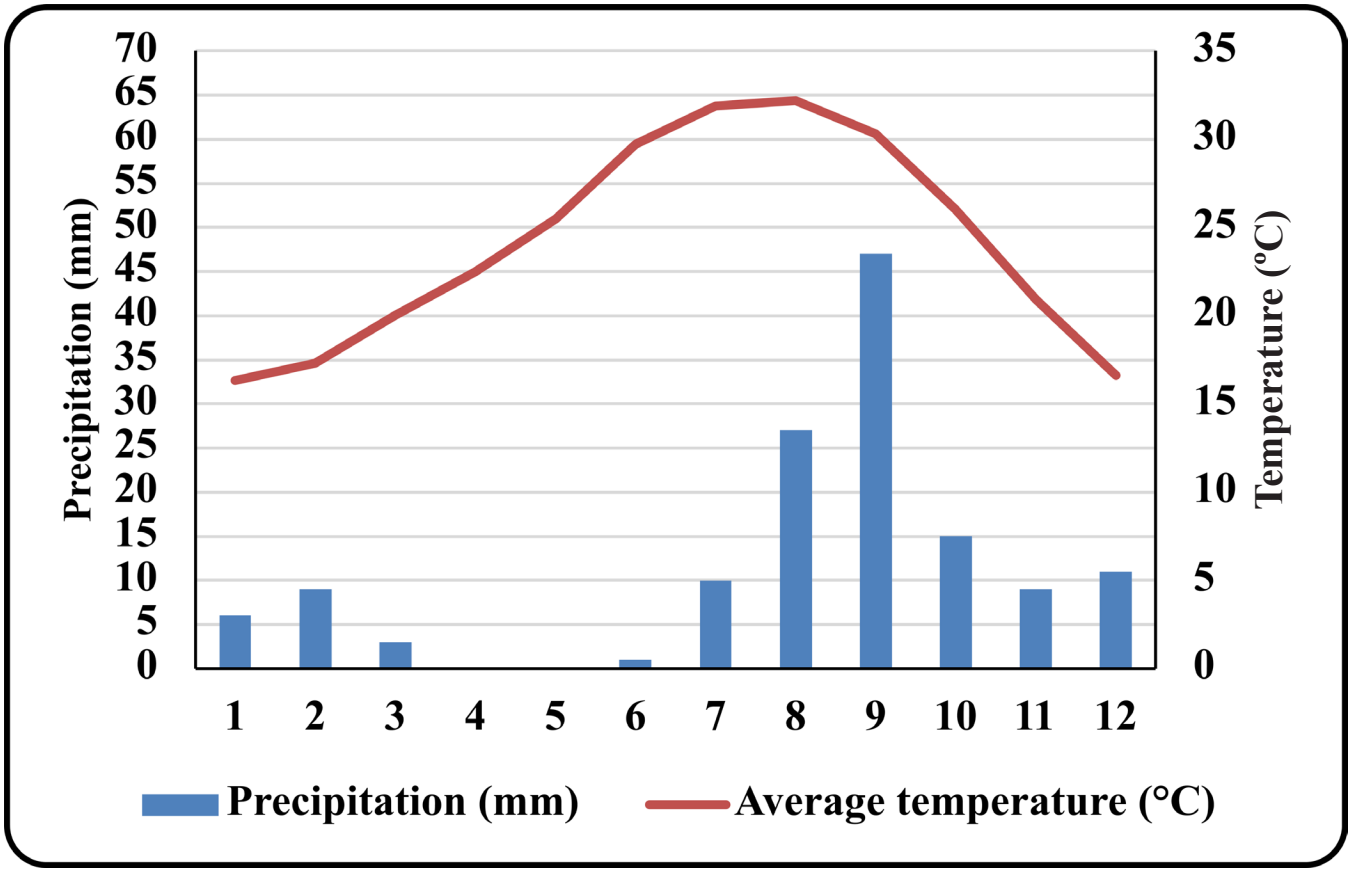

Fig. 2. Climate chart of Kino Bay, Hermosillo, Sonora, Mexico, showing mean precipitation and temperature for the period 1991–2021 (January–December).

Prism (version 10.0.0) for Windows, GraphPad Software (Boston, Massachusetts, USA; www.graphpad.com). Values in percentages were first transformed to arcsine data for analysis.

RESULTS

Active Nests

The identified nests were categorized as either active or inactive based on their usage and maintenance. A total of 33 nests were identified, of which 22 were active during at least one season, while 11 showed no activity during the study period (Fig. 3). No significant difference (p = .87) was found in the number of active nests across seasons. In both the 2017 and 2018 seasons, 14 active nests were recorded; in the 2019 season, 13 active nests were documented; and in the 2020 season, 15 active nests were recorded. During the four seasons, a total of 56 nest clutches, 164 eggs, 121 chicks, and 91 fledglings were recorded.

Egg-laying began in January and ended in March. In the 2017 season, laying occurred in January and March, while in 2018, egg-laying took place in January and February. During the 2019 and 2020 seasons, the layoff spanned three months (January to March).

Clutch Sizes by Season

The most common clutch size for pairs was three eggs during the four monitored seasons (Fig. 4). This clutch size occurred in 82% of the nests (46 of 56). A higher percentage of nesting pairs started egg-laying in January during all seasons. Averages of 40–43 eggs, 28–35 chicks, and 18–29 fledglings were recorded (Table 1).

Hatching and Nesting Success

Hatching success varied by clutch size (Table 2; Fig. 5). Across the four breeding seasons, clutches of one, two, three, and four eggs showed hatching success rates of 0%, 50%, 70%–90%, and 50%–100%, respectively. No significant differences (p = .90) were detected in hatching success between breeding seasons. However, highly significant differences (p = .01) were recorded in hatching success by clutch size. Higher mortality was recorded in the clutches of three eggs. This is because, in most small clutches (one to two eggs), the eggs did not hatch. In terms of productivity, despite the higher mortality, three-egg clutches were the most efficient, producing the greatest number of fledglings across the four breeding seasons evaluated.

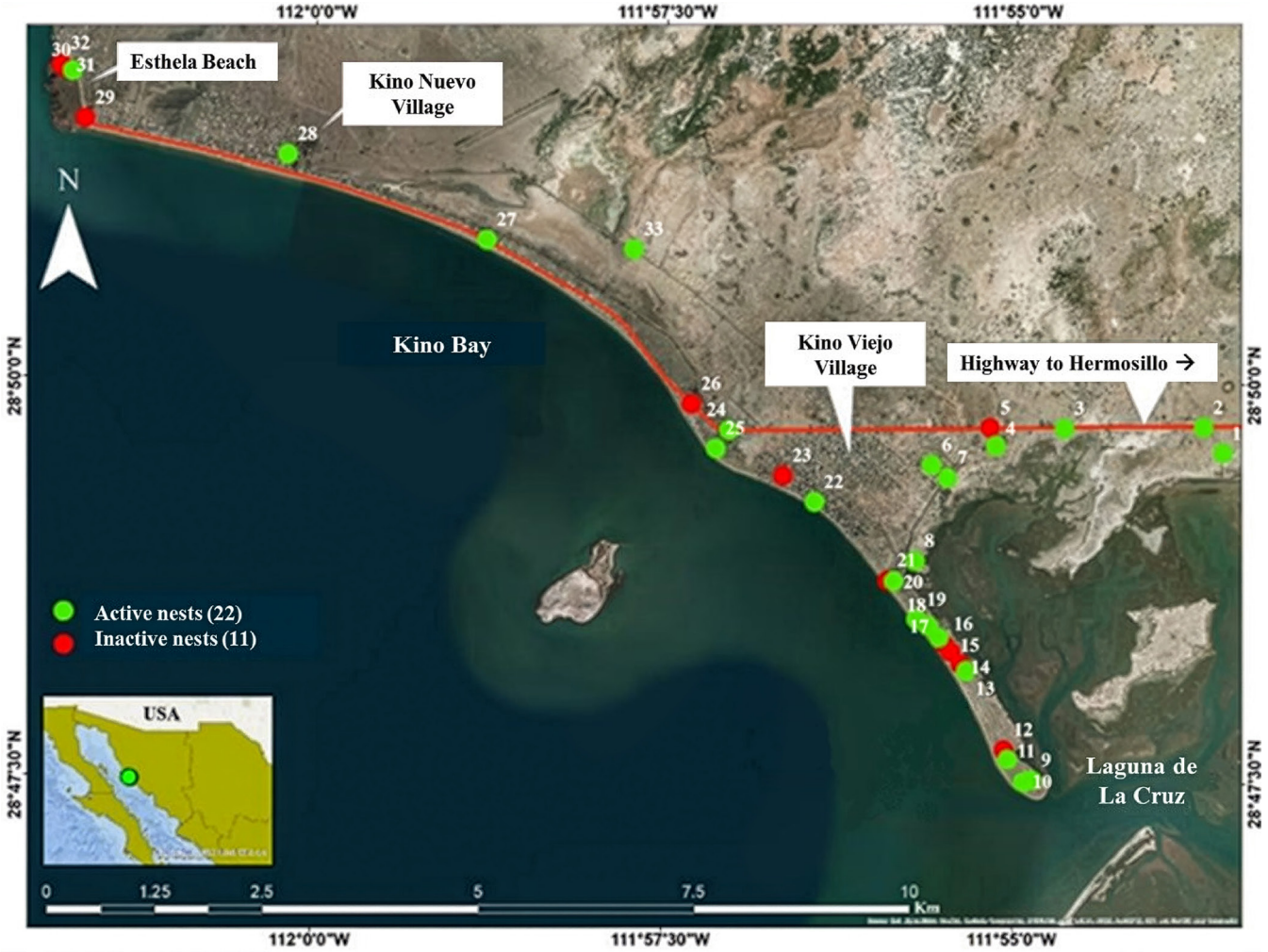

Fig. 3. Osprey *Pandion haliaetus carolinensis* nests were monitored during four breeding seasons (2017–2020) in Kino Bay and Laguna La Cruz, Sonora, Mexico. Nests active in at least one season are shown in green, whereas inactive nests are shown in red.

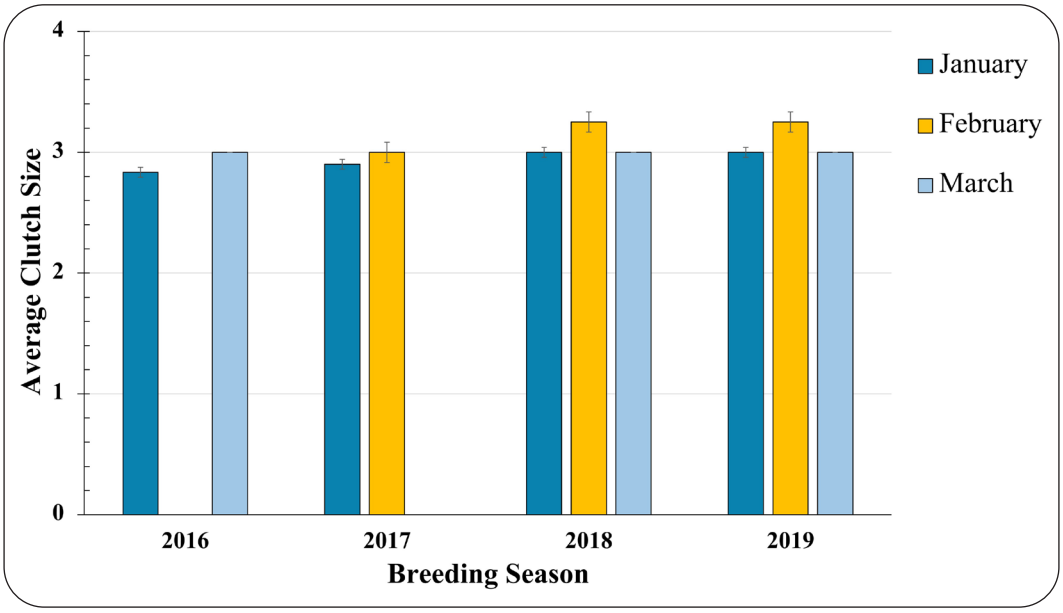

Fig. 4. Average clutch size (± standard error) of Osprey *Pandion haliaetus carolinensis* by month of egg laying during four breeding seasons in Kino Bay and Laguna La Cruz, Sonora, Mexico.

TABLE 1
Reproductive performance of Osprey *Pandion haliaetus carolinensis* according to clutch size for each breeding season in Kino Bay and Laguna La Cruz, Sonora, Mexico

Breeding Season	Clutch size[a]	Active nests	Number of eggs	Number of chicks	Number of fledglings[b]	Chick mortality
2017	1	1	1	0	0	0
	2	1	2	1	1	0
	3	11	33	26	15	11
	4	1	4	2	2	0
	Total	**14**	**40**	**29**	**18**	**11**
2018	1	0	0	0	0	0
	2	1	2	1	1	0
	3	13	39	34	28	6
	4	0	0	0	0	0
	Total	**14**	**41**	**35**	**29**	**6**
2019	1	0	0	0	0	0
	2	0	0	0	0	0
	3	12	36	25	22	3
	4	1	4	4	4	0
	Total	**13**	**40**	**29**	**26**	**3**
2020	1	1	1	1	0	0
	2	1	2	0	0	0
	3	12	36	24	16	8
	4	1	4	3	2	1
	Total	**15**	**43**	**28**	**18**	**10**

[a] Number of eggs laid by the female
[b] Fledgling: A juvenile about to leave its nest and showing morphological characteristics similar to an adult.

Nesting success indicates the ratio of nests that had at least one fledgling relative to the total number of active nests. The clutch size with the highest nesting success was four eggs (100%), followed by clutches of two (100% in two seasons) and three eggs (50%–90%).

Considering all clutches, the 2019 season presented the highest nesting success (100%) compared to the rest of the seasons, followed by the 2018 (92.86%), 2017 (71.43%), and 2020 (66.67%) seasons.

TABLE 2
Estimated reproductive parameters for Osprey *Pandion haliaetus carolinensis* during four breeding seasons in Kino Bay, Sonora, Mexico

Parameter[a]	2017	2018	2019	2020
Average clutch size (CS)	2.86	2.93	3.08	2.87
Brood size (BS)	2.07	2.50	2.23	1.87
Hatching success (HS)	72.50	85.37	72.50	65.1
Fledging success (FS)	62.07	82.86	89.66	64.29
Nesting success (NS)	71.43	92.86	100	66.67
Mortality numbers (MN)	11	6	3	10
Mortality rate (MR)	37.93	17.14	10.34	35.71
Average productivity (AP)	1.80	2.23	2.00	2.00
Global productivity (GP)	1.29	2.07	2.00	1.20
Reproductive success (RS)	45.00	70.73	65.00	41.86

[a] Units of measure: CS = eggs/nest, BS = chicks/nest, HS = chicks/eggs (%), FS = fledglings/chicks (%), NS = Nests with at least one fledgling/active nests (%), MN = chicks (*n*), MR = dead chicks (%), AP = fledglings/nests with at least one fledgling (*n*), GP = fledglings/active nest (*n*), RS = fledglings/eggs (%)

Fledgling and Reproductive Success

The reproductive performance of each nest was assessed based on reproductive success, or the number of fledglings per egg, and the fledgling success, or the number of fledglings per chick. These attributes are directly affected by hatching success and chick mortality; therefore, both parameters (reproductive and fledgling success) were analyzed independently in the present study. Reproductive and fledging success were higher in the 2018 and 2019 seasons, whereas both measures were below 60% in 2017 and 2020 (Fig. 6).

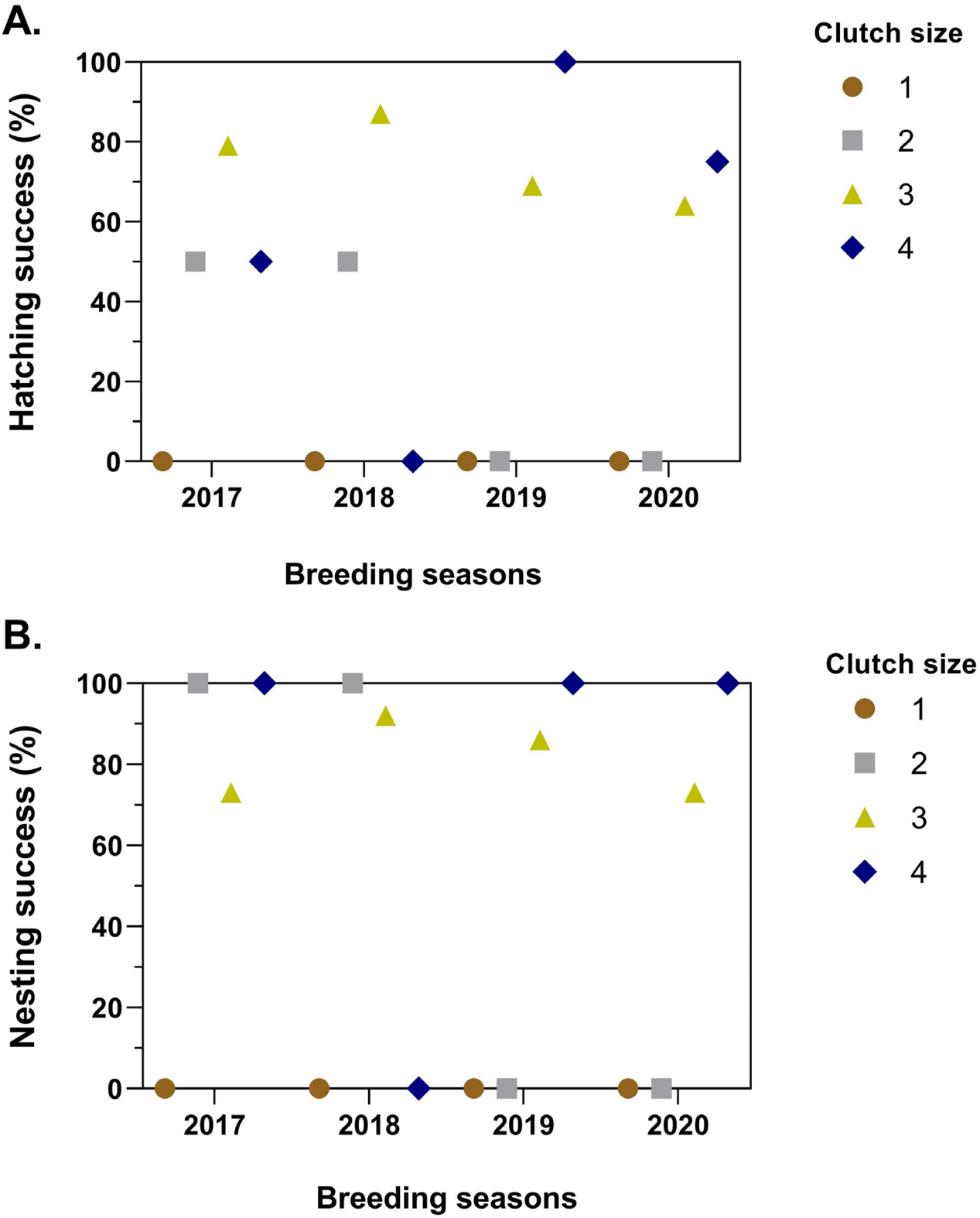

Fig. 5. (A) Hatching success and (B) nesting success of Osprey *Pandion haliaetus carolinensis* according to clutch size during four breeding seasons in Kino Bay and Laguna La Cruz, Sonora, Mexico.

A positive relationship was observed between fledgling and reproductive success in all breeding seasons except 2019. In 2019, fledgling success was relatively high, whereas reproductive success remained lower. Because reproductive success reflects the number of eggs relative to the number of fledglings, this difference may be attributable to reduced hatching success rather than chick mortality, which was low during the 2019 breeding season.

Global productivity in Kino Bay and Laguna La Cruz reached values above 1.2 fledglings per active nest in all seasons. Higher productivity occurred during the 2018 and 2019 seasons, with 2.07 and 2.00 fledglings per active nest, respectively. These findings coincide with seasons when the average maximum temperatures during the incubation and chick-rearing period (February to May) were lower.

DISCUSSION

Active Nests

Henny et al. (2008) reported an increase in the percentage of nests on artificial structures along the coast of Sonora and northern Sinaloa, from 3.2% in 1993 to 16.7% in 2006. In contrast, during our study, the number of nesting pairs on artificial structures was constant over the four seasons. However, all active nests were located on power line poles, indicating a clear preference for these structures as nesting sites. This pattern suggests that, despite the absence of an increase in nest numbers, artificial structures continue to play a critical role in supporting the local breeding population.

Clutch Sizes by Season

Our results are consistent with those reported by Forys et al. (2021) for Osprey populations in Florida, USA. The authors reported an early nesting peak during the incubation period in January, followed by nesting in February and March. In both cases, the most experienced breeding pairs initiated incubation earlier.

Steeger and Ydenberg (1993) and Bierregaard et al. (2020) reported that Osprey breeding pairs that started nesting earlier in the season tended to have larger clutch sizes and higher fledgling success. Similarly, Daniel-Denemann (1994) observed that on Isla Ballena, Baja California Sur, egg-laying mainly took place during the first three months of the year. Cartron (2000) also noted that early-season clutches were associated with increased colony productivity, whereas late-season clutches tended to have lower reproductive success. This pattern may have been influenced by environmental conditions, especially temperatures during the warmer months (April and May). Despite parental efforts to shade their young with their bodies to reduce heat stress, high temperatures had a noticeable impact. In contrast, this thermoregulatory behavior was not seen during the cooler months.

Rodríguez et al. (2013) and Judge (1983) noted that the survival of offspring depends on environmental conditions, food availability, and human disturbance. Larger clutches may therefore place greater demands on parents and require greater parental investment in offspring care. Consequently, chick mortality may be higher in clutch sizes of three or four eggs.

Academia et al. (2023) concluded that both the average number of fish delivered per day and its coefficient of variation during the early breeding season are effective predictors of nest success. They reported that nests receiving an average of three or more fish daily were more likely to succeed. Additionally, low variation in the number of fish delivered to the nest was associated with nesting success. In the present study, pairs across four seasons had an average of two chicks and one or two fledglings per nest, indicating lower chick mortality and proper development of the young. Although diet evaluation was not performed, it can be inferred that the number of fish delivered per day to each nest remained stable, at least during the first part of the breeding season.

Based on these findings, it can be inferred that food resources and availability at Laguna La Cruz and Kino Bay do not limit the successful rearing of offspring from large clutches.

Hatching and Nesting Success

Multiple factors may contribute to hatching failure in Osprey clutches, including competition for nesting sites, contaminants in the diet that cause egg infertility, late clutches, replacement clutches following clutch loss, and pairs in their first reproductive year (Henny et al., 1978). Although higher hatching success does not guarantee that the chicks reach the fledgling stage, it increases the likelihood of greater reproductive success (Fig. 5).

Our results suggest that clutches of three to four eggs are associated with higher hatching success. Kabeer et al. (2020) reported that hatching success in nests on artificial structures (nesting platforms) is 87%, which exceeds the success of nests in natural sites (70%). In our study, hatching success was not recorded at natural nesting sites because active nests were found exclusively on artificial structures (power line poles). Nevertheless, hatching success at these artificial nest sites on Laguna La Cruz and Kino Bay was high, even with large clutch sizes.

Glass and Watts (2009) and Academia et al. (2022) agree that the nesting success of Ospreys depends on both the quantity of prey delivered to chicks and the nutritional composition of the prey. During casual nest observations, we identified the following fish species: White Mullet *Mugil curema*, Pacific Needlefish *Tylosurus pacificus*, Mojarra *Eucinostomus* sp., Cortez Bonefish *Albula gilberti*, and False Grunion *Colpichthys regis*, among others. However, the nutritional contributions of these fish to chick diets and their potential relationship with nesting success in Laguna La Cruz and Kino Bay are unknown. In a study of prey remains found under Osprey nests at coastal sites located 65 km north of our study area, Cartron and Molles (2002) identified at least 19 species from 18 fish families. Mullets and needlefish were the most frequently represented taxa among prey remains, consistent with our observations.

Fledgling and Reproductive Success

Airola et al. (2022) reported greater reproductive success in Osprey nests located on anthropogenic structures (80%) compared to nests on live trees or dry logs (0%) in California, USA. Bai et al. (2009) reported that nest site (pole or tree), distance to the nearest water body, size of the water body, and the settlement area did not influence the reproductive success of Osprey populations in Germany. In our study, nests were located at similar distances from the food source, all breeding pairs nested on human-made

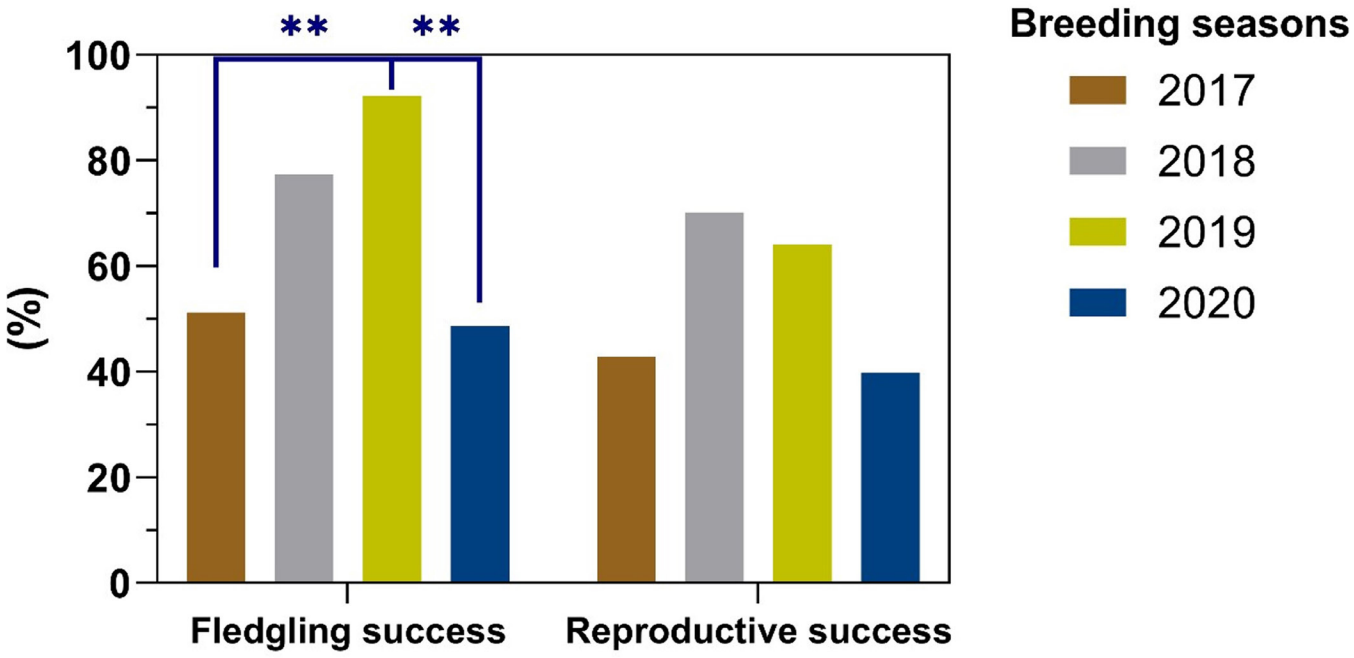

Fig. 6. Fledgling success and reproductive success of Osprey *Pandion haliaetus carolinensis* during the four breeding seasons in Laguna La Cruz and Kino Bay, Sonora, Mexico. Significance: (**) $p < .01$.

structures, and nests were built from similar materials (plant remains, bones, and human garbage). Despite these similarities, reproductive success varied among breeding seasons, possibly due to differences in environmental conditions, including prey availability. Our results suggest that small clutch sizes (two eggs) produced fledglings inconsistently, and one-egg clutches sometimes fail to produce fledglings. Conversely, larger clutches (three or four eggs) help bring new members into the colony. However, no significant differences were found in fledgling success among breeding seasons ($p = .08$), nor among clutch sizes ($p = .79$).

Overall, Osprey reproductive success is affected by various biological and environmental factors beyond diet. Solonen et al. (2008) reported that Osprey reproduction on the southern coast of Finland was significantly associated with recent large-scale climatic phenomena, with the effects of these changes potentially becoming evident only after a considerable time lag. The differences in reproductive success observed in our study may likewise be a consequence of environmental conditions in previous years. Therefore, reproductive success varied among breeding seasons despite the absence of apparent ecological differences during the years monitored.

Among the various factors influencing reproductive success, food availability and food quality are key. According to Muriel et al. (2013), when food is abundant, parents in better physical condition and with larger clutches can raise more offspring, outperforming lower-quality parents with fewer chicks. In the present study, reproductive success fell below 50% in two of the four breeding seasons analyzed. This decline might have been attributable to differences in the quantity or nutritional quality of food available to both offspring and parents. Although we have not yet conducted a strict quantitative analysis of diet, we confirmed that Ospreys fed exclusively on marine fish, as noted above. Consequently, continued research is essential to deepen our understanding of Osprey feeding ecology throughout the reproductive period and to assess how it influences reproductive outcomes.

Additionally, maximum daytime temperature during the incubation and chick-rearing period appears to influence hatching and survival of chicks. Both hatching and fledgling success were negatively correlated ($r \approx -0.66$) with mean maximum temperature (Fig. 7). In particular, hatching success increased as the mean maximum temperature from February through May 2018 decreased. The increase in fledgling success during 2018 and 2019 was even more notable in 2018 and 2019 when average maximum temperatures decreased. Conversely, when mean maximum temperatures during February to May were higher in 2020, both hatching and fledgling success decreased significantly.

Finally, Muriel et al. (2013) concluded that proximity of human infrastructure did not influence chick body condition or productivity and, therefore, was not a limiting factor for development. Our results do not allow us to quantify the relationship between human infrastructure and reproductive success. However, it is possible to deduce that human disturbance did not affect the reproduction and survival of the species.

CONCLUSIONS

This study shows that nesting on human-made structures does not impact the reproductive success of Ospreys in the Kino Bay study area. The data indicate that variation in fledgling success across breeding seasons may be related to environmental factors, particularly maximum temperatures during the chick-rearing period, and to the nutrition of both breeding pairs and their young. Similarly, environmental changes and diet tend to decrease hatching and nesting success.

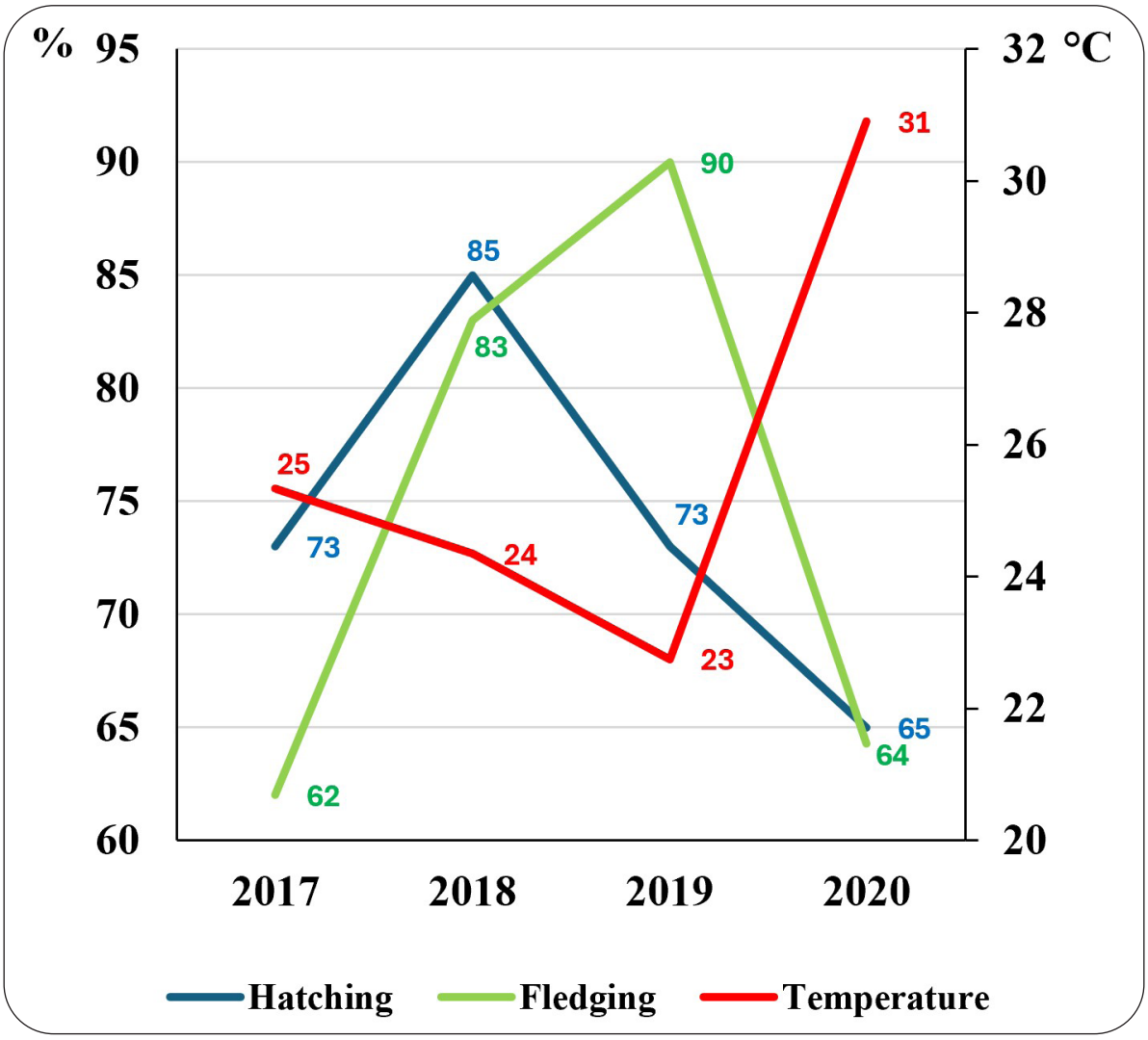

Fig. 7. Relationships between hatching success, fledging success, and average maximum temperature during the incubation and chick-rearing of Osprey *Pandion haliaetus carolinensis* over four breeding seasons (February–May) in Kino Bay and Laguna La Cruz, Sonora, Mexico.

Larger clutches (three or four eggs) demand more effort from breeding pairs. However, these clutch sizes are the main contributors to the populations in Kino Bay and Laguna La Cruz. Overall, no significant differences in reproductive success were observed between breeding seasons, indicating that Osprey reproductive success remained relatively stable over time despite nesting in human-made structures.

Further research is needed to better understand the impact of human activity on Osprey behavior and reproductive success, especially with respect to disturbance tolerance and habitat use in human-influenced landscapes. Nonetheless, these findings offer a useful baseline for monitoring Osprey populations and can guide conservation and management efforts within the Laguna de La Cruz Ramsar site.

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AUTHOR CONTRIBUTIONS

Conceptualization: KFP, RHBG, CHAG. Formal analysis: CHAG, KFP, RHBG. Funding acquisition: RHBG. Investigation: KFP, RHBG, CHAG. Methodology: KFP, RHBG, CHAG, MJZP. Project administration: RHBG, KFP, CHAG. Writing—original draft: CHAG, KFP, RHBG. Writing—review & editing: CHAG, KFP, RHBG, JAMG, MJZP.

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