ORNITOLOGÍA NEOTROPICAL
(2024) 35: 13–19
DOI: 10.58843/ornneo.v35i1.1209
ORIGINAL ARTICLE

Sociedad de Ornitología Neotropical

BREEDING BIOLOGY OF THE LOGGERHEAD SHRIKE *LANIUS LUDOVICIANUS* IN CENTRAL MEXICO

Octavio Soto-Rojas[1] · Javier Salgado-Ortiz[1*] · Stephen C. Lougheed[2] · J. Fernando Villaseñor-Gómez[1] · Leonardo Chapa-Vargas[3]

[1] Laboratorio de Ornitología, Facultad de Biología, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, México.

[2] Department of Biology, Queen´s University, Kingston, Ontario K7L3N6, Canada.

[3] Instituto Potosino de Investigación Científica y Tecnológica (IPICyT), San Luis Potosí.

E-mail: Javier Salgado-Ortiz · javier.salgado@umich.mx

Abstract · The Loggerhead Shrike *Lanius ludovicianus* has an exceptionally broad distribution in North America, with the southernmost populations found in central Mexico. The species has experienced severe declines throughout its range, and thus, is of conservation concern, particularly in USA and Canada. Life history data is scarce for Mexico, where both resident and migratory populations are found. In this study we provide information on the breeding biology of a population of Loggerhead Shrikes near the southern limit of its distribution in central Mexico. Based on data from 70 nests over three breeding seasons (2007–2009), we estimated the average nest density as 0.85 nests/ha with most nests built in mesquite trees *Prosopis laevigata*. Average clutch initiation date was March 28, with variation among years. The breeding period averaged 3.5 months, starting at the end of February, and extending to early June. The laying period averaged 4.6 days, incubation averaged 18 days, and the average brooding period 16.6 days, for a total average of 39.2 days from egg laying to the end of brooding. Clutch size averaged 4.1 eggs (range 2–5) with a mode of four eggs. The nesting success for the three years combined was 64.3% (range 54.5–68.9%). Daily survival rate was estimated to be 0.749 using logistic exposure. The average number of fledglings at successful nests was 1.5. Predation was the main cause of nest failure, accounting for 35.7% of all active nests. In general, life history traits of this Mexican Loggerhead Shrike population are like those reported for breeding populations in more northern parts of its range; however, clutch size was smaller and average incubation period was significantly longer, probably because of latitudinally-related environmental factors.

Resumen · Biología reproductiva del verdugo americano *Lanius ludovicianus* en el centro de México

El verdugo americano *Lanius ludovicianus* presenta una amplia distribución en Norteamérica con poblaciones sureñas hacia el centro de México. La especie ha experimentado disminuciones poblacionales drásticas en todo su rango de distribución y como tal, es considerada amenazada, particularmente en Estados Unidos y Canadá; en México, sin embargo, el conocimiento de sus poblaciones residentes y migratorias es escaso. En este estudio presentamos información de la biología reproductiva de una población ubicada en el centro de México. Con base en 70 nidos de tres temporadas reproductivas (2007–2009) determinamos que la densidad promedio de nidos fue de 0.85/ha, siendo el árbol de mesquite (*Prosopis laevigata*) el sustrato principal de anidación. La fecha promedio de inicio de puesta fue marzo 28, con variación entre años. El periodo de reproducción fue de 3,5 meses, (desde finales de febrero a principios de junio). El periodo promedio de puesta fue de 4,6 días y el de incubación 18 días y de 16,6 días de empollamiento, para un promedio de 39,2 días desde el inicio de la puesta hasta la salida de los pollos del nido. El tamaño promedio de nidada fue de 4,1 huevos (rango de 2–5) con una moda de cuatro huevos. El éxito reproductivo para los tres años combinados fue de 64,3% (54,5–68.9). La sobrevivencia diaria global de los nidos según exposición logística fue de 0,749. El promedio de volantones en nidos exitosos fue de 1,5. La depredación fue la principal causa de fracaso (35,7% de nidos). Los atributos de historia de vida son en general similares a lo reportado en la literatura para las poblaciones reproductivas en su rango norteño, sin embargo, el tamaño de nidada fue menor y el periodo de incubación más largo, probablemente como resultado de factores ambientales asociados con la latitud.

Key words: *Agriculture · Clutch initiation · Latitudinal variation · Life history · Mexico · Nesting Success*

INTRODUCTION

Describing traits of the breeding biology of a species is crucial, as they determine how demographic parameters (productivity, abundance, survival, mortality, and recruitment) of populations change in space and time. Moreover, understanding how these parameters are affected by both abiotic and biotic factors is essential to provide evidence to effectively develop conservation programs, especially for species in urgent need of protection. Among the various attributes of the breeding biology of birds, nesting success, defined as the proportion of *observed nests that fledge at least one offspring,* has been widely used as a metric to assess breeding performance of specific populations at different geographic locations. Nesting success, together with other attrib-

Submitted 06 Jul 2023 · First decision 19 Jul 2023 · Acceptance 12 Dec 2023 · Online publication 17 Mar 2024
Communicated by Paula L Enríquez

Figure 1. Loggerhead Shrike study area at the northern portion of the state of Michoacán. Study sites are shown with numbers: 1) San Agustín del Maíz, 2) Cuitzeo-San Agustín del Pulque Road, 3) Ejido Epifanio C. Pérez, and 4) Cuitzeo-Huandacareo Road.

utes such as clutch size, hatching success and duration of incubation and brooding periods, are key to determine how populations are responding to local environmental factors and whether these might change in relation to anthropogenic activities.

The Loggerhead Shrike *Lanius ludovicianus*, like many other grassland bird species, has shown sustained declines in abundance across its range over the last few decades (Cade & Woods 1997, Berlanga et al. 2010, Fink et al. 2022). As such, the Loggerhead Shrike is included, along with many other species, as being of conservation concern by the tri-national (Canada-USA-Mexico) Partners in Flight bird conservation initiative (Berlanga et al. 2010). As a species of conservation concern, the description of life history attributes such as breeding phenology and nesting success are essential to aid in ensuring the long-term persistence of the species; for example, conversion of habitat can profoundly impact nest site attributes, and concomitantly, reproductive success.

This species is broadly distributed, with a range extending from southern Canada through the continental United States, south to central Mexico (Yosef 2020). In Mexico, it is mainly a breeding resident and is the only one of the two North American shrike species to commonly occur in the country (Howell & Webb 1995). Long-term monitoring data from the Breeding Bird Survey and the Christmas Bird Count in North America have shown substantial declines of Loggerhead Shrike populations since 1995 (Sauer et al. 1995, Cade & Woods 1997), with an estimated decline of 3.2% per year between 1966 to 2011 (Sauer et al. 2017). More recently, eBird Status and Trends 2007–2021 (Fink et al. 2022) showed that continental populations continue in decline (up to 30%) over most of the species' range. In Canada, populations of the subspecies *L. l. migrans* and *L. l. excubitorides* have been classified as endangered and threatened, respectively, by the Committee on the Status of Endangered Wildlife (COSEWIC 2000, 2004). In the USA, it has been identified as a species of conservation concern and near-threatened by the IUCN (U.S. Fish and Wildlife Service 2008, Yosef 2020) due to drastic and ongoing decline, with contemporary population size estimated to comprise up to 75% of the historical size (Berlanga et al. 2010, Fink et al. 2022).

Many reasons have been posited for the decline of Loggerhead Shrike populations: loss of habitat, climatic factors, collision with vehicles nest predation, and high mortality in the first year of life (Yosef 2020). More recently, wind turbine fatalities have been also reported (Smallwood & Smallwood 2021). However, most authors agree that the main factor for decline of this species is the loss of habitat (Gawlik & Bildstein 1993, Cade & Woods 1997, Yosef 2001, Walk et al. 2006, Pool et al. 2014). In Canada and USA, data suggest that there is reduced reproductive success and higher predation in intensive agricultural croplands (Yosef 2020, Walk et al. 2006) compared to grasslands, old fields, cattle pastures, and open areas (Gawlik & Bildstein 1993, Yosef 2001, Collister & De Smet 1997, Chabot et al. 2001).

The breeding biology of the Loggerhead Shrike has not been well studied in Mexico compared to the USA and Canada; thus, in general, data are lacking for Mexico where several subspecies exist (Phillips 1986) and where breeding populations are resident (Yosef 2020). To address this knowledge deficit, we examine the breeding biology in a population of Loggerhead Shrikes in the Western Mexico state of Michoacán, in an agriculture area on the shore of lake Cuitzeo. In this study, we quantify key life history attributes of the breeding biology of a resident population of the species at the southern limit of its continental distribution.

METHODS

Study sites. Our study area was selected based on information available from specimens housed in the scientific collection held at the Laboratory of Ornithology at Universidad Michoacana de San Nicolás de Hidalgo, in Michoacán, Mexico. The study focused on four study sites distributed along the shore of Lake Cuitzeo (Figure 1): 1. San Agustín del Maíz (19°54'01.53"N, 101°09'42.10"W); 2. The Cuitzeo-San Agustín del Pulque Road (19°57'22.28"N, 101°06'52.53"W); 3. Ejido Epifanio C. Pérez (20°00'08.99"N, 101°08'59.30"W) and 4. The Cuitzeo-Huandacareo Road (19°57'47.94"N and 101°13'

15.22"W).

The sites are situated in an area with rain-fed agriculture used once a year, principally to cultivate corn, chickpeas, and sorghum, with a few smaller fields of alfalfa (an annual crop). Fields were interspersed with live fencerows consisting of linear stone fences mixed with mesquite *Prosopis laevigata*, huisache *Acacia farnesiana*, cactus and other native shrubs and trees, as well as isolated patches of mesquite and some huisaches, and uña de gato *Acacia* sp. In addition, there were some patches of original subtropical semiarid matorral vegetation (*Ipomoea murucoides*, *Bursera copalifera*, *Eysenhardtia polystachya* and *Opuntia spp.*) interspersed with grasslands where livestock pastured. Our four study sites had similar landscape features (Figure 2) and were separated by an average of 8.3 km distance from each other.

Field Methods. Breeding data were collected from the end of February to the beginning of June over three breeding seasons: 2007, 2008, and 2009. We found focal nests primarily using behavioural cues that would imply nesting, including courtship, carrying nest material, territory defence, and food transport (Ralph et al. 1996). Once a supposed nesting pair was identified, we conducted intensive searches in all trees and shrubs in surrounding areas to locate the nest, which were easy to identify by their conspicuous open cup shape with interwoven plant material, and protection afforded by thorny twigs on the exterior. To quantify multiple aspects of the breeding phenology and reproductive success, we conducted nest checks every third day, beginning at egg laying (Martin et al. 1997). To reduce stress on parents and prevent our actions from attracting predators, we first confirmed that potential predators were not nearby. We checked nests for parental presence using binoculars; if either or both parents were present, we waited until they left the nest. Then, two persons approached the nest, one holding a mirror mounted in a pole to check the contents and the second using binoculars to confirm the presence of either eggs or nestlings. A nest was considered predated when, in addition to the absence of eggs or nestlings since the last check, we also noticed damage (partial or severe) to the nest. Among potential predators in the area are included birds (Great-tailed Grackle *Quiscalus mexicanus*, Common Raven *Corvus corax*, American Kestrel *Falco sparverius*, Copper's and Sharp-shinned Hawks *Accipiter cooperii and A. striatus*), as well as mammals (ground squirrels, *Otospermophilus variegatus*, Field rats *Peromyscus sp.*, *Neotoma sp.*, and *Rattus sp.*, Weasel *Neogale frenata*, Opossum *Didelphis virginiana*, and feral cats), and reptiles (Mexican bullsnake *Pituophis deppei*). We recorded the day that the first egg was laid, clutch size, hatching and fledging dates, duration of laying, incubation and nestling periods, number of eggs hatched, and number of nestlings fledged. We also obtained data on precipitation for 2008 and 2009 from a weather station close to our study area, (Huandacareo ca. 6 to 12 km from our study sites) to relate this to the timing of breeding. Precipitation data for 2007 were omitted from analysis because we did not conduct nest searches for the entire breeding season in this year.

Statistical Analyses. We calculated the average of hatching success as the percentage of eggs that hatched by year at each study site, and nesting success as the percentage of pairs that fledged at least one young. We also estimated survival rate of nests using two methods: the Mayfield method (1961, 1975) to allow comparison to previous work, and the logistic exposure method (Shaffer 2004). The Mayfield estimator calculates the total exposure in nest-days. The resulting value, expressed as losses per nest-day, is the estimated daily mortality rate of nests. The logistic exposure method is preferred for calculating nest survival (Shaffer 2004) as it is based on the history of encounters of individual nests, allows visitation intervals to vary, and requires no assumptions about when nest losses occur (Dinsmore et al. 2002). We estimated the survival rate of nests by using the logistic exposure model available in the module PROC NLMIXED (Rotella et al. 2007) of SAS (SAS Institute 2009). We used date and age of nests as explanatory variables to model Loggerhead Shrike's daily nest survival.

Unless otherwise indicated, we report means ± SD for all metrics. We used a Wilcoxon test to compare the clutch initiation between 2008 and 2009. We exclude the nesting season of 2007 from this analysis because we were unable to sample the entire reproductive season.

RESULTS

Over three reproductive seasons, we located 70 nests, 11 in 2007, 30 in 2008 and 29 in 2009. Average nest density for all sites combined (2008–2009) was 0.85 nests/ha (range 0.90–1.21 nests/ha), with higher density at Ejido Epifanio C. Pérez (see Figure 1). Nest were located on different substrates; two (2.9%) were placed in uña de gato *Acacia* sp., 11 (15.7%) were placed in *A. farnesiana*, and most, 57 (81.4%) were placed in *P. laevigata*), either isolated in small stands or in fencerows. All substrates have thorns or spines. On average, nests were

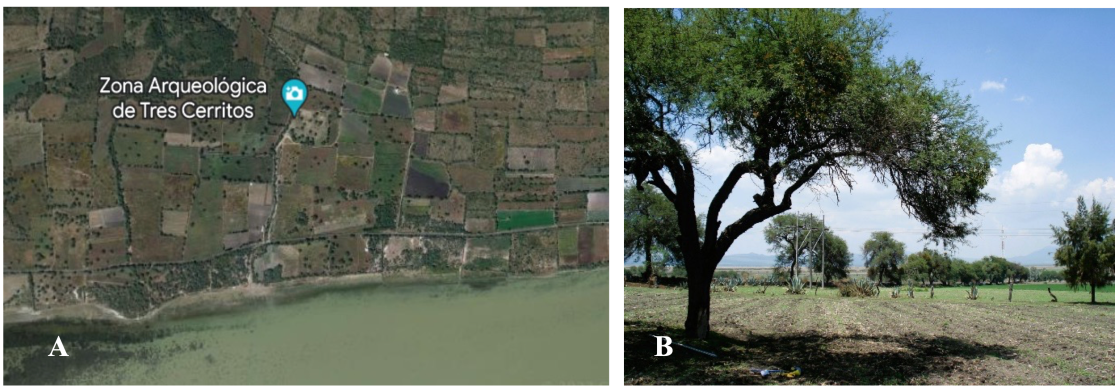

Figure 2. Landscape features prevailing at the Loggerhead Shrike study sites in the shore of Lake Cuitzeo located north of Michoacán, Mexico. A) satellite image from Google Earth dated 2012 from site 2, San Agustín del Pulque Road, showing the landscape arrangement of agricultural plots interspersed by live fences, isolated mesquite trees and patches of semiarid subtropical forest. B) Close-up photo of a Loggerhead Shrike territory.

Table 1. Breeding traits of the Lake Cuitzeo population of Loggerhead Shrike *Lanius ludovicianus*, from 2007 to 2009. Values are mean ± standard deviation.

	2007	2008	2009	Global
Active nests	11	30	29	70
Eggs laid	47	124	118	289
Total eggs hatched	31	80	98	209
Clutch size	4.2 ± 0.6	4.1 ± 0.7	4.1 ± 0.8	4.1 ± 0.7
Eggs hatched by nest	3.8 ± 0.9	3.3 ± 0.9	3.6 ± 1.0	3.5 ±1.0
Laid period (days)	5.2 ± 1.1	4.4 ± 0.9	4.5 ± 0.9	4.6 ± 1.0
Incubation period (days)	18.6 ± 0.9	18.5 ± 1.1	17.4 ± 0.9	18.0 ± 1.16
Nestling period (days)	16.3 ± 1.36	16.5 ± 1.3	16.7 ± 1.2	16.6 ± 1.3
Fledglings by successful nest	1.8 ± 0.7	1.4 ± 0.6	1.6 ± 1.0	1.5 ± 0.1
Nesting success %	54.5	63.3	68.9	64.3
Nesting success Mayfield %		53.2	62.3	55.3
Hatching success %	65.9	64.5	83.0	72.3

located at a height of 4.3 m ± 0.2, (range 1.2–8.6 m; N = 70 nests), and the perpendicular distance from the main tree stem averaged 3.4 m ± 0.24 (range 0.28–5.23 m). Nests in isolated trees (92% of all nests) in agriculture fields were on average 30.8 ± 0.8 m from fencerows. Nest construction was directly observed in only four nests, which required between 4 to 6 days to complete; the 66 other nests were already complete when found. The longest span between the end of nest construction and day of laying of the first egg was 28 days. The earliest clutch recorded was on 21 February 2009 and the latest on 3 June 3 2008; in general, the breeding season extended for three- and one-half months (March to June). The longest nesting season (defined as the elapsed time between laying of the first egg until the last fledging event each year) was 109 days in 2009 (from 21 February to 9 June); the mean for years 2008 and 2009 combined was 105 ± 5 days.

The mean clutch size (N = 70 nests) across all three years was 4.1 eggs/nest (range: 2–5, Table 1). The proportion of nests with two eggs was 4.4%, with three eggs 10.3%, with four eggs 52.9% and with five eggs 32.3%. Of the 289 eggs laid over three years, 209 eggs (72.3%) hatched. We found a similar hatching success for 2007 and 2008, but a higher value in 2009 (Table 1). Fifty-two eggs (18%) were predated, 23 eggs (8%) were infertile, and 5 eggs (1.7%) were in clutches abandoned by the parents (two nests). Of the total eggs hatched, 136 nestlings (65%) were lost by predation and 73 (35%) successfully fledged. In 49 nests (70%), we found that hatch interval was 48 hours, with the last egg laid usually the last to hatch.

Overall, the average laying period (N= 70 nests for all years combined) was 4.6 days, (range 2–7). Incubation started with the second egg laid and averaged 18 days (range 16–20 days; Table 1). The average for the nestling period for all three years combined (N = 70 nests) was 16.6 days (range 14–20 days, Table 1). The average clutch initiation date for 2008 was 3 April whereas for 2009 it was 23 March, with significant differences between years (Wilcoxon X^2 = 6.9, p = 0.0082, Figure 3). Most clutches were initiated during the final part of the dry season (March–April), before the arrival of the rains (Figure 3). Overall, 1.5% clutches began in February, 56% in March, 37% in April, and 6% in May. Over the three reproductive seasons, we only registered two re-nesting events (nests built after the first failed nest). The new nests were all constructed near to the original nest, <100 m away.

The nesting success for the three years combined was 64.3 % (percentage of nests where at least one young fledged). Estimated nest survival was 55.3% with Mayfield method (success per year in Table 1), while the logistic exposure analysis showed a global daily nest survival rate of 0.749 with a confidence interval of 0.084–0.967. Daily nest survival was higher in 2009 (0.72) than in 2008 (0.62).

We recorded 73 fledglings in all three breeding seasons (mean of 1.5 ± 0.1 fledglings/successful nest; Table 1). Nest predation was the main cause of nest failure with a total loss of 25 nests (35.7%) in three years, of which 48% (12 nests) were predated during the incubation period and 52 % (13 nests) during the nestling period. Nests that that were successful in fledgling were an average distance of 37.09 ± 3.59 m (n = 43) from fencerows, with unsuccessful nests located at 20.68 ± 3.67 m (n = 27). In general, nest that were predated were found with material removed or were destroyed. We observed squirrels, ravens, Cooper´s and Sharp-shinned Hawks, and Great-tailed Grackles on trees where some nest failures occurred.

DISCUSSION

Overall, our observations of nest site selection and reproductive success of Loggerhead Shrikes are broadly comparable to those from Canada and USA, with some notable differences. Average clutch size of 4.1 eggs is like average clutch size in Florida of 4.3 eggs (Yosef 2001), but smaller than most values reported at higher latitudes (5 or 6 eggs; Yosef 2020). Such latitudinal variation is consistent with bird species where larger clutches occur in more seasonal environments (Jetz et al. 2008). Thus, this disparity is possibly the result of local environmental factors including local food abundance (Martin et al. 1997, Martin 2002), but further investigation is necessary to understand such latitudinal variation. Compared to other studies of *L. ludovicianus*, the average incubation length of 18 days for this Mexican population is the longest reported so far (Kridelbaugh 1983, Tyler 1992, Lefranc 1997, Prescott & Bjorge 1999, Esely & Bollinger 2001, Yosef 2001, Posadas-Leal et al. 2010). In some bird species, differences in incubation period vary due to female body size (Zicus et al. 1995), presence of predators (Hepp et al. 2006), environmental temperature (Conway & Martin 2000), available food (Chalfoun & Martin 2007), and clutch size (Hötker 1998). The average nestling period of 16.6 days coincides in general with data reported for other North American populations (Pruitt 2000); however, the average nestling period we found was shorter than the 19.1 days reported by Posadas-Leal et al. (2010) from another Mexican population breeding in a similar semiarid agricultural landscape.

Our focal population showed marked seasonality in breeding, occurring from March through May coinciding with the dry season. We found no evidence that rainfall affected clutch initiation as, in both 2008 and 2009, shrikes begun clutches in the absence of precipitation. Nonetheless, combined with other environmental factors such as temperature, rainfall might influence the timing of breeding by affecting the amount of food available for reproduction (but see Borgman & Wolf 2016). Although we did not measure food availability directly, breeding of shrikes in our study site appears to match the time when food was most plentiful to feed nestlings (Salgado-Ortiz et al. 2009). Particularly, at our study site grasshoppers are an agricultural pest that are abundant at the end of the rain season (October–November), continuing throughout the dry season towards the end of March when Loggerhead clutches were more numerous (Figure 3). Grasshoppers and other insects are common prey for Loggerhead Shrikes, especially during the breeding season (Yosef 2020). Further research is necessary to determine whether this connection between invertebrate abundance and maximum number of clutches holds true.

The combined hatching success of 72.3% obtained for the three years is high but less than that found in Florida (87%; Yosef 2001). Failure of eggs to hatch was mostly attributable to predation. Infertility of 8% is comparable to values at higher latitudes (9.6%) for 155 species of birds, where different factors have been suggested to affect egg fertility, including rainfall, temperature, food availability, or the participation of only one parent in a nest (Koenig 1982). Predation was the top factor to affect the fate of the eggs, resulting in 18% of lost eggs and 35.7% of the total of nest failure. We documented one case of parasitism by Red-eyed Cowbird *Molothrus aeneus*, but this nest was predated before the subsequent visit; although parasitism events are unusual, nest parasitism in shrikes has been reported before (Degeus & Best 1991).

The combined nesting success for the three years was 64.3% (nests where at least one young fledged), close to the higher values reported by Pruitt (2000) that ranged between 25–72%, comparable to Colorado shrikes at 66.2% (Porter et al. 1975), less than reported for Missouri with 87.5% (Kridelbaugh 1983), and in between values reported for Illinois (50–100%; Chabot et al. 2016). Estimated nest survival of 55.3% based on the Mayfield method was less than that found in an Ontario population at 98% (Chabot et al. 2001), but higher than the reported 26% in Illinois (Walk et al. 2006). The rate of daily nest survival (0.749) estimated by the logistic exposure method in our population cannot be compared with other studies as relevant data using the same method in other populations are not available.

The landscape structure and rain-fed agriculture in our study site, featuring bare fields and isolated trees and shrubs where shrikes nest, provide an optimal habitat for breeding Loggerhead Shrikes in Michoacán. Nonetheless, we found higher nest failure in nests closer to fencerows compared to those farther away in isolated mesquite patches. If we combine this observation with the fact that we witnessed isolated trees being cut down, the lack of substrates for nesting may pose an imminent threat and underlie population declines (Smallwood & Smallwood 2021). Although studies of this species are scarce for Mexico, unlike USA and Canada, Loggerhead Shrike populations appear to be experiencing significant declines throughout the southern continental range, including the region where we conducted our study (Berlanga et al. 2010, Fink et al. 2022). To better understand the situation in Mexico, we must replicate such demographic and distributional studies across different geographical regions of the country and in different habitats.

ACKNOWLEDGMENTS

This study was part of Octavio Soto Rojas Master's in Science program at Universidad Michoacana (UMSNH) and was partially funded by the Mexican National Council of Science (CONACYT) and the Coordinación de Investigación Científica (CIC-UMSNH). We thank students and staff from the Ornithology Lab at UMSNH for field assistance. We also thank anonymous reviewers for their input that greatly improved the manuscript. For this study, there was no direct manipulation of

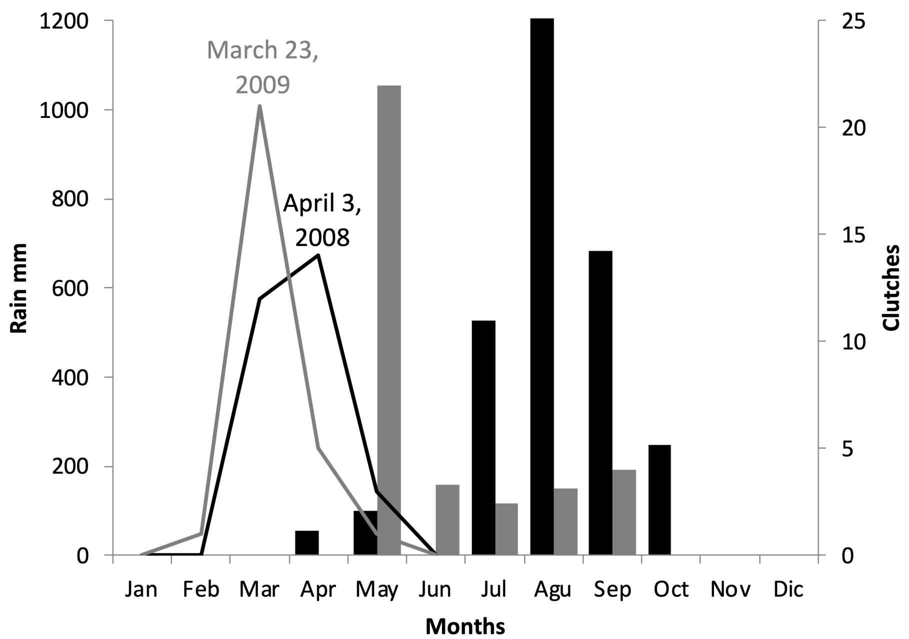

Figure 3. Relationships between rain and timing of clutches of two breeding seasons in the Lake Cuitzeo shore, Michoacán. Bars represent rain, and lines represent clutches. 2008: Rain represented by Black bars and peak clutch (3 April) by black line. 2009: Rain represented by gray bars and peak clutch (23 March) by grey line.

birds. Field protocols were approved and authorized by the Graduate Program Committee of the Biology Department at Universidad Michoacana.

REFERENCES

Berlanga HJ, A Kennedy, TD Rich, MC Arizmendi, CJ Beardmore, PJ Blancher, G Butcher, et al. (2010) Saving our shared birds: Partners in Flight Tri-National Vision for Landbird Conservation. Cornell Lab of Ornithology: Ithaca, NY.

Borgman CC & BO Wolf (2016) The indirect effects of climate variability on the reproductive dynamics and productivity of an avian predator in the arid Southwest. *Oecologia* 180:279–291. https://doi.org/10.1007/s00442-015-3456-6

Cade TJ & CP Woods (1997) Changes in distribution and abundance of Loggerhead Shrike. *Conservation Biology* 11: 21–31. https://doi.org/10.1046/j.1523-1739.1997.95279.x

Chabot A, DM Bird & RD Titman (2001) Breeding biology and nesting success of Loggerhead Shrike in Ontario. *Wilson Bull*etin 113:285–289. https://doi.org/10.1676/0043-5643(2001)113[0285:BBANSO]2.0.CO;2

Chabot A, F Harty, J Herkert & W Glass (2016). Population demographics of the Loggerhead Shrike: insights into the species decline from a long-term study in the Midewin National Tallgrass Prairie. *North American Prairie Conference Proceedings*. 13. Available at https://ir.library.illinoisstate.edu/napc/13 [Accessed 18 May 2023]

Chalfoun AD & TE Martin (2007) Latitudinal variation in avian incubation attentiveness. *Animal Behaviour* 73:579–589. https://doi.org/10.1016/j.anbehav.2006.09.010

Collister DM & K De Smet (1997) Breeding and natal dispersal in the Loggerhead Shrike. *Field Ornithology*. 68:273–282.

Conway CJ & TM Martin (2000) Effects of ambient temperature on avian incubation behavior. *Behavioral Ecology.* 11:178–188. https://doi.org/10.1093/beheco/11.2.178

COSEWIC (2000) Committee on the Status of Endangered Wildlife (COSEWIC). Available at http://www.cosewic.gc.ca/eng/sct1/SearchResult_e.cfm?commonName=Loggerhead+Shrike&scienceName=Lanius&Submit=Submit [Accessed 4 April 2023]

COSEWIC (2004). COSEWIC assessment and update status report on the Loggerhead Shrike *excubitorides* subspecies *Lanius ludovicianus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 24 pp. Available at www.sararegistry.gc.ca/status/status_e.cfm [Accessed 10 July 2023]

Degeus D W & LB Best (1991) Brown-headed Cowbirds parasitize Loggerhead Shrikes: first records for family *Laniidae*. *Wilson Bulletin* 103:504–506.

Dinsmore SJ, GC White & FL Knopf (2002) Advanced techniques for modeling avian nest survival. *Ecology* 83:3476–3488. https://doi.org/10.1890/0012-9658(2002)083[3476:ATFMAN]2.0.CO;2

Esely JD Jr & EK Bollinger (2001) Habitat selection and reproductive success of Loggerhead Shrike in Northwest Missouri: A hierarchical approach. *Wilson Bulletin* 113: 290–296. https://doi.org/10.1676/0043-5643(2001)113[0290:HSARSO]2.0.CO;2

Fink DT, AA Johnston, M Strimas-Mackey, S Ligocki, O Robinson, W Hochachka, L Jaromczyk, A Rodewald, C Wood, I Davies & A Spencer. (2022). eBird status and trends, data version: 2021; Released: 2022. Cornell Lab of Ornithology, Ithaca, New York. Available at https://doi.org/10.2173/ebirdst.2021 [Accessed 6 September 2023]

Gawlik DE & KL Bildstein (1993) Seasonal habitat use and abundance of Loggerhead Shrikes in South Carolina. *Journal of Wildlife Management* 57:352–357. https://doi.org/10.2307/3809433

Hepp GR, RA Kennamer & MH Johnson (2006) Maternal effects in Wood Ducks: incubation temperature influences incubation period and neonate phenotype. *Functional Ecology* 20:307–314. https://doi.org/10.1111/j.1365-2435.2006.01108.x

Hötker H (1998) Intraspecific variation in length of incubation period in Avocets *Recurvirostra avosetta*. *Ardea* 86:33–41.

Howell SNG & S Webb (1995) *A Guide to the Birds of Mexico and Northern Central America.* Oxford University Press Inc, New York, USA. https://doi.org/10.1093/oso/9780198540137.001.0001

Jetz W, Sekercioglu CH, Böhning-Gaese K (2008) The worldwide variation in avian clutch size across species and space. PLoS Biol 6:e303. https://doi.org/10.1371/journal.pbio.0060303

Koenig D (1982) Ecological and social factors affecting hatchability of eggs. *The Auk* 99:526–536.

Kridelbaugh A. (1983). Nesting ecology of the Loggerhead Shrike in central Missouri. The *Wilson Bulletin* 95:303–308.

Lefranc N (1997) Shrikes: *A Guide to the Shrikes of the World*. Ed. Yale University Press, USA.

Martin TE (2002) A new view of avian life-history evolution tested on an incubation paradox. *Proceedings of the Royal Society of London, Series B* 269:309–316. https://doi.org/10.1098/rspb.2001.1879

Martin EM, C Paine, CJ Conway, WM Hochachka, P Allen & P Jenkins (1997) *Breeding biology research and monitoring database*. Montana Coop. Wildlife Research Unit. University of Montana, USA.

Mayfield H (1961). Nesting success calculated from exposure. *Wilson Bulletin* 73:255–261.

Mayfield H (1975) Suggestions for calculating nest success. *Wilson Bulletin* 87:456–466.

Phillips AR (1986) *The Known Birds of North and Middle America, Part I.Hirundinidae to Mimidae;* Certhiidae. Denver Museum of Natural History, Denver, CO, USA.

Pool DB, AO Panjabi, A Macias-Duarte & DM Solhjem (2014) Rapid expansion of croplands in Chihuahua, Mexico threatens declining North American grassland bird species. *Biological Conservation* 170: 274–281. https://doi.org/10.1016/j.biocon.2013.12.019

Porter DK, MA Strong, JB Giezentanner & RA Ryder (1975) Nest ecology, productivity, and growth of the Loggerhead Shrike on the shortgrass prairie. *Southwestern Naturalist* 19:429–436. https://doi.org/10.2307/3670401

Posadas-Leal C, L Chapa-Vargas, MJT Arredondo & E Huber-Sannwald (2010) Effects of habitat type on bird breeding ecology in dessert grasslands of central Mexico. *Fauna and Flora International, Oryx* 44:448–454. https://doi.org/10.1017/S0030605310000426

Prescott DRC & RR Bjorge (1999) Status of the Loggerhead Shrike (*Lanius ludovicianus*) in Alberta. Alberta Environment, Fisheries and Wildlife Management Division, and Alberta Conservation Association, Wildlife Status Report No. 24. Edmonton, Alberta, Canada.

Pruitt, L., 2000, Loggerhead Shrike status assessment: Bloomington, Ind., U.S. Fish and Wildlife Service, 169 p., accessed January 2023 at https://www.fws.gov/midwest/es/soc/birds/losh.

Ralph CJ, GR Geupel, P Pyle, TE Martin, DF DeSante & B Milá (1996) Manual de métodos de campo para el monitoreo de aves terrestres. Gen. Tech. Rep. PSW-GTR-159. Albany, CA: Southwest Research Station, Forest Service, U. S. Department of Agriculture, USA. https://doi.org/10.2737/PSW-GTR-159

Rotella J, M Taper, S Stephens, & M Lindberg (2007) Extending methods for modelling heterogeneity in nest-survival data using generalized mixed models. *Studies in Avian Biology*. 34:34–44.

Salgado-Ortiz J, PP Marra & RJ Robertson (2009) Breeding seasonality of the Mangrove Warbler (*Dendroica petechia bryanti*) from southern Mexico. *Ornitología Neotropical* 20:255–263.

SAS Institute (2009) SAS/STAT User's Guide. SAS Institute Inc., Cary, USA

Sauer JR, S Orsillo & BG Peterjohn (1995) Geographic patterns and population trends of breeding and wintering Loggerhead Shrike in North America. *Proceedings of the Western Foundation of Vertebrate Zoology.* 6:128–141.

Sauer JR, DK Niven, JE Hines, DJ Ziolkowski Jr, KL Pardieck, JE Fallon, & WA Link (2017) The North American Breeding Bird Survey, Results and Analysis 1966–2015. Version 12.23.2015 USGS Patuxent Wildlife Research Center, Laurel, MD, USA.

Shaffer TL (2004) A unified approach to analyzing nest success. *Auk* 121:526–540. https://doi.org/10.1642/0004-8038(2004)121[0526:AUATAN]2.0.CO;2

Smallwood KS, & NL Smallwood (2021). Breeding density and collision mortality of Loggerhead Shrike (*Lanius ludovicianus*) in the Altamont Pass Wind Resource Area. Diversity 13, 54. https://doi.org/10.3390/d13110540

Tyler JD (1992) Nesting ecology of the Loggerhead Shrike in southwestern Oklahoma. *Wilson Bulletin* 104:95–104.

U.S. Fish and Wildlife Service (2008) *Birds of conservation concern 2008.* US Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, USA. Available at http://www.fws.gov/migratorybirds/NewReportsPublications/SpecialTopics/BCC2008/BCC2008.pdf [Accessed 7 July 2012]

Walk JW, EL Kershner & RE Warner (2006) Low nesting success of Loggerhead Shrike in an agricultural landscape. *Wilson Bulletin* 118:70–74. https://doi.org/10.1676/1559-4491(2006)118[0070:LNSOLS]2.0.CO;2

Yosef R (2001) Nesting ecology of resident Loggerhead Shrikes in south-central Florida. *Wilson Bulletin* 113:279–284. https://doi.org/10.1676/0043-5643(2001)113[0279:NEORLS]2.0.CO;2

Yosef R (2020) Loggerhead Shrike (*Lanius ludovicianus*), version 1.0. In Birds of the World (A. F. Poole and F. B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.logshr.01

Zicus MC, SK Hennes & MR Riggs (1995) Common Goldeneye nest attendance patterns. *Condor* 97:461–472. https://doi.org/10.2307/1369032