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Use of Nest Web Cameras and Citizen Science to Quantify Osprey Prey Delivery Rate and Nest Success

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Abstract.—Ospreys (*Pandion haliaetus*) are obligate piscivores and their nesting success depends on sufficient amounts of fish delivered to the nests during the breeding season. Nests are considered successful when pairs raise a minimum of one young to fledging or near-fledging age. Through web cameras and online broadcasts of Osprey nests, citizen scientists quantified daily number of fish deliveries, nest survival, and nest success. We received and analyzed curated data (one to seven seasons, 2014–2020) from citizen scientist groups representing 19 Osprey web cameras from four countries in North America and Europe. We compared the average and the coefficient of variation of the number of fish delivered per day within the early breeding season between the failed and successful nests using a Wilcoxon rank-sum test. We also analyzed the effects of the average and the coefficient of variation of the number of fish delivered per day on the number of days of nest survival and whether a nest was successful or not using generalized linear mixed models. Successful and failed nests had significant differences in the average number of fish delivered per day and the failed nests had a higher variation in the number of fish deliveries. Moreover, the variation and average number of fish delivered per day had strong associations with whether a nest would fail or succeed. The global effort and manner in which these data were collected are novel and can further our understanding of this charismatic species. The combination of citizen science and technology is a powerful modern tool that can provide insights and has the potential to advance raptor research worldwide.

Key Words: *Osprey*; Pandion haliaetus; *citizen science*; *nest success*; *prey*; *provisioning*; *web camera.*

USO DE CÁMARAS WEB EN NIDOS Y CIENCIA CIUDADANA PARA CUANTIFICAR LA TASA DE ENTREGA DE PRESAS Y EL ÉXITO DEL NIDO DE *PANDION HALIAETUS*

Resumen.—*Pandion haliaetus* es una especie piscívora obligada y su éxito de anidación depende de la cantidad suficiente de peces entregados a los nidos durante la temporada reproductiva. Los nidos se consideran exitosos cuando las parejas crían al menos un polluelo hasta la edad de emplumar o casi emplumar. A través de cámaras web y transmisiones en línea de los nidos de *P. haliaetus*, los científicos ciudadanos cuantificaron el número diario de entregas de peces, la supervivencia del nido y el éxito del nido. Recibimos y analizamos datos seleccionados (de una a siete temporadas, 2014-2020) de grupos de científicos ciudadanos correspondientes a 19 cámaras web de *P. haliaetus* provenientes de cuatro países de América del Norte y Europa. Comparamos el promedio y el coeficiente de variación del número de peces entregados por día durante la temporada reproductiva temprana entre los nidos fallidos y exitosos utilizando una prueba de suma de rangos de Wilcoxon. También analizamos los efectos del promedio y el coeficiente de variación del número de peces entregados por día sobre el número de días de supervivencia del nido y si un nido fue exitoso o no utilizando Modelos Lineales Mixtos Generalizados. Los nidos exitosos y fallidos tuvieron un número promedio similar de peces entregados por día, pero los nidos fallidos tuvieron una mayor variación en el número de entregas de peces. Además, la variación y el número promedio de peces entregados por día tuvo una fuerte asociación con el éxito del nido. El esfuerzo global y

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la forma en que se recopilaron estos datos son novedosos y pueden ayudarnos a comprender mejor esta carismática especie. La combinación de ciencia ciudadana y tecnología es una poderosa herramienta moderna que puede proporcionar conocimientos y tiene el potencial de promover la investigación de aves rapaces en todo el mundo.

[Traducción del equipo editorial]

Introduction

Nesting success of Ospreys (*Pandion haliaetus)* depends on adequate amounts of prey delivered to the young. Although proximate causes of nest failure can include adverse weather conditions, predation, inexperienced parents, and siblicide (Poole 2019), the ultimate cause of nest failure may often be food shortage (Steenhof and Newton 2007). Nests are considered successful when pairs raise at a minimum of one young to fledging or near-fledging age (Steenhof and Newton 2007). Nesting success is a fundamental component of avian demography (Hoekman et al. 2002, Johnson et al. 2007), and is frequently measured to monitor population health (Johnson et al. 2007). Determining nest success can be time consuming and requires significant investment of human resources. However, the abundance of web cameras focused on raptor nests and the growing numbers of citizen scientists make it possible to explore critical questions relating to Osprey nesting success more efficiently in a cost-effective way. For example, we may assess which metrics can be used to predict nest failure and whether we can use nest web cameras to predict nest success or failure.

Ospreys are highly visible and display their prey, which makes them ideal for observation through nest web cameras. In addition, they acquire fish near nest sites, they are tolerant of short-term nest disturbance, and they habituate to humans (Henny et al. 2008, Johnson et al. 2008, Grove et al. 2009). Because of this, private property owners and organizations ranging from nonprofit organizations and foundations to utility companies and universities have made close-up views of nesting Ospreys accessible to the public at large via web cameras and live broadcasts (e.g., on YouTube). Footage from these cameras is monitored by dedicated observers during the breeding season. With the assistance of citizen science and modern technology, the influence of the number of fish deliveries on nest survival, nest success, and the number of fledglings can be investigated.

Despite the wealth of information generated by citizen scientists, data from citizen science are underutilized and the beneficial results for science and society are mostly unrealized as yet (Bonney et al. 2014). Under the right circumstances (direction from professional scientists and academic institutions, organized data collection, and quality assurance), citizen science can produce high quality data with reliable scientific conclusions, which can lead to unexpected insights and innovations (Trumbull et al. 2000). Here we present information from a global network of citizen scientists and 19 Osprey web cameras located in two bioregions, North America and Europe, with a total of 42 observed nest-seasons. To control for potential bias in the data used in this study, we included nests that met these criteria: (1) citizen scientists had direction and oversight from professional or academic organizations, (2) the data were publicly available or available upon request, (3) the data included daily prey delivery tallies, beginning with incubation, (4) supervisors had the ability to playback or review broadcasts, and (5) the data were organized and validated with quality assurance protocols (i.e., to account for overcounting or undercounting) performed by supervisors. These supervisors were live broadcast and chat moderators, or managers of the information gathered from citizen scientists, who organized the collected data.

The objectives of this study were to assess the relationship between the number of prey deliveries to the nest and nest success. Specifically, we analyzed how both the mean and the coefficient of variation of the number of fish delivered per day during the early breeding season may influence nest success or failure. Furthermore, to explore the relationship between food abundance and nest success, we asked two questions: (1) Does the average and/or variation in the number of fish delivered per day differ between failed and successful nests? and (2) For successful nests, does the average and/or variation in the number of fish delivered per day influence the number of young fledged? We predicted that higher numbers of fish delivered per day would be associated with greater nest success and that lower numbers and greater variation in the number of fish delivered per day would be associated with lower nest success.

Methods

From 2014–2020, observations were conducted during the Osprey breeding season and were recorded by citizen scientists. A total of 19 nests were included, with data sets ranging from one season to seven seasons. Nest failures were recorded for 11 nest-seasons from eight nests, while nest success was recorded for 31 nest-seasons from 15 nests. Total number of young fledged was 62, with an overall reproductive rate of 1.47 young per nest-season (62 young per 42 nest-seasons). This study represents two bioregions: North America (13 nests in Canada and the United States of America) and Europe (six nests in Finland and the United Kingdom; Table 1, Fig. 1). Nests were located in coastal and inland areas, at different altitudes, and in a variety of aquatic environments including coastal bays, estuaries, marshes, swamps, rivers, lakes, and ponds.

Table 1. Number of fish delivered per day to 19 Osprey nests within the first 46 d of the breeding season, beginning with the laying of the first egg (median, mean, SD). Years observed, successful years, and average fledged represent data of complete breeding seasons.

Nest Name	Location[a]	Fish Delivered per d Median	Fish Delivered per d Mean	Fish Delivered per d SD	No. Years Observed	% Successful Years	Average No. Fledged per Years Observed
California	Richmond, CA, USA	2	2.65	1.27	3	100	2.3
Canada	Osoyoos, BC, CAN	2	2.41	1.73	1	0	0
Colorado 1	Boulder County, CO, USA	2	2.37	1.08	1	0	0
Colorado 2	Boulder County, CO, USA	2	2.13	0.78	1	100	3
Colorado 3	Emma, CO, USA	3	3.20	1.56	1	100	2
Finland 1	Seili Island, Pargas, FIN	2	1.87	1.13	1	0	0
Finland 2	Satakunnan sääkset, FIN	2	2.51	1.47	3	100	2.7
Finland 3	Satakunnan sääkset, FIN	2	2.45	1.21	1	100	2
Georgia	Savannah, GA, USA	5	4.78	1.19	1	100	2
Maine	Hog Island, ME, USA	2	2.42	0.97	7	71	1.1
Maryland	Kent Island, MD, USA	2	2.52	1.66	4	50	1.5
Montana 1	Lolo, MT, USA	2	2.14	1.22	6	83	1.7
Montana 2	Charlo, MT, USA	4	4.00	1.74	4	100	1.8
New Jersey	Barnegat, NJ, USA	3	2.64	1.28	1	100	3
South Carolina	Lake Murray, SC, USA	5	4.76	1.57	1	100	2
United Kingdom 1	Loch Garten, Aviemore, UK	1	0.99	0.78	3	30	0.7
United Kingdom 2	Glaslyn, Snowdon, UK	2	2.00	0.72	1	100	3
United Kingdom 3	Glaslyn, Snowdon, UK	1	1.17	0.47	1	0	0
Washington	Cowlitz County, WA, USA	3	2.76	1.34	1	100	1

[a] city/county, state/province, and country

Observers recorded the number of fish delivered per day, days of nest survival (days to failure), the number of fledglings, and the final outcome (nest success or failure) during the daylight hours including weekends and holidays. The Ospreys observed in this study did not bring any prey types other than fish to the nests. If cameras experienced technical difficulties such as being offline for more than 4 hr/d, we did not include data for those days.

Observers' data collection often started when nests became occupied (i.e., the territorial pair copulated or built or refurbished their nest). However, we specifically used the observer data starting when the first egg was laid and incubation began; Ospreys typically lay 1–4 eggs and incubate for 36–42 d (Poole 1989, Bierregaard et al. 2020). Observer data collection was terminated when: (1) the nest failed, (2) the camera went offline or failed, (3) the nestlings fledged, or (4) the fledglings became more independent. If a camera failed before the breeding season ended, we received later communication from the supervisors to report nest success/failure and the number of fledglings.

A nest is considered successful when a pair raise at least one young to the minimum acceptable age (Steenhof and Newton 2007). We defined the number of fledglings as the number of young in the nest that reached the 80% first-flight age criterion. If all young died before the age of fledging or before the 80% first-flight age criterion, we recorded zero fledglings. We defined the days of survival from the start of incubation, until the end of data collection, or the death of nestlings if that occurred first.

In our data set, among nests that failed, the average time to failure was 46 d; this represents incubation and the first 1–2 wk of the nestling period. Thus, we chose the first 46 d as the time period for testing for differences in the number of daily prey deliveries between the successful and failed nests. We note that some nests that reached 46 d of nest survival failed later and did not ultimately fledge young. Therefore for our statistical analysis, we analyzed data from the first 46 d to make comparisons between successful and failed nests. We compared the average and coefficient of variation of the number of fish delivered per day between the successful and failed nests using the Wilcoxon rank-sum test.

We also used generalized linear mixed models (GLMMs; *glmer* function with a Poisson distribution and log link), with nest as a random effect, to analyze the effects of the mean and coefficient of variation of the number of fish delivered per day on the number of days of nest survival (days to failure), including data from the first 46 d for both successful and failed nests. The unit for the response variable was days. Additionally, we analyzed whether or not a nest succeeded using GLMMs, with nest as a random effect, using the *glmer* function with a binomial distribution and logit link of the *lme4* package (in R version 4.0.2; Venables and Ripley 2002, Bolker et al. 2009, R Core Team 2020). We used the Laplace approximation for maximum likelihood

Figure 1. Locations of 19 Osprey nests and web cameras, representing data collected by citizen scientists for one to seven breeding seasons (2014–2020): (a) North America, (b) Europe.

in the *lme4* package for the Poisson and binomial distributions and GLMMs (Venables and Ripley 2002), and we reported 95% confidence intervals for parameter estimates and considered a variable to be influential when its 95% confidence interval did not include zero.

To assess whether the number of fish delivered per day influenced the number of young fledged, we used the Wilcoxon rank-sum test. For this analysis, we did not use data from the failed nests. Specifically, we included all the days observed from the successful nests (i.e., incubation and throughout the entire nesting period).

RESULTS

Of the 42 nest-seasons observed, 74% were successful and 26% failed (Table 1). The average number of fish delivered per day (for the first 46 d) differed significantly between the successful and failed nests, as indicated by the median of 1.8 fish delivered per day to the failed nests and the median of 2.6 fish delivered per day to the successful nests (Fig. 2a). In addition, failed nests had significantly higher variation in the number of fish delivered per day compared to successful nests (Fig. 2b). The average number of fish delivered per day was a significant predictor of whether or not a nest succeeded (df residual = 39, $P = 0.008$, CI = 0.566, 3.69, $\beta = 2.13$, SE = 0.80). Successful nests had lower variation in the number of fish delivered per day, while failed nests experienced higher variation in the number of fish delivered per day (df residual = 39, $P = 0.027$, CI = –0.124, –0.008, $\beta = -0.07$, SE = 0.03).

The average number of fish delivered per day was not a significant predictor of the number of days to failure (df residual = 8, $P = 0.13$, CI = –0.07, 0.59, $\beta = 0.25$, SE = 0.16). However, greater variation in the number of fish delivered per day was associated with shorter time to nest failure (df residual = 8, $P = 0.03$, CI = –0.01, –0.0005, $\beta = -0.006$, SE = 0.003). Neither the average nor the coefficient of variation in the number of fish delivered per day differed between nests with a single fledgling compared to those with more than one fledgling (Fig. 3).

DISCUSSION

Our study is the first to use data collected from citizen scientists from a worldwide network of Osprey nest web cameras. The main conclusion of this study suggests that the average and the coefficient of variation of the number of fish delivered per day in the early portion of the breeding season can be used as effective predictors for nest success or failure. In our study, nests that had an average of three or more fish delivered per day were more likely to be successful. This is, on average, one fish per day more than that observed for failed nests. Low variation in the number of fish delivered per day was also associated with nest success.

Although the average number of fish delivered per day significantly contributed to nest success, the number of days a nest survived before failing was influenced by another predictor, the coefficient of variation. Nests with higher variation during the early portion of the breeding season were more likely to fail.

Even though we expected that more fish delivered would be associated with higher numbers of fledglings, we did not see that pattern. Neither the average number of fish delivered per day nor the coefficient of variation differed between nests that fledged one or more than one young. This could be due to the small sample size. In our study, nest-seasons that produced one fledgling ($n = 7$) were less common than those that produced more than one fledging ($n = 24$). Diet quality may also play a role; prey composition with varying energy content due to spatial differences influenced the reproductive success of the Chesapeake Bay Osprey population (Glass and Watts 2009).

Our study represents an innovative and resourceful approach to investigate the number of fish delivered per day to nests, but there are limitations and much potential for future work. Some qualitative aspects of diet composition such as fish size and species are missing because they are difficult to obtain and require more advances in technology, more web cameras per site, and highly trained volunteers who can correctly identify fish species. Prey identification is an essential component of animal ecology (Errington 1935) and, for raptors, prey species types and their distributions can influence raptor population shifts (Newton 1979). Consequently, knowledge of prey composition is vital for the successful management and conservation of raptors (Giovanni et al. 2007). In addition, future research should target weather associations with the number of fish deliveries, address seasonal changes in diet composition, and explore food distribution among young (Poole 2019). We have much to gain with nest web cameras and citizen science can provide quantitative and qualitative information about prey and provisioning. The potential opportunities and applications of data collected through raptor nest web cameras and citizen scientists have yet to be fully explored, realized, and implemented in education, conservation, and policy.

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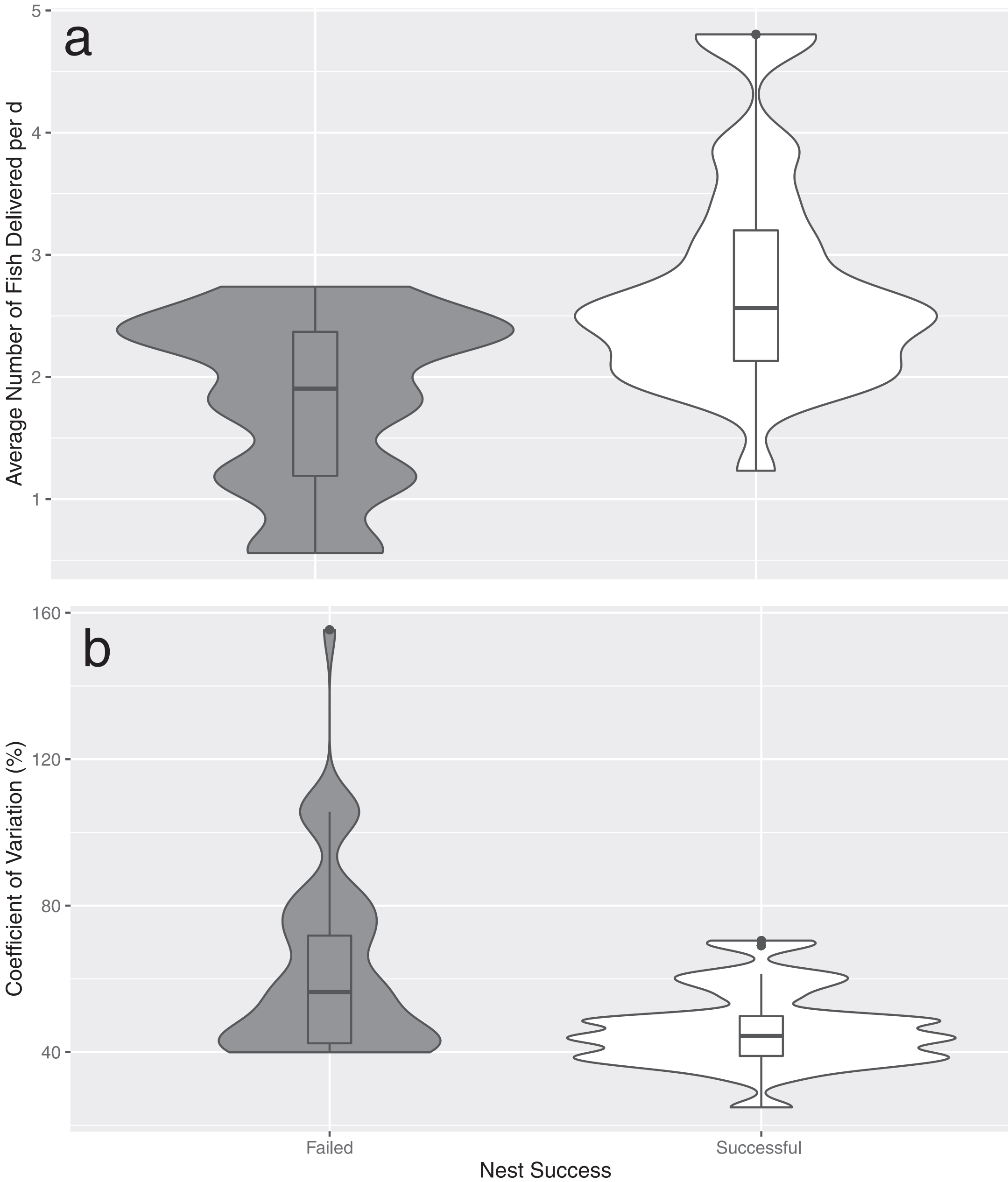

Figure 2. Food delivery at failed and successful nests: (a) mean number of fish delivered per day ($P < 0.001$, CI = –0.85, –0.70) and (b) coefficient of variation ($P < 0.001$, CI = 7.9, 11.9). Violin shapes represent the density of data distribution and the middle lines in the box plots represent the median values.

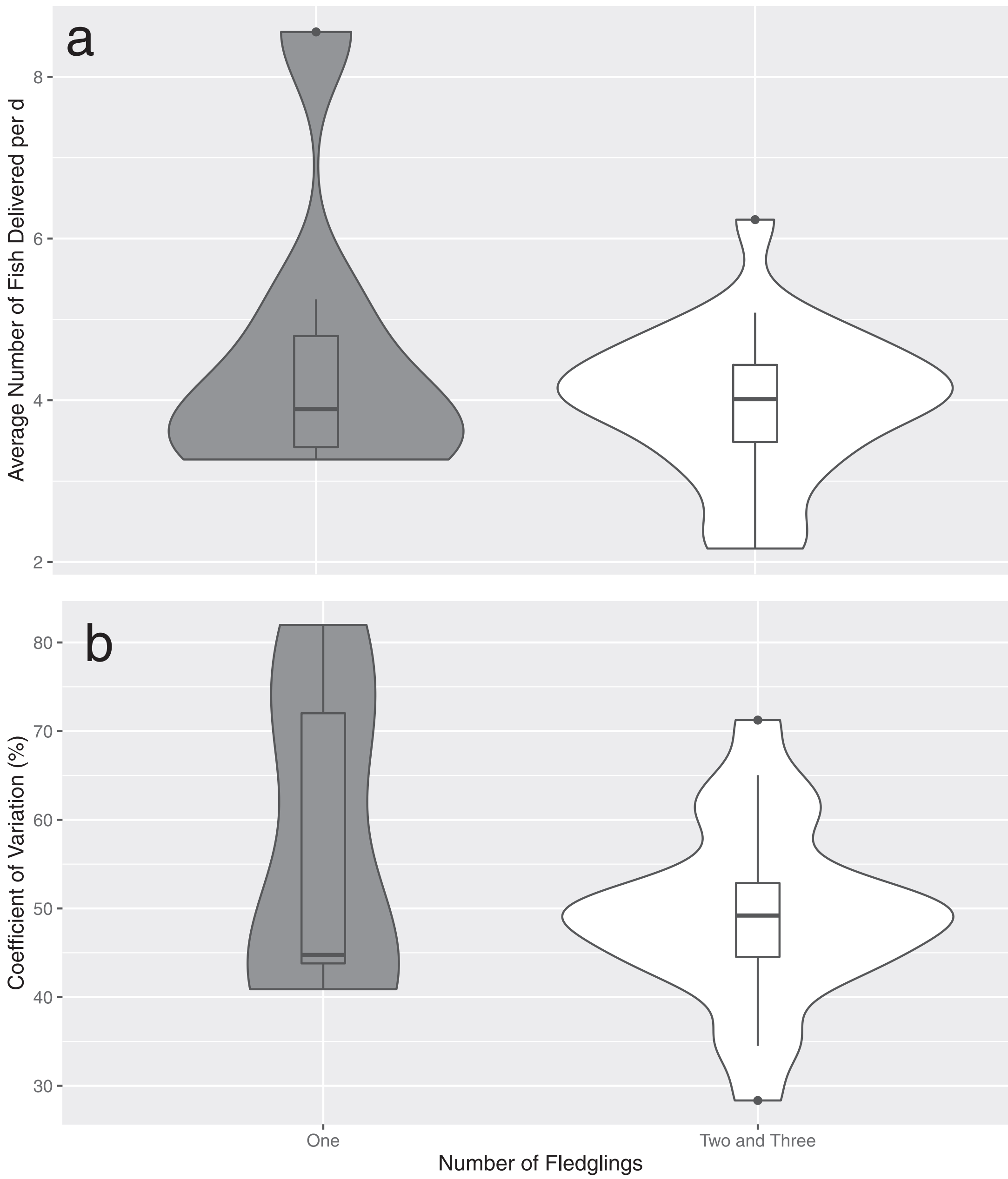

Figure 3. Food delivery at Osprey nests that produced one fledgling ($n = 7$) and nests that produced two or more fledglings ($n = 24$): (a) average number of fish delivered per day ($P = 0.87$, CI = –0.73, 1.27), and (b) the coefficient of variation ($P = 0.72$, CI = –6.41, 23.3). The violin shapes indicate that the density of data distribution was more variable for the nests/seasons with one fledgling. Average values did not differ significantly.

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