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Road surveys detect unusually high Wedge-tailed Shearwater fallout in SE O‘ahu during the 2011 fledging season

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INTRODUCTION

The Wedge-tailed Shearwater (*Ardenna pacifica, WTSH,* ‘Ua‘u Kani) nests throughout the Hawaiian Archipelago, from Kure Atoll in the north to the offshore islets of Maui in the south, with a total estimated population of 270,000 breeding pairs (bp) (Whittow 1997, Pyle & Pyle 2017). Approximately 34,000 WTSH bp nest in five colonies along the southeast shore of O‘ahu: Mānana (32,930 bp), Kāohikaipu (649 bp), Popoia (669 bp), Mokulua Nui and Mokulua Iki (8,968 bp) (Pyle & Pyle 2017, Friswold et al. 2020).

While this species has declined in abundance, due to impacts from introduced mammalian predators (i.e., rats, cats, dogs), coastal development, and encroachment of their colonies (i.e., trampling of burrows, light pollution), it is not considered at risk by the U.S. Fish and Wildlife Service (USFWS 2021) or by the International Union for the Conservation of Nature (BirdLife International 2021).

During the fledging season, from early November to late December (Whittow 1997), hundreds of WTSH chicks are attracted to urban lights and become grounded along the windward (east) shore of the island of O‘ahu due to exhaustion and collisions with utility wires and poles (Work & Rameyer 1999, Friswold et al. 2020). Stranded birds reported to state and federal wildlife agencies are recorded, noting the date and location of each stranding, and have been used to assess the magnitude of annual fallout (Work & Rameyer 1999).

Starting in 2002, the U.S. Fish and Wildlife Service (USFWS) initiated a program of systematic surveys to document fallout, the grounding of WTSH, during the fledging season (November – December). Between 2002 and 2010, road surveys of grounded WTSH during their fledging season (November – December) along a 25.7-km section of the Kalaniana‘ole Highway, a coastal roadway along the SE coastline of O‘ahu, documented an average of 44.0 +/- 25.9 S.D. (range = 9 – 91) annually (Friswold et al. 2020).

In this paper, we document an unusually large fallout event in 2011, in the context of the existing surveys (2002 - 2010). We first describe the spatial and the temporal distribution of the 2011 fallout in relation to the lunar cycle. Then, to place these observations in a broader context, we relate the interannual magnitude of WTSH fallout to the lunar cycle over the entire 10-year study period (2002 - 2011). Previous studies around the globe have shown a negative relationship between the number of grounded shearwaters and the amount of lunar illumination, with night-time fallout peaking around the new moon and decreasing around the full moon (Telfer et al. 1987, Ainley et al. 2001, Le Corre et al. 2002, Rodriguez and Rodriguez 2009, Rodriguez et al. 2014, Syposz et al. 2018).

For instance, records of Newell’s Shearwater (*Puffinus newelli*) fallout in Kaua‘i between 1978 - 1983 peaked between mid-October and the first week of November. Despite substantial year-to-year variability in the amount of fallout, the moon phase was deemed the most important variable affecting the daily number of grounded fledglings. Fallout was lowest around the full moon, and highest around the new moon. Moreover, the moon cycle shaped the temporal distribution of fallout, with a single peak in years when the new moon coincided with the peak fledging period, and with two separate peaks in years when the full moon coincided with the peak fledging period (Telfer et al. 1987).

Overall, the total number of Newell's Shearwater fledglings retrieved by rescue programs in Kaua'i each fall (September - November) between 1980 and 1994, was significantly related to how closely the full moon coincided with the peak of fledging (mid-October). Quantitative analyses revealed a quadratic relationship between the timing of the full moon and the number of grounded birds, with fewer groundings when the full moon coincided with the period of peak fledging (Ainley et al. 2001). While the influence of the lunar cycle on the timing and magnitude of Newell's Shearwater fallout is well understood, a similar pattern has not been established for WTSH.

METHODS

Road Surveys of the Study Area - Our study area spans the SE corner of the island of Oʻahu, along the windward coast and downwind from the Mānana Island and Kāohikaipu Island WTSH colonies (Figure 1).

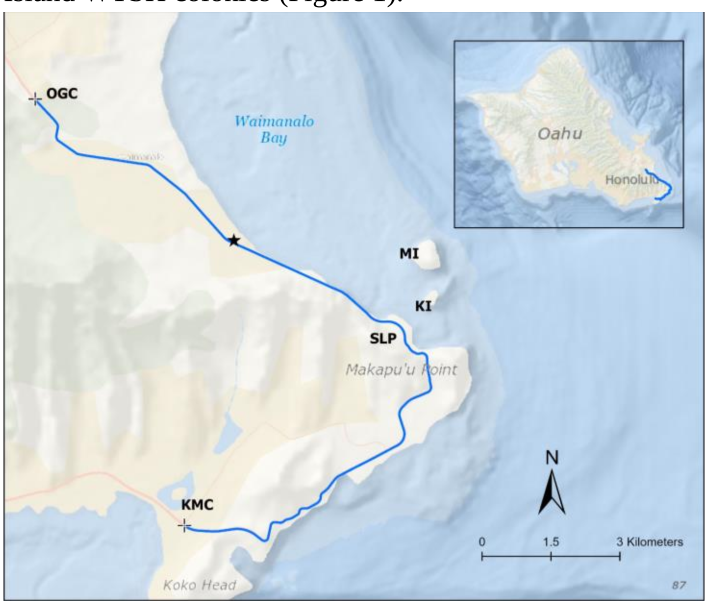

Figure 1. Map of the study area, showing the coastal highway from Olomana Golf Course (OGC) to the Koko Marina Center (KMC) and running through Waimānalo town, where the Sea Life Park (SLP) seabird rehabilitation center, and two WTSH colonies (Mānana Island, MI; Kāohikaipu Island, KI) are located. The star highlights the Waimānalo district park, the site of a recreational sports field and an area of historical (2002 – 2010) peak fallout.

Previously, Friswold et al. (2020) showed that this is an area of high WTSH fallout, with grounded birds concentrated within 5 km from offshore colonies and aggregated around utility poles and lights.

In 2011, we surveyed a 17.3-km section of the Kalanianaʻole Highway (State Route 72) from the Koko Marina Center in Hawaiʻi Kai to the Olomana Golf Course (Figure 1), repeatedly during the WTSH fledging season (Nov. 1 – Dec. 28). We used the same standardized methods described in Friswold et al. (2020) to document live and dead grounded WTSH. Starting shortly after dawn, a trained observer drove the same predetermined route in both directions (out-and-back trip). While posted speed limits along the route were 20–45 mph, survey speeds ranged from 25–35 mph.

Analysis of Fallout Distribution - We recorded the location (latitude, longitude) of the WTSH fallout with a hand-held GPS (Garmin etrex) and used the ArcGIS software to map these locations using kernel density distributions. We modelled fallout using several percentage contours (5%, 25%, 50%, 75%, 95%), which estimate the smallest areas that encompassed a given proportion of all the locations of grounded WTSH. We equated the range (areal extent encompassing the fallout events) with the 95% contour and identified the hotspots (areas of highest fallout density) with the 25% contour.

Analysis of Lunar Cycle - We analyzed the influence of the lunar cycle in two ways. First, we focused on 2011 and used simple linear regression to explore how well the percent of WTSH fallout observed during a given road survey was explained by the lunar illumination during the previous night. We quantified lunar illumination using the percent of the lunar disk that was illuminated each night, using publicly available data from the U.S. Naval Observatory (*www.usno.navy.mil/USNO/astronomical-applications*).

Second, we expanded the analysis to the entire 10-year dataset (2002 – 2011) and related the total WTSH fallout during road surveys to the temporal match between the moon cycle and November 25, the peak date of WTSH fallout from the observed daily totals reported by Friswold et al. (2020). Thus, we calculated the lunar match as the interval (number of days) between November 25 and the date of the closest new moon. Because we hypothesized that total fallout would be higher in years when the new moon coincided with the day of peak historical fallout, we anticipated that total fallout would decline as the interval increased, yielding a negative correlation.

RESULTS

Overall WTSH Fallout in 2011- We completed 18 replicate surveys spanning 46 hours, and documented a total of 131 grounded WTSH along the survey route. The total count of grounded shearwaters observed in 2011 was anomalous in the context of the historical surveys (2002 - 2010) of Friswold et al. (2020). Because the historical counts were normally distributed (Shapiro-Wilk normality test, n = 9, w = 0.9349, p = 0.5292), we calculated a Z-score to assess the probability of obtaining the fallout observed in 2011. This analysis confirmed that the number of grounded WTSH in 2011 was an extreme outlier, over three standard deviations beyond the long-term (2002 - 2010) average (mean = 44.0 +/- 25.9 S.D.) (Figure 2). In fact, the resulting Z score (3.36) was highly anomalous, with a significant probability value (p = 0.0008). This result means that, given the previous 9 years of surveys, we would expect to observe an annual fallout of 131 or higher with a frequency of less than 1 in 1000 years.

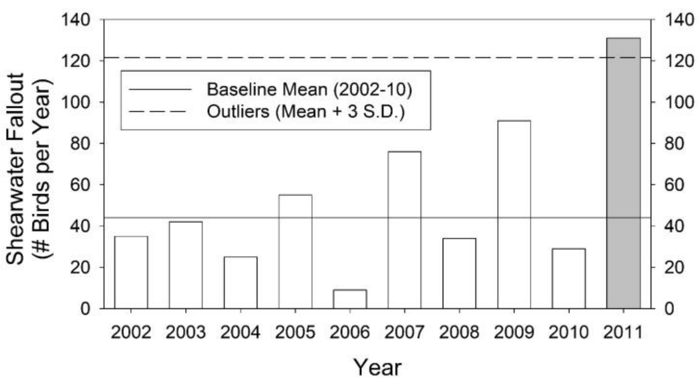

Figure 2. Time series of annual WTSH fallout documented during road surveys. The grey bar indicates the anomalous 2011 data, significantly higher than the baseline (2002 – 2010) average.

Spatial Distribution of Fallout in 2011 - Most grounded WTSH were found in Waimānalo town, as evidenced by the core fallout area, identified by the 25% density contour (Figure 3). In particular, the two "hotspots" with the highest fallout density (5% contour) focused on the sports field and the urbanized area to the northwest. These results are consistent with previous spatial analyses, which identified an area of peak historical (2002 – 2010) WTSH fallout in Waimānalo town, within 5 km from the breeding sites (Mānana Island and Kāohikaipu Island), and clustered in the vicinity of light poles (Friswold et al. 2020).

Temporal Distribution of Fallout in 2011 - In 2011, fallout was widespread, with 77.8% (14 of 18) of the road surveys detecting grounded WTSH. There were two disjunct fallout periods, separated by the full moon: a larger early period (November 14 – December 8) and a smaller late period (December 19 – 22) (Figure 4).

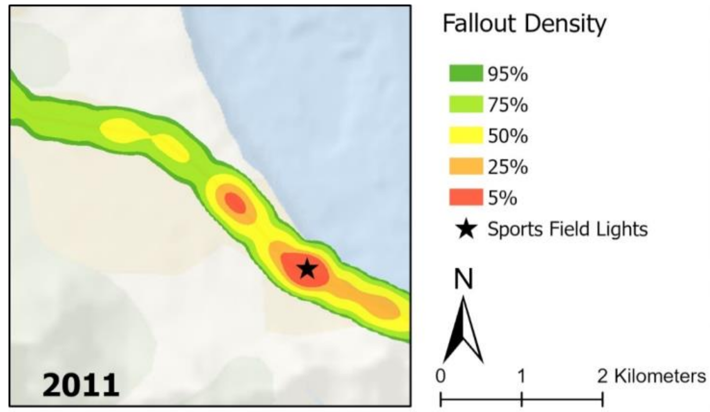

Figure 3. Kernel modelling of the spatial distribution of WTSH fallout from road surveys, with the contours indicating the proportional areal extent of grounded birds along the survey route. The 95% and the 50% contours denote the range and the core fallout areas. Two high density "hotspots", denoted by the 5% contour, occurred in Waimānalo town, in the vicinity of the recreational sports field (denoted by the star). For a broader spatial context see Figure 1.

Fallout was highly aggregated temporally, with 69% of the grounded birds occurring within a 10-day period (November 23 – December 2).

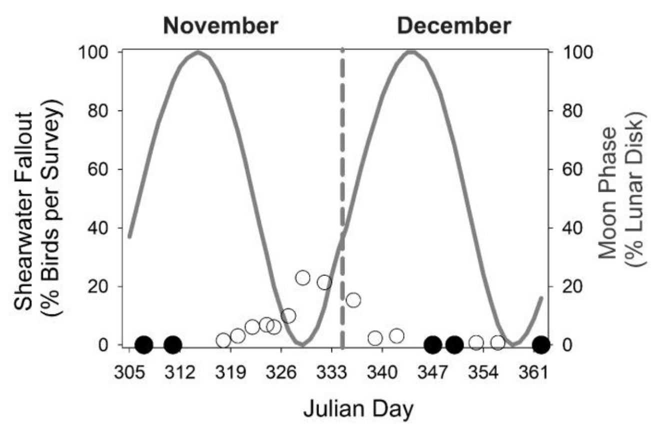

Figure 4. Temporal distribution of WTSH fallout during 2011 road surveys, in relation to the lunar cycle. Open and filled circles indicate surveys with and without fallout, respectively. The vertical dashed line indicates the shift in calendar months.

The number of WTSH per survey ranged from 0 to 30 (mean = 5.5 +/- 7.3 S.D., median = 2.7), with the highest daily count occurring on November 25 (Julian Day 329). Interestingly, this is the same date previously identified as the daily peak of historical WTSH fallout (2002 – 2010) (Friswold et al. 2020).

When we analyzed the timing of WTSH fallout (the number of grounded birds detected per survey) in relation to the date

(Julian Day) and to the lunar cycle, quantified using the percent of the lunar disk illuminated the night before the road surveys took place, we found three highly significant relationships. Simple linear regression revealed that WTSH fallout during a given survey was negatively correlated to lunar illumination (coefficient = -221.0208 +/- 87.1385 S.E., t = -2.536, p = 0.0237) and was negatively correlated to the Julian Day (coefficient = -0.4569 +/- 0.1552 S.E., t = -2.945, p = 0.0107). Furthermore, there was a significant interaction between lunar illumination and Julian Date, whereby fallout during moonless nights was higher earlier in the fledging season (coefficient = +0.6190 +/- 0.2591 S.E., t = -2.389, p = 0.0315). Overall, this model was highly significant (F statistic = 5.884, df = 3 and 14, p = 0.0081), and explained 46.3% of the observed fallout (adjusted R-squared = 0.463). Moreover, the residuals were normally distributed, justifying the use of linear regression (Shapiro-Wilk test, W = 0.9103, p = 0.0871).

Influence of the Lunar Cycle - Finally, we investigated whether the significant correlation we documented in 2011, between higher lunar illumination and lower WTSH fallout, could be used to explain the year-to-year variability observed over the entire study (2002 – 2011). Because the new moon in 2011 coincided with the historical peak fallout date (November 25), the lunar interval for that year was 0 days. When we considered the influence of the lunar cycle across the 10 years (2002 – 2011) of surveys, the total yearly fallout and the annual lunar interval using the historical peak fallout date of November 25 were negatively correlated, but the result was not significant (Pearson correlation = -0.243, df = 8, p = 0.4984).

DISCUSSION

Fledging shearwaters are attracted to lights and grounded due to exhaustion and collisions with utility wires, and other anthropogenic structures, with published reports of WTSH fallout documenting an average of 41 and 56 birds collected each year in Maui and Kaua‘i (Rodríguez et al. 2017). Our recent surveys of SE O‘ahu between 2002 and 2011 documented an average of 52.7 +/- 36.7 S.D. (range = 9 – 131) grounded WTSH annually.

While these average annual fallout numbers from road surveys are low, in relation to the estimated WTSH breeding population, large WTSH mass strandings have been documented during years of unusual weather conditions. For instance, during the 1994 fledging season, island-wide admission records from Sea Life Park recorded 1226 underweight and dehydrated chicks, stranded along the SE coast of O‘ahu, with fewer birds documented along the northeast and southwest coasts of the island. In comparison, additional Sea Life Park records revealed low fallout during two years of “normal” weather conditions, with 119 (1992) and 112 (1993) grounded birds (Work & Rameyer 1999).

Despite underestimating total island-wide WTSH fallout, these road survey counts in SE O‘ahu provide a relative index of the timing and magnitude of groundings within a known fallout hotspot. For instance, 667 WTSH were rescued and delivered to Sea Life Park during the 2011 fledging season, the same year we recorded our highest survey count of 131 grounded WTSH (Jeff Pawloswki, Sea Life Park, pers. comm.). For reference, this figure is approximately half of the total fallout documented during the 1994 mass stranding event (Work & Rameyer 1999).

The narrow timing (November 14 – December 8) and the focused spatial distribution of fallout, suggest that an unusual mortality event happened during the 2011 WTSH fledging season, like the one documented in 1994 by Work & Rameyer (1999). During the 1994 mortality event, grounded fledglings were dispersed throughout the windward coast of O‘ahu, north of our study area and into Kailua and *Kāne‘ohe*, and fallout spanned an 8-week period, from week 44 (October 29 – November 4) to week 51 (December 17 – 23) (Work & Rameyer 1999). Thus, the unusually high fallout in 2011 was likely caused by the alignment of the new moon and the date of WTSH peak fledging, which caused two discrete fallout peaks during low moon periods (< 50% lunar disk illuminated) (Figure 4). Nevertheless, the synchrony of the lunar cycle with WTSH peak fledging did not explain the interannual variability we observed, based on the statistical analysis of the data from 2002 to 2011.

Evidence that WTSH fallout was spatially aggregated around the Waimānalo district park led to a targeted management action by the State of Hawai‘i Department of Land and Natural Resources (DLNR). The DLNR Division of Forestry and Wildlife (DOFAW) state seabird coordinator contacted the City of Honolulu Parks and Recreation Department to request that the stadium lights illuminating the recreational sports field be turned off at night during the shearwater fledging season (N. Creps, pers. comm.).

Starting in the 2012 fledging season, the lights were turned off at night. Because the night-time illumination of the Waimānalo district park seems to have influenced the distribution and magnitude of WTSH fallout in 2011 (Figure 3) and during the previous study years (2002-2010; Friswold et al. 2020), surveys after 2011 are expected to yield more dispersed fallout and lower overall groundings. In addition to data on the spatial and temporal distribution of grounded WTSH, interpreting the likely causes of unusually large fallout events requires the integration of demographic information. Namely, the breeding population size and the reproductive success of WTSH are needed to understand how the productivity of chicks and their development influences the magnitude and timing of fallout. Additionally, information on the environmental drivers of fallout, including the timing of the lunar cycle and the prevailing wind conditions, can help interpret how weather and light attraction modulate fallout, given the supply of fledging WTSH chicks (e.g., Rodriguez et al. 2014, Syposz et al. 2018). In particular, establishing a baseline of the magnitude, timing, and spatial distribution of fallout is critical for detecting unusual events, and for identifying whether mass strandings are the result of biotic (e.g., year of higher chick fledging, poor body condition) or abiotic (e.g., lunar cycle timing, unusual weather) drivers (e.g., Work & Rameyer 1999, Ainley et al. 2001).

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