FACTORS INFLUENCING THE PRODUCTIVITY OF COCOS BOOBY *SULA BREWSTERI* IN THE GULF OF PANAMA

SILVIA MELCHIORI[1]*, JONAS HENTATI-SUNDBERG[2], GIACOMO SANTINI[3], & HECTOR M. GUZMÁN[1]

[1]*Naos Marine Laboratory, Smithsonian Tropical Research Institute, Panama City, Panama *(silviamelc@gmail.com)*
[2]*Department of Aquatic Resources, Swedish University of Agricultural Sciences, Uppsala, Sweden*
[3]*Department of Biology, University of Florence, Sesto Fiorentino, Italy*

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ABSTRACT

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In the Eastern Tropical Pacific, nutrient-rich upwelling benefits seabirds by increasing prey availability, thereby improving breeding success. El Niño, however, can disrupt upwelling intensity, altering food availability and consequently having significant ecological consequences for seabirds. These effects vary with El Niño intensity and local oceanographic conditions. This study examines how varying ocean conditions influence the breeding performance of the Cocos Booby *Sula brewsteri* on Bona Island, Gulf of Panama. We compare productivity over two years that differed in El Niño intensity (weak and strong) and assess the effects on local oceanographic conditions. No dramatic effects on Cocos Booby were observed, although overall breeding success was low in both years. A few differences in breeding performance were evident between the two years despite significant differences in oceanographic conditions. Nevertheless, conditions remained close to the average observed over the past 15 years, suggesting that upwelling in the Gulf of Panama may act as a buffer, reducing the scope and impact of El Niño events on seabirds. These findings need to be confirmed by research during very strong El Niño and neutral years. Despite the short timeframe of this study, it offers important preliminary insights into a phenomenon that significantly affects tropical seabirds and has been described only sporadically in Panama.

Key words: Panama, *Sula brewsteri*, breeding performance, oceanographic conditions, upwelling, El Niño

INTRODUCTION

The Eastern Tropical Pacific (ETP) is a biotically diverse and productive region (Ballance et al., 2006; Lavín et al., 2006). In this area, Ekman transport and vertical mixing influence key physical oceanographic parameters, including sea surface temperature (SST), sea surface salinity (SSS), and the depth and intensity of the thermocline (Lavín et al., 2006). In the gulfs of Tehuantepec, Papagayo, and Panama, Ekman pumping plays a significant role in generating coastal upwellings, thus shaping thermocline topography. The process involves seasonal replacement of warm, low-productivity surface waters with cooler, nutrient-rich deep waters (Amador et al., 2006; Corredor-Acosta et al., 2020). The upwelling process promotes zooplankton production and fish population growth, supporting the foraging needs of large marine predators (Amador et al., 2006; Corredor-Acosta et al., 2020; Thompson et al., 2012). However, climatic events such as marine heatwaves (MHW) (Cavole et al., 2016; Piatt et al., 2024; Smith et al., 2023) and the El Niño-Southern Oscillation (ENSO) (Torres et al., 2023) can alter these regular oceanographic conditions (Lavín et al., 2006). During the El Niño phase of ENSO, weakened winds reduce the intensity and duration of upwelling, leading to increased SST and decreased chlorophyll-*a* (Chl-*a*) concentrations (Lavín et al., 2006; Torres et al., 2023). These changes in primary productivity (PP) cascade up the food chain, ultimately affecting the survival, reproduction, and distribution of higher-trophic-level organisms, including seabirds (Ballance et al., 2006; Champagnon et al., 2018; Glynn, 1988). In addition, very strong El Niño events can amplify the intensity, duration, and spatial extension of MHW (Di Lorenzo & Mantua, 2016).

Seabirds are highly mobile marine predators that play an important role in the functioning of tropical ecosystems (Baum & Worm, 2009; Graham et al., 2018). Their sensitivity to environmental variability makes them vulnerable during periods of oceanographic disruption and diminished prey abundance, such as El Niño (Castillo-Guerrero et al., 2016; Jaksic & Fariña, 2010). In the ETP, episodes of high seabird mortality and reduced reproductive success have been documented during strong El Niño events, including those of 1982–1983 and 2015–2016 (Dueñas et al., 2021; England, 2000; Valle, 1987). Seabirds exhibit varied responses to positive climatic anomalies as a function of their body size, diet, foraging strategies, and degree of behavioural plasticity (Oro, 2014). Some species adapt to unfavourable conditions by extending their foraging ranges or switching target prey (Castillo-Guerrero et al., 2016; Glynn, 1988; Lerma et al., 2020). Although adults can buffer the effects of unfavourable conditions, breeding performance is more sensitive to changes in prey availability (Beadell et al., 2009; Burger & Piatt, 1990; Howard et al., 2021; Lerma et al., 2020).

The Gulf of Panama, one of the key coastal upwelling areas in the ETP, experiences seasonal upwelling (D'Croz & O'Dea, 2007) that benefits both migratory and resident seabirds, including the Cocos Booby *Sula brewsteri*, which exhibits enhanced reproductive success during periods of normal upwelling (Esparza et al., 2022). However, local responses of seabirds to positive climatic anomalies remain poorly documented. Strong El Niño events, such as those during 1982–1983, have been associated with reduced seabird reproductive success and high mortality in some seabird species

(Glynn, 1988). Conversely, observations indicate that some species that typically breed farther south in the Pacific—including those in the genus *Sula*—arrive in the Gulf in good condition and remain for over one year. This suggests that the Gulf of Panama may act as a refuge from adverse El Niño events (Smith, 1990). Similar patterns were observed during the 2015–2016 El Niño in Panama (Buitrago-Rosas et al., 2020) and in other areas of the central Pacific (Sandoval et al., 2016; Van Dort, 2018).

During the 2023–2024 breeding season, anomalous oceanographic conditions were expected in the equatorial Pacific due to an intense El Niño (Li et al., 2023). In this study, we examined potential effects on the Cocos Booby by comparing breeding success and local oceanographic data from the 2023–2024 season with data from 2018–2019, a year marked by a mild El Niño. We sought to improve our understanding of seabird sensitivity to positive climate anomalies, which may help inform conservation strategies in the ETP.

METHODS

Study Area

Fieldwork was conducted on Bona Island (08°34′30″N; 079°35′30″W), a small island in the Gulf of Panama near the mainland (Fig. 1) (Esparza et al., 2022). The island was declared a Wildlife Refuge in 2019 (Decree No. DM-0616-2019), the primary purpose being to conserve, protect, and restore its terrestrial and marine ecosystems (Guzman & Steeves, 2019). Several seabird species breed on Bona Island, including the Cocos Booby *Sula brewsteri* (subspecies *estatica*; VanderWerf, 2025), which was previously known as Brown Booby *S. leucogaster* but was split from Brown Booby in 2024 based on genetic analysis (Mlodinow et al., 2024); Brown Pelican *Pelecanus occidentalis*; Magnificent Frigatebird *Fregata magnificens*; and occasionally Blue-footed Booby *S. nebouxii* (Melchiori et al., 2025). The breeding locations of these species do not overlap spatially. Brown Pelicans and Magnificent Frigatebirds nest in the high canopies of trees distributed across the island and near the rocky coastline, respectively (Melchiori et al., 2025), whereas Cocos Boobies nest on the ground or on top of cacti or rocks, mainly in the western area of the island (Guzman & Steeves, 2019).

The breeding grounds of the Cocos Booby overlap with habitats used extensively by two native iguana species: Black Iguana *Ctenosaura similis* and Green Iguana *Iguana iguana*. Both species are protected in Panama (Law 24 of 07 June 1995). The Black Iguana is omnivorous and, in the Pacific region, has often been observed preying on bird eggs, chicks, and occasionally adult birds (Astorga-Acuña & Mora, 2023; García-Rosales et al., 2020), whereas the Green Iguana is primarily herbivorous, exhibiting only opportunistic omnivorous behaviour (Falcón et al., 2013). Iguanas have traditionally been hunted in Panama, and on Bona Island, despite their formal protection, fires are still sometimes deliberately set to facilitate their capture (Guzman & Steeves, 2019).

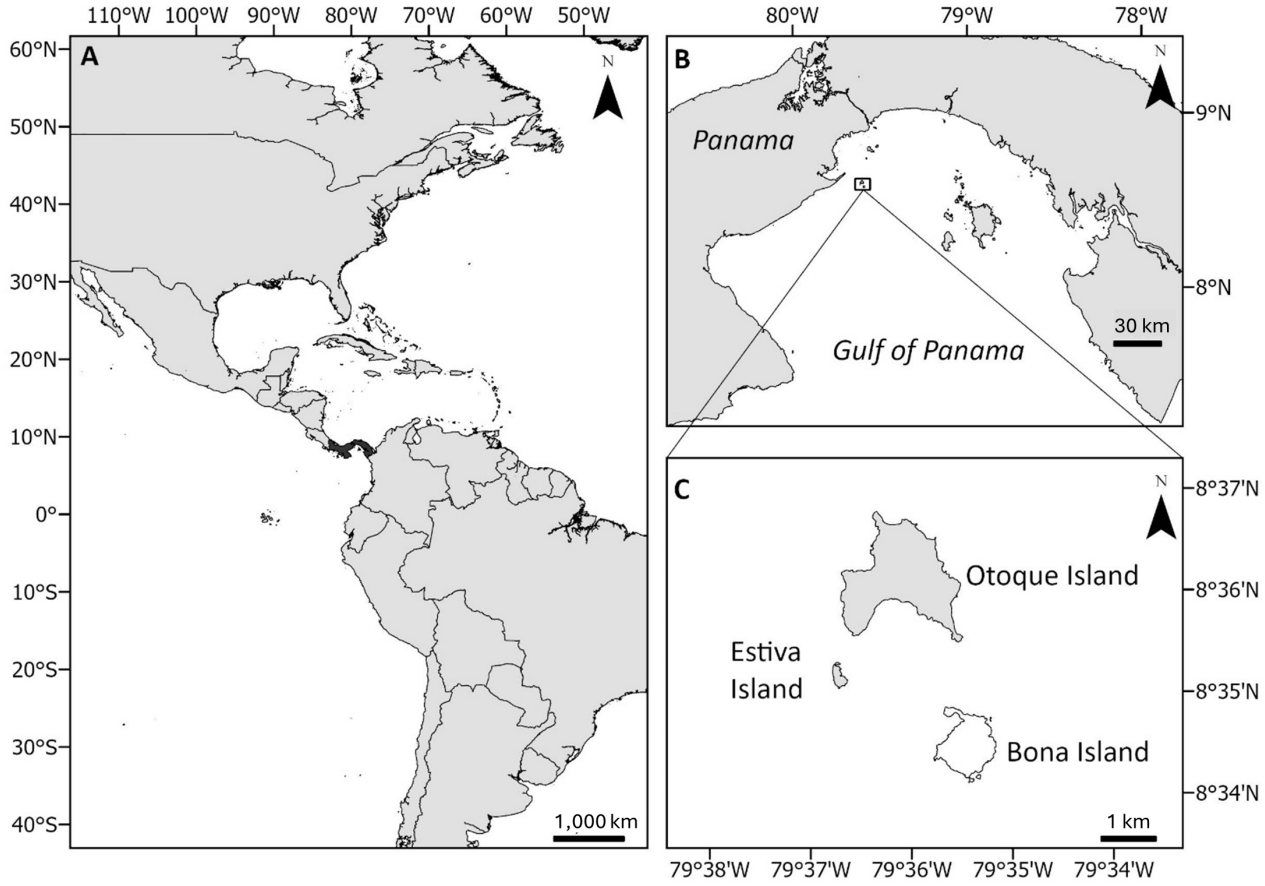


Fig. 1. (A) Location of Panama (black), (B) the Gulf of Panama, (C) Bona Island (white), and the nearby islands of Otoque and Estiva (from Melchiori et al., 2025).

Upwelling occurs between December and April, coinciding with the dry season (D'Croz & O'Dea, 2007), whereas the rainy season extends from May to November. During the upwelling season, when SST is lower, the Gulf experiences the highest Chl-*a* concentrations (0.5–1.5 mg/m^3, with coastal areas reaching peaks of > 2.0 mg/m^3). In contrast, minimum concentrations (~0.25 mg/m^3) are recorded during the rainy season (Corredor-Acosta et al., 2020; Torres et al., 2023). Strong seasonal patterns are also evident in fish abundance. For instance, the Pacific Anchoveta *Cetengraulis mysticetus* and herrings *Opisthonema* spp., which contribute substantially to the diet of Brown Booby (Castillo-Guerrero et al., 2016; Mellink et al., 2001), dominate the fish catches in the Gulf of Panama between April–July and July–October, respectively (Canales & Sánchez, 2024).

Oceanography

Oceanographic data were compiled for the entire Gulf of Panama (07.3°N–09.05°N, 077.9°W–080.6°W) for October to September of 2018–2019 and 2023–2024. Daily Chl-*a* concentration (mg/m^3) and SST (°C) (Donlon et al., 2012; Good et al., 2020; Stark et al., 2007) and monthly PP (mg/m^2) were downloaded from the Marine Data Store of the E.U. Copernicus Marine Service Information (2024). The spatial resolution was 5.6 km for SST and 4 km for Chl-*a* and PP. We included the four months preceding nest monitoring to account for a potential time lag between oceanographic anomalies and their impact on seabird breeding performance (Smith et al., 2017). For example, on nearby Gorgona Island, Colombia, Brown Booby chick abundance correlated with SST registered four months earlier (Perlaza-Gamboa et al., 2020). Data on inter-annual variation in actual food availability for the Cocos Booby is unavailable; only seasonal patterns are available for key prey such as the Pacific Anchoveta and herrings (Canales & Sánchez, 2024).

We used the Oceanic Niño Index (ONI), which defines El Niño events as five consecutive positive anomalies in the three-month running mean SST in the Niño 3.4 region (05°N–05°S, 170°W–120°W) exceeding a threshold of +0.5 °C (National Oceanic and Atmospheric Administration [NOAA], 2024a). Based on the ONI values, we further categorized El Niño into four sub-classes: "weak" (0.5 ≤ ONI < 1), "moderate" (1 ≤ ONI < 1.5), "strong" (1.5 ≤ ONI < 2), and "very strong" (ONI ≥ 2) (Null, 2026). Monthly SST positive anomalies were also characterized for the 1+2 Niño region (0°–10°S, 090°W–080°W), which is closer to Panama; data were retrieved from the Climate Prediction Center of NOAA (NOAA, 2024b). ONI and SST positive anomalies were observed for both study periods and for the 2015–2016 season, which represents the most recent "very strong" El Niño (Chen et al., 2017), from October through September.

Breeding Performance

Cocos Booby breeding performance was monitored between 22 February and 15 October 2024 in a 17.85 m^2 study plot, the species' main breeding area on the island. Data were compared with those obtained by Esparza et al. (2022) between 02 April and 23 August 2019.

Following the methodology of Esparza et al. (2022), a polyvinyl chloride (PVC) pole with a unique identification number was placed beside each nest, and GPS coordinates were recorded. Every two weeks (with slight variation due to weather conditions), we visited the nesting area and documented the nest status, registering the presence of eggs, chicks, and fledglings. Photographic records were used to estimate the ages of chicks and fledglings and to determine laying dates. We assessed hatching success (eggs hatched/eggs laid) and fledgling success (fledglings/hatched eggs). A breeding attempt was considered successful if a chick approximately 70 d of age was recorded. Although Cocos Booby fledging typically occurs at 90 d (Mlodinow et al., 2024), chicks often begin moving from the nest before fledging. Because of the steep terrain, it was often difficult to monitor birds through to fledging. Therefore, 70 d was used as a conservative threshold indicating survival to near-fledging age.

Statistical Analyses

All the analyses were carried out in R version 4.3.2 (R Core Team, 2023). Differences in SST and Chl-*a* were analysed using the non-parametric Kruskal-Wallis test (Lerma et al., 2020). To account for both year and month effects, a single categorical predictor variable was created by merging the factors *year* and *month* to represent each month-year group (e.g., October 2018–2019), with oceanographic data (SST or Chl-*a*) as response variables. When significant differences were found, pairwise comparisons were performed using post hoc Mann-Whitney *U*-tests, with *p* values adjusted for multiple comparisons using the Benjamini-Hochberg (BH) method. The results of the pairwise comparisons were then summarised to assess which groups differed significantly using the *multcompView* library. PP was excluded from this analysis because its trend in the preliminary assessment resembled that of Chl-*a*.

Laying date distributions of Cocos Boobies were compared between 2018–2019 and 2023–2024 using a non-parametric Mann-Whitney *U*-test, considering only data collected through 23 August for both study years. A chi-square test was used to compare Cocos Booby hatching and fledging success between years (Catry et al., 2013). For the analysis of hatching success, nests first observed after 05 August were excluded. For analysis of fledgling success, nests first observed after 30 April were excluded because monitoring could not continue until hatching or fledging was completed. To investigate the influence of additional predictor variables on hatching success, a non-parametric Generalized Additive Model (GAM; adapted from Castillo-Guerrero et al., 2011) was fitted using the *mgcv* library. Three models were tested (Appendix, Table A1, available on the website). The first model (Model 1) included only laying date as a continuous predictor variable to test its effect on hatching success. The second model (Model 2) added year as a predictor variable, and the third model (Model 3) incorporated an interaction between laying date and year to investigate possible year-level variation in the relationship between laying date and hatching success. Model selection was based on the Akaike information criterion (AIC), with the model having the lowest AIC considered the most reliable. Only nests monitored from the egg stage in both years (2018–2019 and 2023–2024) were included in this analysis.

RESULTS

Oceanographic Conditions

Significant differences in SST and Chl-*a* concentrations were detected across years and months (SST: Kruskal-Wallis $\chi^2 = 982.58$, $p < .0001$, $df = 35$; Chl-*a*: Kruskal-Wallis $\chi^2 = 706.05$, $p < .0001$, $df = 35$). Pairwise comparisons showed that SST and Chl-*a* values differed between 2023–2024 and 2018–2019 across almost all

months, whereas significant deviations from the 15-y mean occurred only during specific months in each year (Fig. 2; Appendix, Table A2). Specifically, nearly all monthly SST values in 2023–2024, as well as Chl-*a* and SST values during the upwelling season in 2018–2019, differed significantly from the 15-y average. Seasonal peaks, characterized by lower SST and higher Chl-*a* and PP during the upwelling season from December to April, were less pronounced in 2023–2024 compared with 2018–2019 (Fig. 2, Table 1).

Both 2018–2019 and 2023–2024 exhibited El Niño conditions, with SST anomalies outside the neutral conditions (−0.5 to +0.5 °C), although their intensities varied (Fig. 3a). The 2023–2024 El Niño exceeded neutral conditions by more than 1 °C and was categorized as strong (1.5 ≤ ONI < 2), while the 2018–2019 El Niño was classified as weak (0.5 ≤ ONI < 1). In both years, ONI values were lower than those recorded during the super El Niño of 2015–2016. SST positive anomalies in the Niño 1+2 region generally followed a pattern similar to that observed in the Niño 3.4 region, with some exceptions (Fig. 3b). During the first part of 2023–2024, higher SST positive anomalies were observed in the Niño 1+2 region than in the Niño 3.4 region. As the season progressed, the trend shifted more quickly toward a La Niña phase in the Niño 1+2 region than in the Niño 3.4 region. Overall, the pattern observed in 2023–2024 resembled that of 2015–2016. In 2018–2019, SST positive anomalies in the Niño 1+2 region were lower than in the Niño 3.4 region.

Breeding Performance

During 2023–2024, Cocos Booby monitoring began approximately one month earlier (on 22 February) than in 2018–2019 (02 April). Despite the earlier start, the median laying date in 2023–2024 was significantly later than in 2018–2019 (Table 2). In 2018–2019, the number of active nests was highest at the end of April, and nesting steadily decreased until August (Fig. 4a). During 2023–2024, the number of active nests was similar to that of 2018–2019 until mid-June and then increased until 15 October (last day of monitoring), in marked contrast to the previous year (Fig. 4a). Considering only the total number of chicks present, the trend was similar to that for active nests in both years (Fig. 4b).

In 2023–2024, a total of 230 nests were monitored. Of the 115 nests for which monitoring was completed, only 20 were successful (17.4%), compared with 14.5% (n = 62) in 2018–2019. In 2018–2019, failures occurred more frequently at the egg stage (66.12%) than in 2023–2024 (47.82%). The reasons for failure were unclear. None of the nests showed the survival of two offspring; therefore, only one breeding attempt per nest was considered when calculating hatching and fledging success. Hatching success was significantly higher in 2023–2024 than in 2018–2019 (Fig. 5a, Table 2). For this analysis, we also included data collected in the early part of the 2023–2024 season (before 02 April), even though equivalent data were not available for 2018–2019. Excluding these data

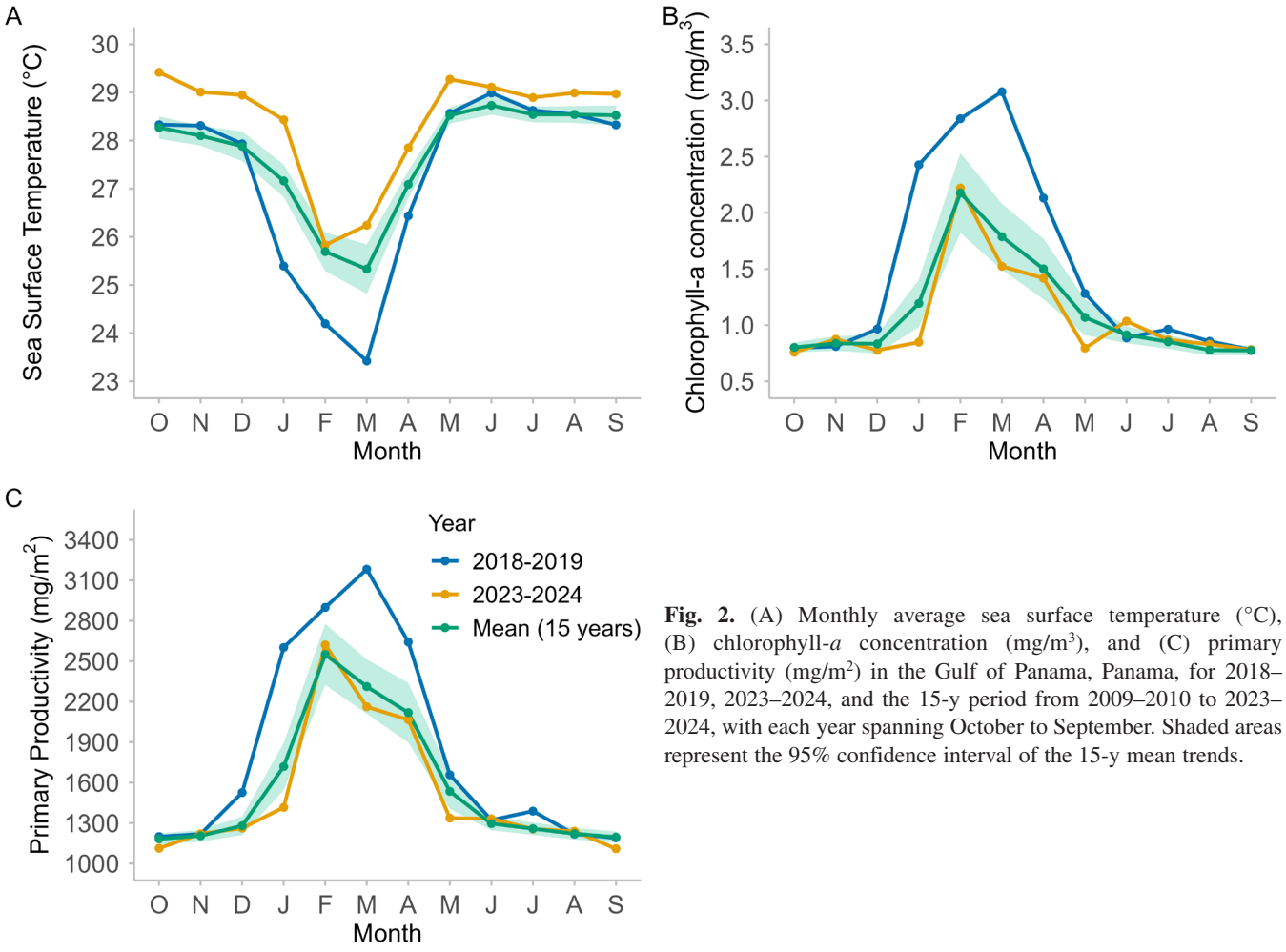


Fig. 2. (A) Monthly average sea surface temperature (°C), (B) chlorophyll-*a* concentration (mg/m^3), and (C) primary productivity (mg/m^2) in the Gulf of Panama, Panama, for 2018–2019, 2023–2024, and the 15-y period from 2009–2010 to 2023–2024, with each year spanning October to September. Shaded areas represent the 95% confidence interval of the 15-y mean trends.

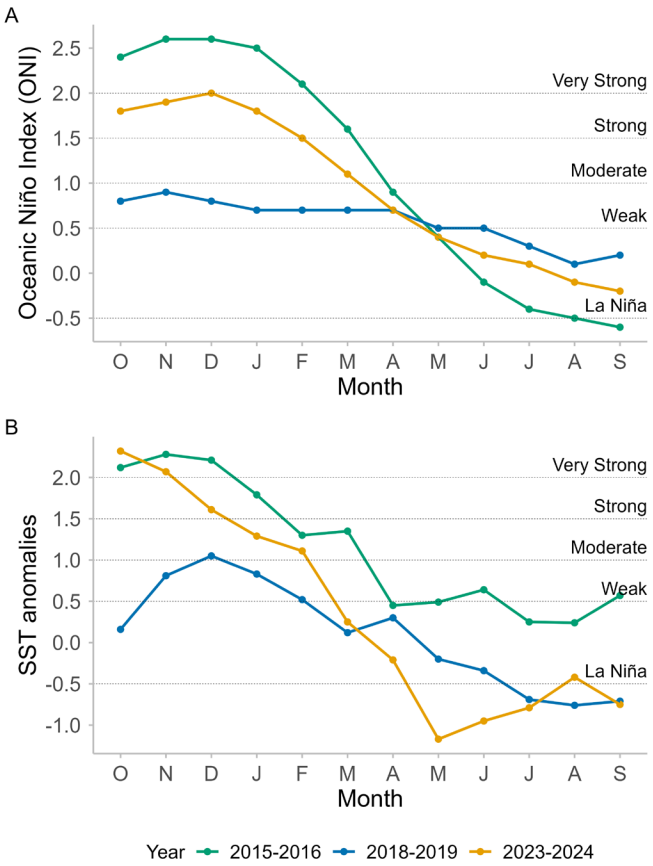


Fig. 3. (A) Oceanic Niño Index (ONI) for the Niño 3.4 region and (B) sea surface temperature (SST; °C) positive anomalies for the Niño 1+2 region during 2015–2016, 2018–2019, and 2023–2024, with each year spanning October to September. Dashed lines represent the threshold for the La Niña phase (< −0.5) and the thresholds for the different intensity classes of El Niño.

did not change the results (χ^2 = 9.1511, p < .01, $n_{2023–2024}$ = 128, $n_{2018–2019}$ = 63). Fledging success did not differ significantly between years (Fig. 5b, Table 2).

GAM comparisons based on the AIC indicated that Model 3 provided the best fit (Appendix Table A1). The model showed a significant interaction between laying date and year, with a significant effect detected only for 2023–2024 (X^2 = 12.626, p = .024) but not for 2018–2019 (X^2 = 9.207, p = .161). This indicates that the effect of laying date on hatching success varied between years. In 2023–2024, the relationship between hatching probability and laying date exhibited different inflection points across the range of laying dates, i.e., early breeders had a higher likelihood of hatching success. However, this relationship reversed as the season progressed and changed again towards the end of the study period (Fig. 6). Conversely, in 2018–2019, hatching probability was initially higher and then steadily decreased among later breeders (Fig. 6). The model explained 38.4% of the deviance, indicating that, although it captured a substantial portion of the variability in hatching success, other factors also likely influenced hatching success.

DISCUSSION

According to the ONI, both study years coincided with El Niño conditions (Lavín et al., 2006), although the phases differed in intensity. The 2023–2024 El Niño was classified as strong and had pronounced effects in Panama, including severe drought in the Panama Canal area (Deng et al., 2023), whereas the 2018–2019 event was weak and had relatively minor impacts (Klingaman & Keat, 2018). These differences were also reflected in oceanographic conditions in the Gulf of Panama, which varied significantly between the two years. However, differences between oceanographic conditions in the study years and the 15-y mean were minimal. This may be partly explained by the fact that neither event reached the magnitude of a "super El Niño," a statistically extreme event that has occurred only six times since 1850 (Webb & Magi, 2022).

The ETP experiences heterogeneous oceanographic variability during ENSO (Lau & Nath, 2003; Radenac et al., 2012), and the Gulf of Panama, in particular, may buffer positive climatic anomalies through upwelling. Local upwelling has been shown to mitigate high SST during El Niño, limiting the effects on corals and benthic organisms (Randall et al., 2020). Our results align with

TABLE 1
Values of oceanographic variables (annual mean ± standard error) for the 2018–2019 and 2023–2024 seasons and for the 15-y mean in the Gulf of Panama

Oceanographic variable	2018–2019	2023–2024	15-year mean
Sea surface temperature	27.2 ± 0.6 °C	28.4 ± 0.3 °C	27.6 ± 0.1 °C
Chlorophyll-*a* concentration	1.4 ± 0.1 mg/m^3	1.0 ± 0.0 mg/m^3	1.1 ± 0.0 mg/m^3
Primary productivity	1,837.4 ± 219.4 mg/m^2	1,511.4 ± 141.4 mg/m^2	1,557.5 ± 41.1 mg/m^2

TABLE 2
Pairwise comparisons (mean ± standard error, sample sizes in brackets) of 2018–2019 vs. 2023–2024 Cocos Booby *Sula brewsteri* breeding parameters (Bona Island, Gulf of Panama)

Parameter	2018–2019	2023–2024	Statistical test[a]
Laying date (Julian days)	96 ± 5.4 (63)	138 ± 6.2 (174)	W = 3,620.5, p < .0001
Hatching success (%)	34 ± 6.1 (63)	59 ± 3.9 (155)	χ^2 = 9.7627, p < .01
Fledging success (%)	42 ± 1.1 (21)	33 ± 6.2 (59)	χ^2 = 0.22007, p = .639

[a] All statistical tests have df = 1. W indicates the Mann-Whitney U-test, χ^2 refers to the chi-square test

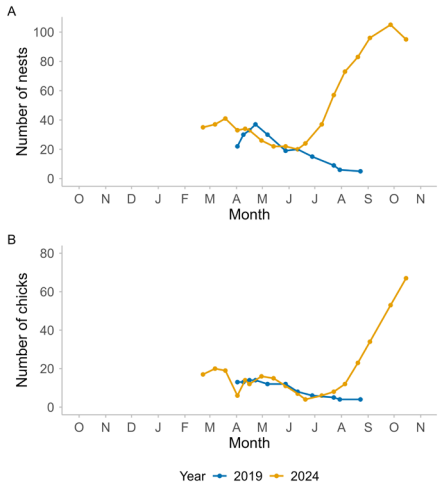


Fig. 4. Number of Cocos Booby *Sula brewsteri* (A) active nests and (B) chicks recorded on each monitoring day during the 2018–2019 (2019) and 2023–2024 (2024) breeding seasons (Bona Island, Gulf of Panama).

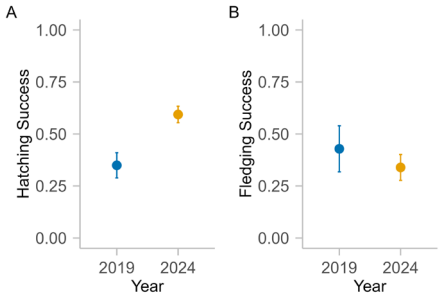


Fig. 5. (A) Hatching success and (B) fledging success of Cocos Booby *Sula brewsteri* on Bona Island, Gulf of Panama, during 2018–2019 (2019) and 2023–2024 (2024) (means ± SE).

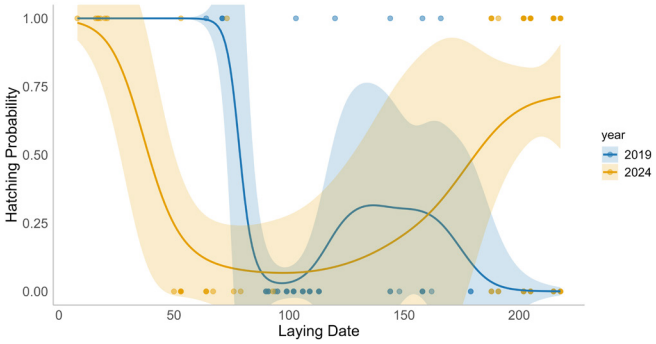


Fig. 6. Hatching probability according to laying date (Julian calendar) across the two study years (2019, 2024) for Cocos Booby *Sula brewsteri* on Bona Island, Gulf of Panama. Shaded area indicates the 95% confidence interval.

this perspective. Despite the stronger El Niño in 2023–2024, the Cocos Booby breeding season was longer, and hatching success was higher, than in 2018–2019, supporting the hypothesis that the Gulf may provide suitable conditions for breeding during positive climatic anomalies. Although data from a non-El Niño year for this colony are lacking, long-term monitoring at the nearby Gorgona Island colony in Colombia (Perlaza-Gamboa et al., 2020) shows that egg-laying peaks between June and August, with chick abundance peaking in October—patterns that are consistent with those observed in 2023–2024. The observed relationship between laying date and hatching probability suggests a favourable laying period in Panama at the onset of upwelling, as noted by Esparza et al. (2022). Notably, in 2023–2024, another favourable laying window was observed later in the season. This pattern could reflect 2023–2024 oceanographic conditions, although it is unclear whether this represents an anomaly or a recurring pattern.

In the Gulf of Panama, prey availability generally peaks between April and October (Canales & Sánchez, 2024), potentially enhancing food supply during the chick-rearing and fledgling phases for the Cocos Booby. A similar strategy is observed in the northern Humboldt Current, where the Peruvian Booby *S. variegata* adjusts its breeding so that fledglings become independent at the time of peak prey availability (Passuni et al., 2018). However, it remains unclear whether the extended breeding in 2023–2024 indicates Cocos Booby adaptability to variable conditions or a delayed breeding onset driven by anomalous conditions. Resolving this question will require longer-term data on breeding phenology, together with measures of interannual prey availability and oceanographic processes. The higher hatching success and prolonged breeding season of the Cocos Booby in 2023–2024 are consistent with the hypothesis that the Gulf of Panama functions as a climatic refuge during El Niño. Similar responses have been observed in the California Current, a highly productive upwelling system, in which warming has led to range expansion and increased abundance of *Sula* species (Russell et al., 2025).

Nonetheless, overall reproductive success for Cocos Booby was low in both years (17.4% in 2023–2024 and 14.5% in 2018–2019). The ratio of eggs hatched to eggs laid may even overestimate true hatching success, as some breeding attempts went undetected due to the bi-weekly monitoring interval, as indicated by sightings of empty nests that were not registered during field visits. Despite this limitation, breeding occurred throughout the season in both years, with no evidence of a dramatic Cocos Booby response to El Niño conditions. Previous studies suggest that significant breeding failures in the ETP predominantly coincide with “super” El Niño events (England, 2000; Valle et al., 1987), which did not occur in either of our study years. For example, during the 1997–1998 super El Niño, Brown Boobies ceased breeding prematurely in the Gulf of California (Mellink, 2000) and experienced complete reproductive failure on Kiritimati Island during the 1982–1983 event (Jaksic & Fariña, 2010). Although the Cocos Booby population in Panama might respond strongly during future super El Niño events, the absence of consistent monitoring across pantropical colonies (Schreiber & Norton, 2020) limits our ability to generalize these findings. Long-term monitoring on Bona Island is therefore essential for assessing how Cocos Boobies respond to interannual variations in oceanographic conditions and extreme El Niño events.

Moreover, long-term monitoring would facilitate the detection of unusual oceanographic events relevant to seabird ecology. For instance, in 2025, despite weak La Niña conditions, upwelling in the Gulf of Panama was exceptionally suppressed by mechanisms that remain only partially understood, with significant consequences for the entire food web (O’Dea et al., 2025). However, the reduced upwelling observed during this period could reflect unrecognized regional variability, as upwelling returned to normal in 2026. Monitoring seabird responses during such negative anomalies would be particularly valuable, given the strong reliance of seabirds

on upwelling for foraging and breeding (Esparza et al., 2022; Melchiori et al., 2025).

In addition to climatic factors, the low reproductive success observed for Cocos Boobies could be related to iguana predation. Field observations of broken eggs and iguana faeces near empty nests suggest potential predation. Isotopic niche analysis of iguana populations across several islands in the Gulf of California indicates that proximity to seabird colonies reinforces the presence of marine origin nutrients in the iguana diets. This enrichment may occur through the consumption of plants fertilized by guano or by the direct ingestion of avian material, such as eggs or carcasses (Barraza-Soltero et al., 2025). Direct consumption of avian material has previously been documented in Black Iguanas (Astorga-Acuña & Mora, 2023). However, further research on Bona Island is needed to determine whether iguanas prey on Cocos Booby eggs or chicks and, if so, whether such predation contributes substantially to breeding failure.

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