Received: 12 June 2024 | Accepted: 11 July 2024

DOI: 10.1002/ecy.4433

THE SCIENTIFIC NATURALIST

ECOLOGY
ECOLOGICAL SOCIETY OF AMERICA

Rainfall during multiyear La Niñas caused the decline of social wasps in Northeastern Amazonia

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Funding information
France's Agence Nationale de la Recherche, Grant/Award Number: CEBA: ANR-10-LABX-25-01

Handling Editor: John Pastor

KEYWORDS: biological indicators, climate change, La Niña years, rainfall impact, social wasps, warming

Greenhouse gases released into the atmosphere have triggered climate change worldwide resulting in higher average temperatures and a greater frequency of warm El Niño and cold La Niña events known as the El Niño Southern Oscillation (ENSO) (Geng et al., 2023; for ENSO values see Null, 2024). In northeastern Amazonia, including French Guiana, weather data compiled over the past 30 years show that La Niña years are correlated with extreme episodes of rainfall, lower temperatures, and less solar radiation (Dejean et al., 2011; see also Gaucherel, 2004; Ponton, 2001).

The excessive rainfall of the exceptionally long and strong 1998–2001 La Niña event (34 months) caused a major decrease in Guianese wasp diversity with 70.5% of the species no longer recorded (Appendix S1: Figure S1; Table S1). Because we noted a similarity between the outcomes of all social wasps pooled and that of *Polybia bistriata* (Polistinae), this species served as a biological indicator on global change in French Guiana when associated with *Clusia grandiflora* (Clusiaceae) whose large and thick leaves protect the wasps' nests from inclement weather (Figure 1) (Corbara et al., 2009; Dejean et al., 2010, 2011, 2022).

Here, we capitalized on a second very long La Niña episode (July 2020–February 2023; 32 months) (Null, 2024) to examine its impact on the *P. bistriata* nests. *Via* this biological indicator, we report the fate of social wasps in French Guiana over 27 years (1997–2023).

The area studied is situated along the road leading to the Petit-Saut dam (5°4′5″ N, 52°59′54″W–5°4′18″ N,

FIGURE 1 At the beginning of the rainy season, an abandoned *Polybia bistriata* nest built under a lower *Clusia grandiflora* leaf was replaced by a new nest constructed under a higher leaf. Indeed, they place their nests on lower leaves during the dry season to benefit from nighttime soil humidity. Then, they move to upper leaves at the onset of the rainy season where the nests dry out more easily. Because the trade winds blow from the back of the picture, the nests are well protected (Photo credit: Alain Dejean).

53°0′19″ W) where *Clusia* is one of the few plants able to grow on soil scraped down to the laterite, and so remains small. Thus, depending on the year, we monitored 93–149 *Clusia* for wasp nests each July between 1997 and 2023 to record individuals sheltering active *P. bistriata* nests in order to obtain percentages to be compared with climatic data from the Enerco405 AK automatic weather station at Paracou situated in the same forest 23.5 km from the area studied.

Using R Core Team (2022) software, we first conducted a binomial generalized linear model (GLM) to identify the climatic variables that best explained, in terms of the Akaike information criterion (AIC), variations in the number of *P. bistriata* nests found compared to the total number of *Clusia*. The climatic variables studied were as follows: (1) El Niño year, (2) La Niña year, (3) years with rainfall over 2700 mm in the rainy season (PRS > 2700), (4) years with rainfall over 300 mm in the dry season (PDS > 300), and (5) mean annual temperature. We added the number of *P. bistriata* nests found in the previous year as an explanatory variable to all the models compared in order to consider population dynamics. To verify whether the number of nests from the previous year is sufficient to take into account the time dependency of the data, we analyzed the time series of the ratio between *Clusia* and *P. bistriata* nests using an autoregressive integrated moving average (ARIMA) model. The best ARIMA model found according to all criteria (e.g., AIC_c, AIC, Bayesian Information Criterium) was ARIMA(0,1,0), a random walk model:

$$\text{Ratio } \textit{Clusia}/\text{wasp nest/year } t = \text{Ratio } \textit{Clusia}/\text{wasp nest/year } t-1 + \text{Gaussian noise.}$$

Our results are summarized in Figure 2 showing first the percentages of *Clusia* sheltering an active *P. bistriata* nest during a survey that extended from 1997 to 2023 (27 years).

The best GLM model obtained, according to the AIC, contained three significant climatic variables: (1) El Niño years, (2) PRS > 2700, and (3) PDS > 300 with significant effects ($p = 1.02e^{-3}$, $p = 9.07e^{-5}$, $p = 3.89e^{-4}$, respectively, Wald test). PRS > 2700 had a negative effect, while El Niño years and PDS > 300 had a positive effect on the number of *P. bistriata* nests (Figure 2b). The other climatic variables degraded the AIC and were not significant.

A time series analysis noted an increase in the mean level of wasp nests by 0.15 in 2009 that coincides with a weak La Niña and the beginning of the 2009–2010 El Niño event, and confirmed three declines, each occurring during multiyear La Niña episodes. The first arose in 2000 (lowered the mean level by 0.3), the second in 2012 (lowered the mean level by 0.1), and the last in 2022, but its effect, although visible, is blurred by the declining number of wasp nests (Figure 2c).

Therefore, the GLM showed that the percentages of *Clusia* sheltering *P. bistriata* nests followed only roughly the ENSO variations mostly due to the influence of the Atlantic on rainfall and to the fact that La Niña or El Niño events can straddle two calendar years (Figure 2d). This was the case for the increase in wasp nests occurring in 2009 during both La Niña and El Niño events noted by the time series analysis (Figure 2c). Yet, it is noteworthy that more than 300 mm of rainfall during the dry seasons was beneficial to *P. bistriata* and perhaps to social wasps as a whole.

We also noted that among the nine declines in the number of wasp nests recorded using the GLM, the time series analysis confirmed only three that occurred during the 1998–2001, 2010–2012, and 2020–2023 La Niña events, the effect of the last one being less visible due to

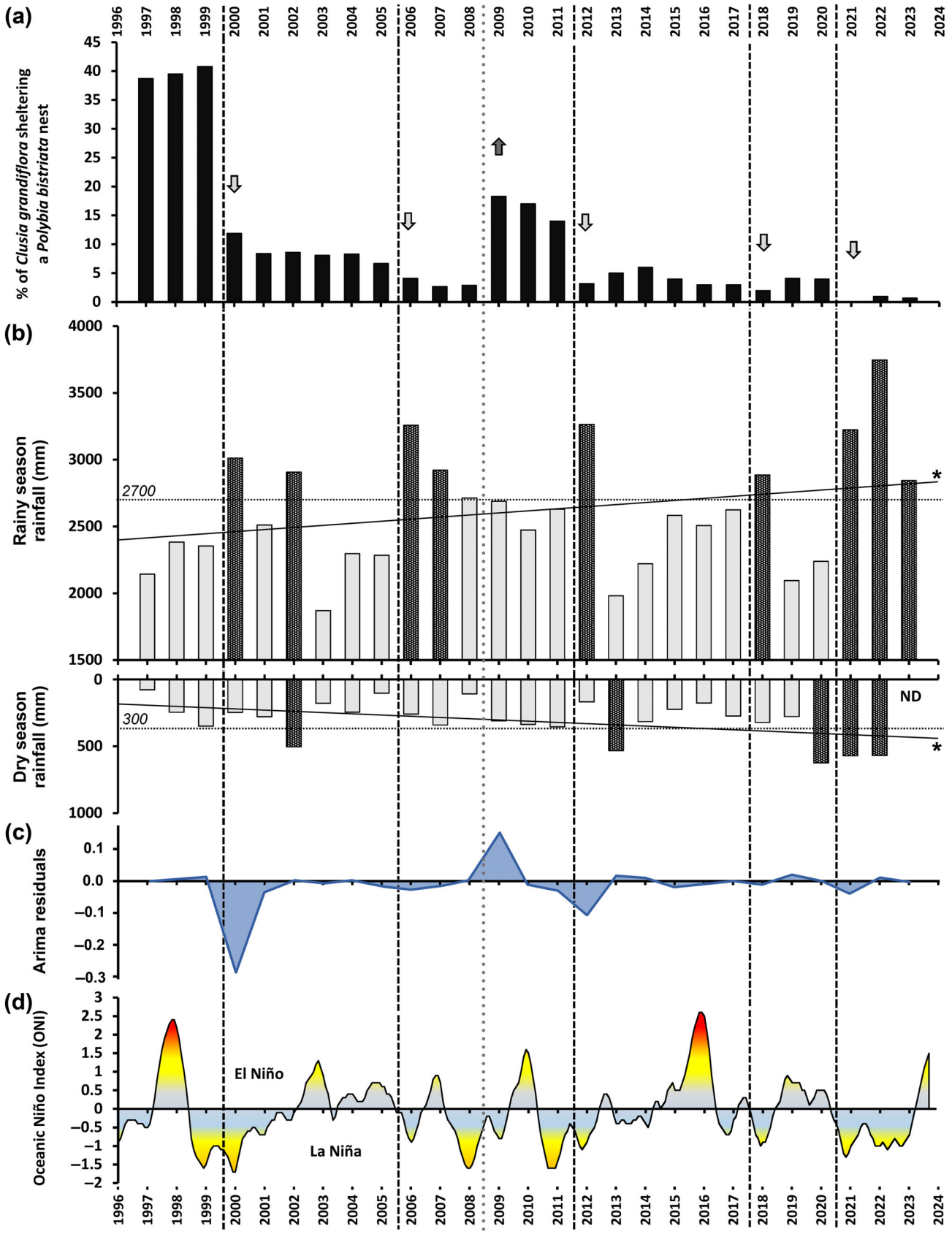

FIGURE 2 Legend on next page.

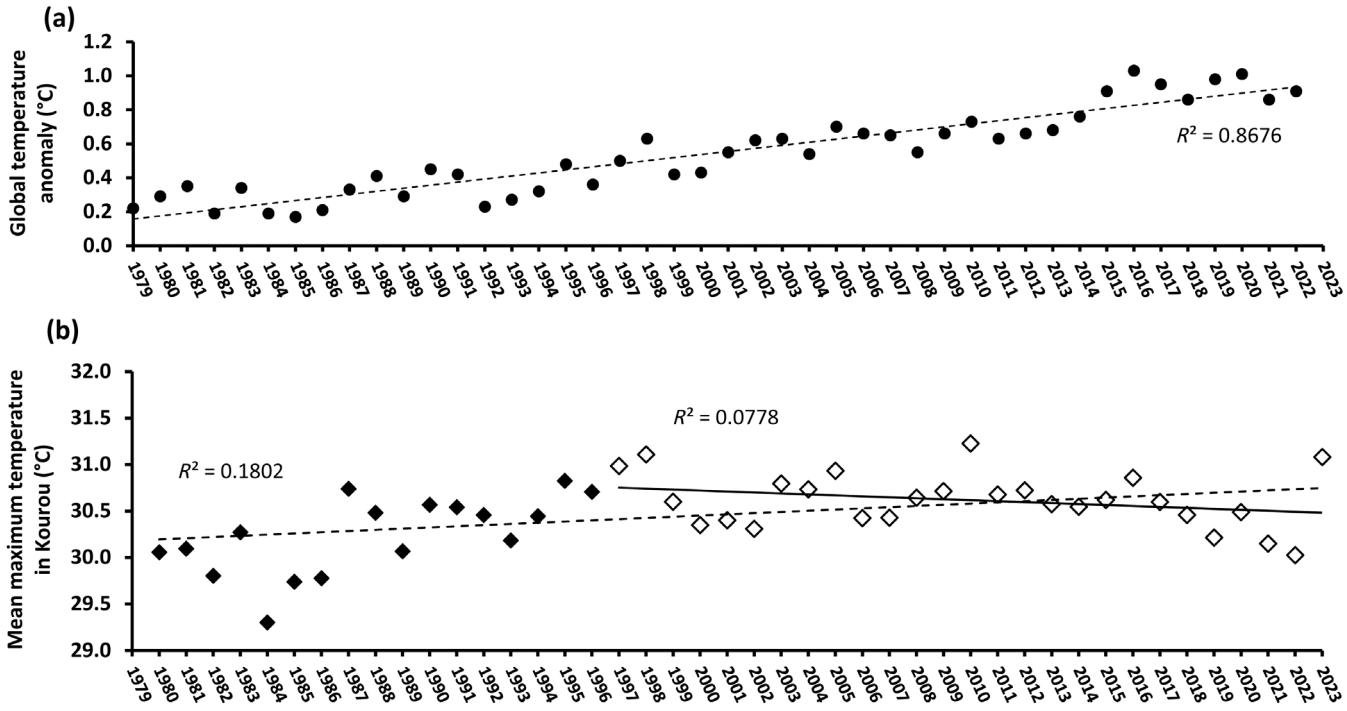

FIGURE 3 (a) 1979–2022 mean global land and ocean temperature anomalies using the years 1901–2000 as a reference (data from NOAA, 2024). (b) 1980–2023 mean maximum temperature readings (most social wasps are diurnal) taken near Petit-Saut (French Guiana) showing a mean increase of ≈0.5°C when considering the entire period (dotted line). During the 1997–2023 period corresponding to this study, the mean maximum temperatures slightly decreased (solid line).

the low number of wasp nests remaining after 2012. As a result, only a few *P. bistriata* nests were recorded during the 2020–2023 La Niña years so that the percentages of *Clusia* sheltering a wasp nest were below 1% despite our choosing this wasp–plant association as a biological indicator. During this period, other wasp species were very difficult to find. As an example, in the Petit-Saut area before the 1998–2001 La Niña event, we recorded 424 nests belonging to 60 wasp species in 1997 along ≈5 km of forest edges, whereas these values declined to only 97 nests and 16 species in 2002 (Appendix S1: Table S1). Consequently, the decrease in the *P. bistriata* population is due to heavy rainfall whose threshold of more than 2700 mm was reached eight times out of nine during the La Niña years (Figure 2). Indeed, as a consequence of heavy rainfall during the extreme rainy seasons, the ambient air becomes so moist inside wasp nests covered by an envelope that the brood decay, something exacerbated as the wasps continue to hunt and store prey that rot in turn. Thus, the development of bacteria, fungi, and gregarine protozoa was facilitated (Bouwma et al., 2005; Dejean et al., 2010; Reason et al., 2022).

We recorded two particularly long-lasting La Niña events. During the 1998–2001 La Niña, only one value went beyond 2700 mm (i.e., 3013 mm for the 2000 rainy season), whereas during the 2020–2023 La Niña, the rainy seasons exceeded 2700 mm three times, the highest peaking at 3746 mm. Because La Niña events are predicted to be longer and more frequent (Geng et al., 2023; Wang et al., 2023), it will be difficult for social wasp populations to survive in large areas of Northern Amazonia where La Niña is correlated with strong rainfall.

Global warming worldwide caused greater temperatures that reached an increase of ≈0.9°C between 1979 and 2023 (Figure 3), contributing to the decline of many species' populations worldwide in recent decades,

FIGURE 2 (a) Percentages of *Clusia grandiflora* individuals sheltering an active *Polybia bistriata* nest. The arrows show a decrease in the percentages of wasp nests that are also delimited by the vertical dotted lines. (b) Rainfall during the rainy season (December to June) and the dry season (August to November; July not considered as intermediary); *The trend lines show a slight increase in rainfall in both cases (rainy season: $R^2 = 0.0782$; dry season: $R^2 = 0.181$). (c) Time series analysis of the ratio between *C. grandiflora* and *P. bistriata* nests (ARIMA(0,1,0) model). (d) El Niño Southern Oscillation variation. The mean maximum temperatures are presented in Figure 3.

including insects (Finn et al., 2023; Harvey et al., 2022). Yet, this effect was limited in French Guiana as the temperatures registered in our weather station decreased slightly between 1980 and 2023 likely due to the 2020–2023 La Niña episode so that the factor temperature is not influential in this study (Figure 3).

In conclusion, the decline of social wasps is related to the greater frequency of heavy rains that are associated with La Niña events in northeastern Amazonia so that the population of the most frequent species serving as a biological indicator was almost nil in 2023. This negative effect of excessive rainfall was also noted around Brasilia and in Brazilian Amazonia and the Atlantic Forest (Carvalho et al., 2021; Raw, 2018) and likely extends to a wider Neotropical region. Because extreme El Niño and La Niña events will become more frequent with global warming (Cai et al., 2023) and because each can be correlated with heavy rains depending on the geographical area, the long-term situation for tropical social wasps could be critical.

ACKNOWLEDGMENTS

We are grateful to the Laboratoire Environnement Hydreco (Petit-Saut) for its logistical assistance and to Andrea Yockey for proofreading the manuscript. This study was funded by a grant from France's Agence Nationale de la Recherche (CEBA: ANR-10-LABX-25-01).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data (Dejean, 2024) are available in figshare at 10.6084/m9.figshare.26013358.v1.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Dejean, Alain, Vivien Rossi, Arthur Compin, Bruno Corbara, James M. Carpenter, Jérôme Orivel, Frédéric Petitclerc, Benoit Burban, and Frédéric Azémar. 2024. "Rainfall during Multiyear La Niñas Caused the Decline of Social Wasps in Northeastern Amazonia." *Ecology* 105(11): e4433. https://doi.org/10.1002/ecy.4433