Latin American Journal of Aquatic Research, 54(2): 251-264, 2026
DOI: 10.3856/vol54-issue2-fulltext-3511

Research Article

Environmental influence on the spatiotemporal distribution of dolphinfish (*Coryphaena hippurus*) catch rates off Cabo San Lucas Baja California Sur, Mexico

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ABSTRACT. Dolphinfish (*Coryphaena hippurus*) is an important target species for the sport-fishing fleet in the southern Gulf of California, Mexico. However, little is known about its spatial distribution, primarily due to the lack of georeferenced data. The main objectives of this study were to evaluate the effect of environmental variability on nominal catch rates (CRs) of dolphinfish and to infer their spatiotemporal distribution. The data used in this study includes the number of individuals caught and the geographic coordinates recorded by one of the main sport-fishing fleets operating out of Cabo San Lucas, Mexico. Generalized additive models were applied to explore the complex, non-linear effects of environmental (temperature and chlorophyll-*a*), physical (depth), spatial, and temporal (year-month) variables on CRs. The results suggest that sea surface temperature, location, depth, and temporal factors significantly influence dolphinfish CRs in the study area. Specifically, higher CRs are expected along the western coast in shallow warm waters during the summer-autumn period (August to November).

Keywords: *Coryphaena hippurus*; spatiotemporal distribution; environmental effect; sport fishery; undersea mountain; GAM; seasonality

INTRODUCTION

Dolphinfish (*Coryphaena hippurus*) is a highly migratory species with a wide distribution across tropical and subtropical waters (Palko et al. 1982). It is targeted by numerous coastal nations throughout its range (Oxenford & Hunte1986, Rivera & Appeldoorn 2000). From the juvenile to adult stages, this species tends to associate with floating objects, both natural and artificial. While this behavior facilitates feeding, it also increases their vulnerability to exploitation by commercial and recreational fisheries worldwide (Kojima 1961, Rose & Hassler 1974, Uchiyama et al. 1986, Whitney et al. 2016).

Dolphinfish are capable of horizontal movements exceeding 40 km d^{-1} (Kingsford & Defries 1999, Merten et al. 2014a), likely following established migratory routes (Kleisner 2009, Farrell et al. 2014, Merten et al. 2016). Vertically, the species typically remains within the upper 10 m of the water column, occasionally making short-duration dives below the thermocline (Furukawa et al. 2014, Merten et al. 2014b).

Associate Editor: Yassir Torres

However, a recent study has revealed variations in diving behavior depending on the availability of thermal habitats (Perle et al. 2020).

Most studies describing the distribution and relative abundance of dolphinfish have focused primarily on its variability associated with sea surface temperature (SST) (Norton 1999, Zúñiga-Flores et al. 2008). However, other environmental variables such as chlorophyll concentration, bathymetry, distance to SST fronts, and proximity to floating objects have also been considered (Kleisner 2009, Martínez-Rincón et al. 2009, Farrell et al. 2014). In addition, dolphinfish exhibit distinct feeding areas depending on prey availability, feeding mainly on teleosts, cephalopods, and crustaceans, with significant variations among areas, sex, and sizes (Olson & Galván-Magaña 2002, Marín-Enríquez et al. 2018).

In the Eastern Pacific Ocean (EPO), dolphinfish movements have been associated with the displacement of the 19-20°C isotherm (Norton 1999), and the highest catches occur when the SST range between 25 and 28°C (Santana-Hernández 2001, Martínez-Rincón et al. 2009, Zúñiga-Flores et al. 2010). In the northeastern Mexican Pacific, peak dolphinfish catches are recorded during the warmer months, when chlorophyll concentration is low (Zúñiga-Flores et al. 2008, 2010).

Dolphinfish distribution and abundance are influenced by oceanic changes driven by large-scale interannual events such as the El Niño Southern Oscillation (ENSO), primarily through their direct impact on SST. In the region of Cabo San Lucas, Baja California Sur, Mexico, dolphinfish catches increased during the 1992-1993 El Niño but declined during the stronger 1997-1998 event, likely because its intensity displaced the species to higher latitudes (Zúñiga-Flores et al. 2008). In waters near Colombia, the resource shifts southward during El Niño, increasing its availability to northern Peru (Lasso & Zapata 1999), whereas during La Niña, the species becomes scarce or disappears entirely (Zapata 2002). These climate events have also been suggested to alter the distribution patterns of floating objects in the EPO, which, in turn, affects the distribution of the associated fauna, dolphinfish being among the most commonly found species (Martínez-Rincón et al. 2009).

In the Mexican Pacific, dolphinfish, like billfish, has been reserved exclusively for sport fishing within the first 50 nm from the coastline (DOF 1995). However, it is also incidentally caught by the artisanal fleet, the longline fleet authorized to target sharks or swordfish, and the international tuna purse-seine fleet, which has led to conflict of interest between these fleets and the sport fishing sector (Santana-Hernández 2001, Solana-Sansores 2001, Martínez-Rincón et al. 2009, Zúñiga-Flores et al. 2010).

In the southern Gulf of California, Mexico, this species is of great importance to the sport fishing fleets, with an average nominal catch rate of 1.33 fish per trip (Zúñiga-Flores et al. 2008). Despite its significance, little is known about its distribution, largely due to a lack of georeferenced data, particularly from the sport-fishing fleet. Given that this region, especially Cabo San Lucas, is recognized as one of the world's premier sport fishing destinations and considering the ecological and economic importance of this species, this study analyzes its spatiotemporal distribution to characterize seasonal movements and assess the influence of environmental variables on its occurrence. In addition to responding to changes in environmental variables, primarily sea surface temperature, dolphin-fish occurrence in the study area has been found to vary seasonally with prey availability. The most important prey species in this area are *Dosidicus gigas*, *Pleuroncodes planipes*, *Balistes polylepis*, and *Auxis* spp. (Aguilar-Palomino et al. 1998). In this regard, chlorophyll concentration can serve as a proxy for prey availability, with a time lag between the chlorophyll peak and the dolphinfish abundance peak (Marín-Enríquez et al. 2018).

Due to its wide distribution and the fact that most of what is known about this species comes from fisheries data, either as a target species or as bycatch, integrating this information, both coastal and oceanic waters will enhance our understanding of its distribution and help infer its movements.

MATERIALS AND METHODS

Catch data

Dolphinfish catch and effort data for 2008-2011 were obtained from the fish reports of one of the main sport-fishing fleets operating in the southern part of the Baja California peninsula.

Catch data were recorded as the number of fish caught (weather retained or released alive) during sport fishing activities, while effort was measured by the number of trips conducted by the fleet in Cabo San Lucas (area between 22.6-23.4°N and 109.2-110.4°W; Fig. 1). Fishery data were grouped by month into 9.26×9.26 km grids, corresponding to 5' quadrants used by this fishery.

Each fishing trip typically lasted about 8 h, taking place between 06:00 and 16:00 h (Klett-Traulsen et al.

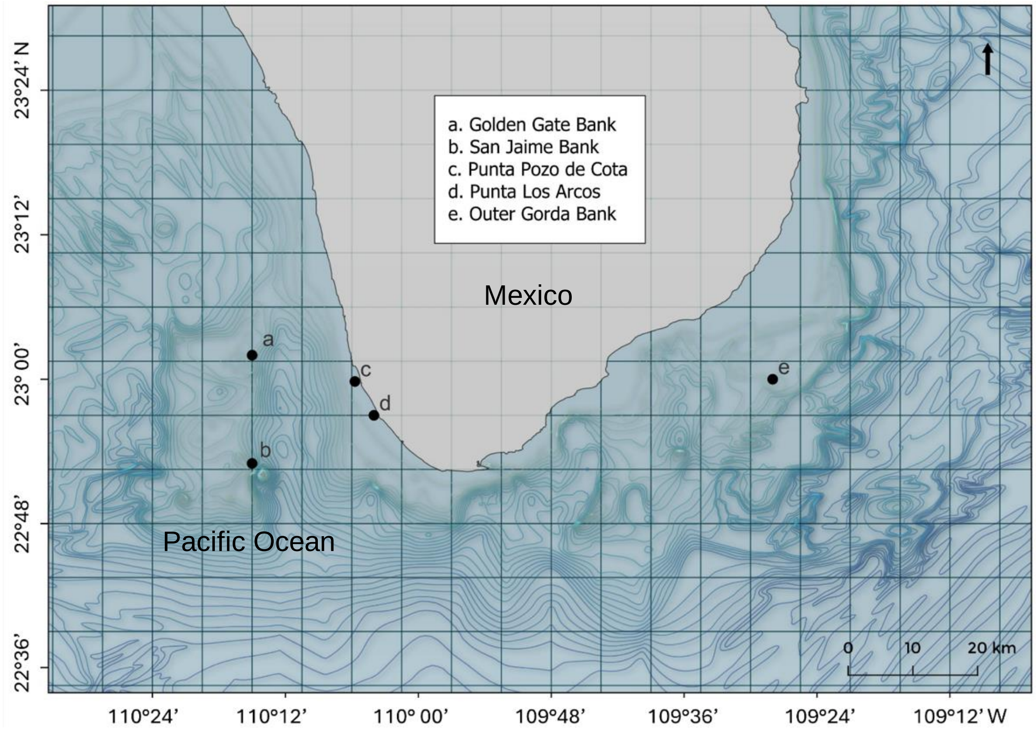

Figure 1. Geographical location of the study area and points of interest (a-e).

1996). The boats ranged in length from 28 to 35 feet, with 4 to 6 fishermen per boat and a consistent crew (including the captain) assigned to each. Due to limited information on the boats' physical characteristics or the number of rods used, nominal catch rates were used in this analysis.

Statistical analyses were performed using the nominal monthly catch rate as the dependent variable; the catch rate (CR) was calculated as CR = C/F, where CR represents the nominal monthly catch rate in number of fish per trip, C is the total catch (including both landed and released fish), and F is the total number of fishing trips. A Lilliefors-corrected Kolmogorov-Smirnov normality test (KS) was applied (Razali & Wah 2011) to determine whether the catch rate data were normally distributed. Given the obtained results (KS = 0.56, $P < 2.2e\text{-}16$), the Kruskal-Wallis test (H) was used to evaluate whether significant differences in nominal catch rates existed by month and year (Zar 2010).

Environmental and spatial data

The environmental variables used in this study include SST, concentration of chlorophyll-*a* (Chl-*a*), absolute sea surface height (ASSH), and depth (bathymetry). All environmental variables were obtained from NOAA satellite data [https://coastwatch.pfeg.noaa.gov/erddap/index.html] (Table 1).

Statistical modeling

Generalized additive models (GAMs) have been widely used to model and predict the spatiotemporal distribution of several large pelagic species, as well as to identify their potential habitat preferences (Su et al. 2008, Martínez-Rincón et al. 2012, 2014, Ortega-García et al. 2015). In this study, GAMs were applied to assess the environmental, spatial, and temporal effects on dolphinfish CRs. GAMs are semi-parametric extensions of generalized linear models that assume additive effects and incorporate smooth functions of predictors (Guisan et al. 2002). For statistical modeling, both fishery and environmental data were aggregated by month into the same 9.26×9.26 km grids across the study area.

The response "dolphinfish nominal CR (number of fish per trip)" (μ_i) was modeled as follows:

$$g(\mu_i) = \alpha + f_1(\mathrm{year}_i) + f_2(\mathrm{month}_i) + f_3(\mathrm{SST}_i) + f_4(\mathrm{Chl}\text{-}a_{\,i}) \\ + f_5(\mathrm{ASSH}_i) + f_6(\mathrm{longitude}_i, \mathrm{latitude}_i) + f_7(\mathrm{depth})$$

where $g(\mu_i)$ is the expected value of the dolphinfish CR, g is the monotonic link function (*inverse*). The gamma distribution was chosen because it can handle continuous,

Table 1. Environmental variables used in statistical models.

Name	Dataset id	Spatial resolution	Temporal resolution
Sea surface temperature	erdMWsstdmday_LonPM180	0.0125°	Monthly
Chlorophyll-*a*	erdMWchlamday_LonPM180	0.0125°	Monthly
Absolute sea surface height	erdTAssh1day_LonPM180	0.25°	Monthly
Depth	etopo180	0.0166°	---

strictly positive data (>0), and the inverse link function ensures that the predicted values (on the response scale) are always non-negative (Zuur et al. 2009). The $f_{1\text{-}7}$ are smooth functions for the covariates: year, month, SST, Chl-*a*, ASSH, longitude and latitude (interaction term), and depth. Smooth functions are represented using thin plate regression splines. All the GAMs were fitted using the "mgcv" package (Wood 2011) of R software (R Core Team 2024).

The model was constructed using a forward variable selection procedure, beginning with a null model that included only the overall mean as a predictor. Predictor variables were then added one at a time to evaluate their contribution to the model. Variable performance was assessed based on explained deviance, Akaike's information criterion (AIC), and adjusted R^2 (Wood 2017).

Diagnostic plots, including a histogram of residuals and a plot of residuals versus the linear predictor, were used to assess model fit and evaluate the statistical assumptions for residuals (i.e. normality and homoscedasticity). These diagnostics are present in Figure S1. Before the model-building procedure, a cross-correlation analysis was conducted between the response and predictor variables to determine whether including lagged variables would improve model performance. Finally, the monthly spatial distribution of the dolphinfish nominal catch rate was predicted using the best-fitted model and environmental data from 2008 to 2011, to identify potential "hot spots" of the species in the study area.

RESULTS

The average dolphinfish CR for the analyzed period was 1.55 ind $trip^{-1}$, with the highest monthly value observed in September 2008 (7.76 ind $trip^{-1}$). Although no significant statistical difference was found in CR between years ($H_{(3)} = 2.81$; $P = 0.4212$), the highest annual average (2.37 ind $trip^{-1}$) was recorded in 2009, while the lowest value (1.09 ind $trip^{-1}$) occurred in 2010. A clear seasonal trend was observed ($H_{(11)} = 29.27$; $P = 0.0020$), with higher CRs during the summer-autumn months (July-December) and lower CRs during the winter-spring months (January-June) (Fig. 2).

Spatially, the highest CRs were recorded on the western side of the study area, highlighting two areas: Golden Gate Bank and the coastal area extending from Punta Pozo de Cota to Punta Los Arcos and Punta Pescadero. In contrast, CRs were relatively low in the southern and eastern side of the study area, except for a single quadrant east of Outer Gorda Bank that showed high values (Fig. 3). The spatial distribution exhibited seasonal variation, with two different patterns: the first occurred at the end of winter and beginning of spring, characterized by low to moderate CRs in the southern area; the second appeared during autumn, with CRs more widely distributed and higher values concentrated in the western region (Fig. 4). While these distribution patterns were consistent across the four years of the study, the magnitude of CRs varied interannual. Notably, during the summer and early autumn of 2009, most quadrants recorded CRs greater than 1 ind $trip^{-1}$ (reaching up to 3 ind $trip^{-1}$). In contrast, in the winter and early spring of 2011, nearly all quadrants exhibited extremely low CRs (<0.25 ind $trip^{-1}$).

The monthly average SST ranged from 20.3 to 30.4°C, showing significant seasonal variability ($H_{(11)} = 34.46$, $P < 0.05$). The highest SSTs were recorded during summer months, while the lowest occurred in winter. Although the highest annual average SST was recorded in 2009 and the lowest in 2010, no significant interannual differences were detected ($H_{(3)} = 0.44$, $P = 0.93$).

The Chl-*a* concentration exhibited well-defined seasonality ($H_{(11)} = 22.48$, $P < 0.05$), with the highest concentrations in spring and the lowest in summer. Notably, in early spring 2008, monthly averages were nearly double those observed in other years. Although the highest annual average Chl-*a* was recorded in 2008 and the lowest in 2010, interannual variability was not significant ($H_{(3)} = 7.21$, $P = 0.06$).

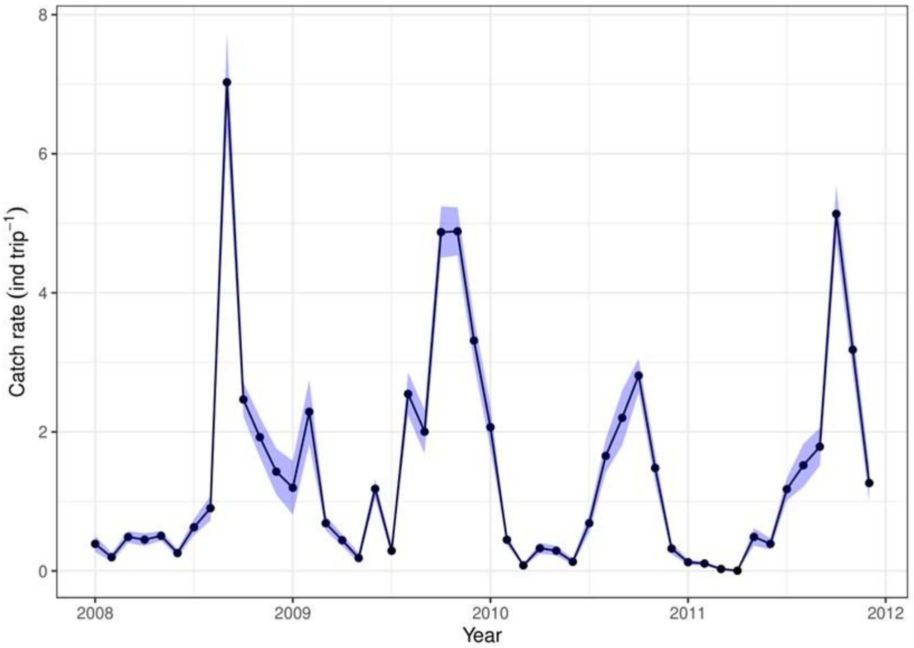

Figure 2. Monthly average dolphinfish catch rates (number of individuals per trip) recorded by the main sport fishing fleets that operated in the area of Cabos San Lucas, Baja California Sur, Mexico, during the 2008-2011 period.

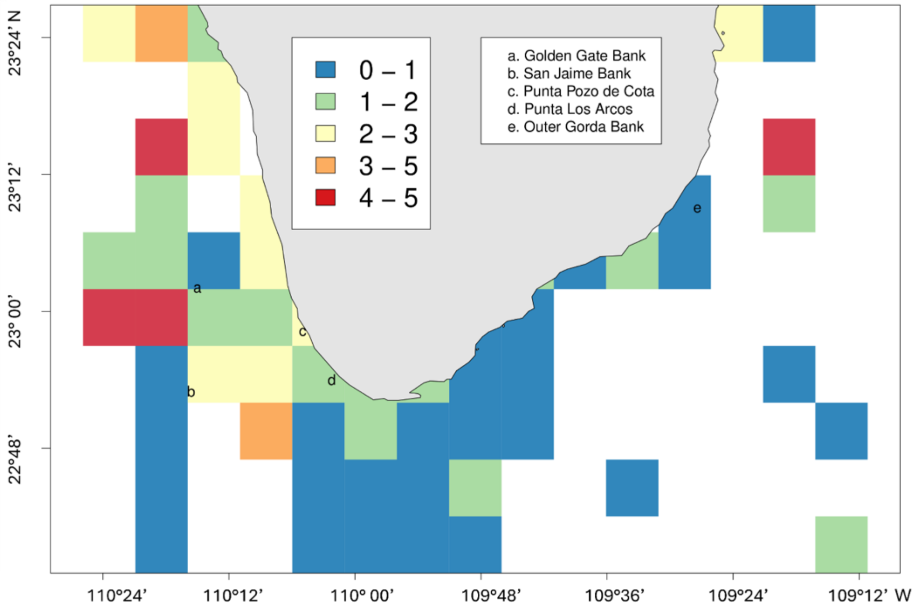

Figure 3. Average dolphinfish catch rates (number of individuals per trip) by quadrant distribution, recorded by the main sport fishing fleets that operated in the area of Cabo San Lucas, Baja California Sur, Mexico, during the 2008-2011 period.

The ASSH showed significant seasonal variability ($H_{(11)} = 27.63$, $P < 0.05$), with the highest values in summer-autumn and the lowest in spring. The highest annual average occurred in 2009 and the lowest in 2011; however, interannual variability was not statistically significant ($H_{(3)} = 0.58$, $P = 0.89$).

The CRs showed a positive and significant correlation with SST ($r = 0.63$, $P < 0.05$) and ASSH

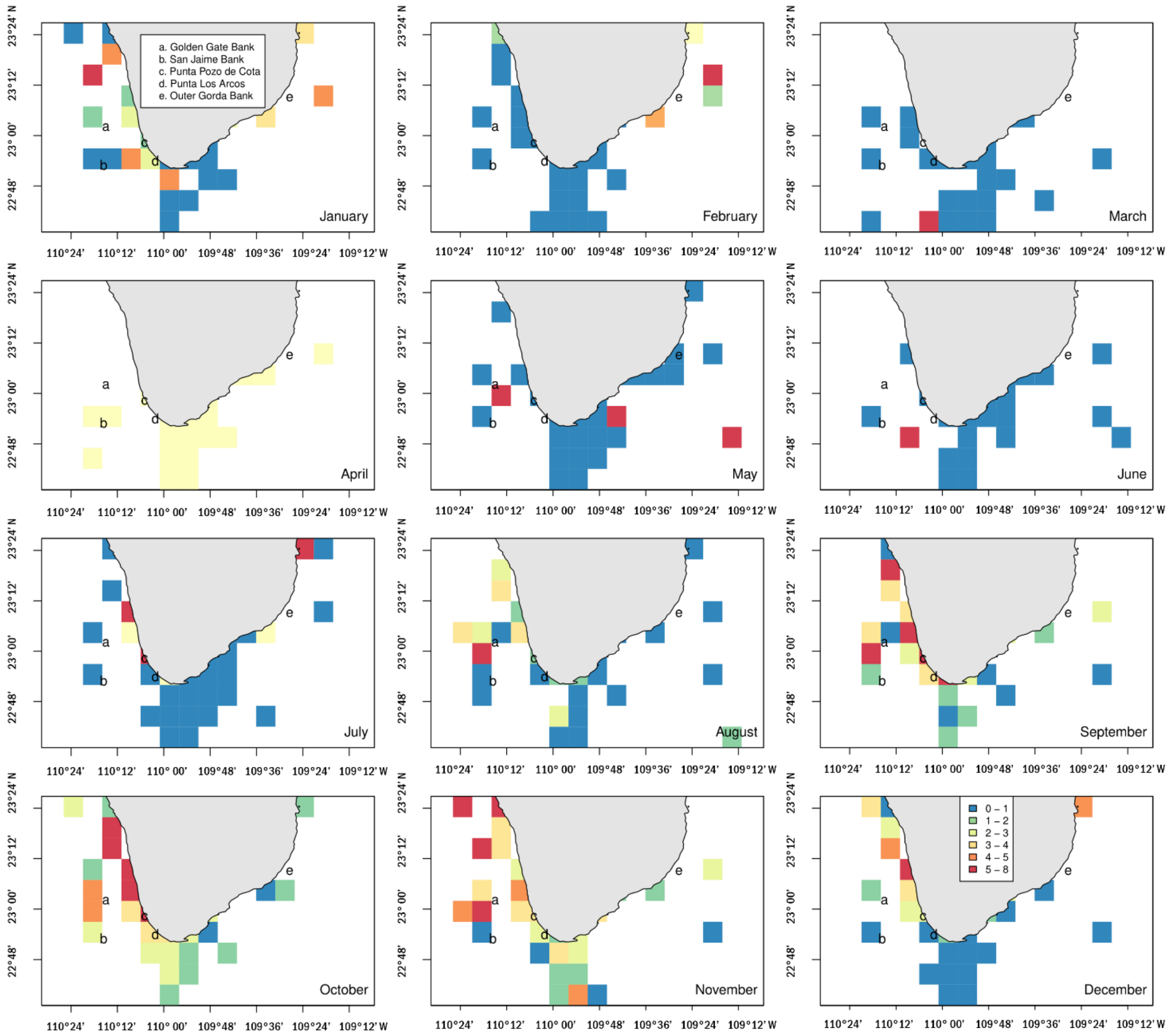

Figure 4. Average dolphinfish catch rates (number of individuals per trip) by quadrant and month, recorded by the main sport fishing fleets that operated in the area of Cabo San Lucas, Baja California Sur, Mexico, during the 2008-2011 period.

($r = 0.77$, $P < 0.05$). A positive but weaker correlation was found between CRs and Chl-*a* ($r = 0.32$, $P < 0.05$), with a lag of five months.

Among the environmental variables, only SST and depth were significant predictors of dolphinfish distribution and abundance, along with spatial (latitude and longitude) and temporal (year) covariates. Although ASSH was initially considered, it showed concurvity with SST and was excluded from the final model, as SST has a more direct biological relevance to dolphinfish ecology. The best-fitting model explained 29.32% of the deviance (Table 2).

Partial effects plots from the model (Fig. 5) indicated that the highest predicted CRs occurred in the western portion of the study area, particularly near Golden Gate Bank and adjacent coastal zones. Moderate CRs were also predicted east of Outer Gorda Bank. Consistent with these results, the species showed a strong preference for warmer waters, with optimal conditions around 28°C and a broader tolerance range of 19-31°C. The temporal effect revealed a peak in CR in 2009, followed by a steady decline to a minimum in early 2011, and a pronounced seasonal pattern, with the highest CRs occurring between August and October.

Table 2. Stepwise regression (forward) was used to get the minimal adequate model (best-fitted generalized additive models). AIC: Akaike information criterion, Dev. exp.: deviance explained, Adj. R^2 = adjusted R^2.

Model	AIC	Dev. exp. (%)	Adj. R^2
Null	5513.60	0.00	0.00
$\mu_i = \alpha + f_1(\text{Time})$	5153.02	24.73	0.20
$\mu_i = \alpha + f_1(\text{Time}) + f_2(\text{Depth})$	5050.93	25.16	0.20
$\mu_i = \alpha + f_1(\text{Time}) + f_2(\text{Depth}) + f_3(\text{SST})$	5049.77	25.65	0.21
$\mu_i = \alpha + f_1(\text{Time}) + f_2(\text{Depth}) + f_3(\text{SST}) + f_4(\text{Lon, Lat})$	5003.97	29.32	0.24

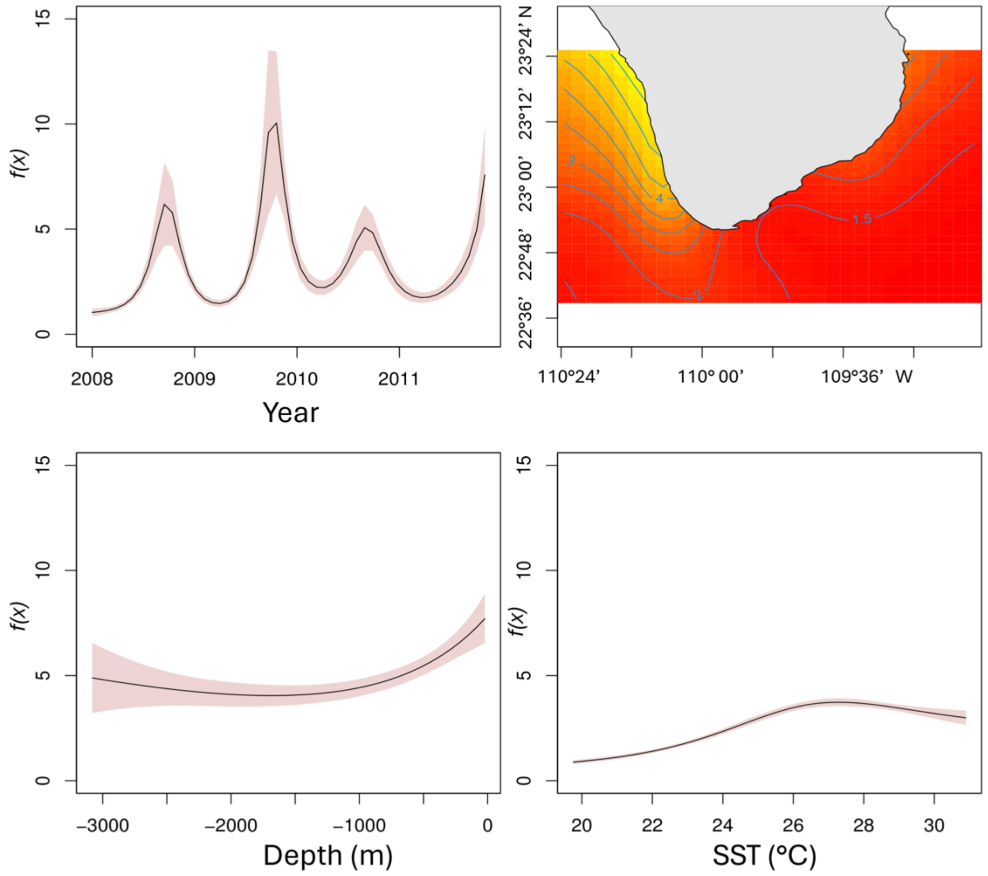

Figure 5. Partial effects plots of dolphinfish catch rates (number of individuals per trip) as a function of predictor variables off Cabo San Lucas, Baja California Sur, Mexico, during the period 2008-2011. SST: sea surface temperature.

Monthly prediction maps (Fig. 6) showed increased CRs during the summer-autumn period, consistent with observations from the sport fishing fleet. Spatially, however, high CRs were predicted year-round in areas associated with seamounts and banks, such as Golden Gate, San Jaime, and Outer Gorda Bank.

DISCUSSION

The CRs in the Cabo San Lucas area showed a clear seasonal trend, with the highest values occurring during the summer and autumn months. This unimodal pattern was previously reported in the region by Zúñiga-Flores et al. (2008) for the period 1990-2000. In contrast, in the Mexican south Pacific, the seasonal pattern is bimodal, with a primary peak between November and

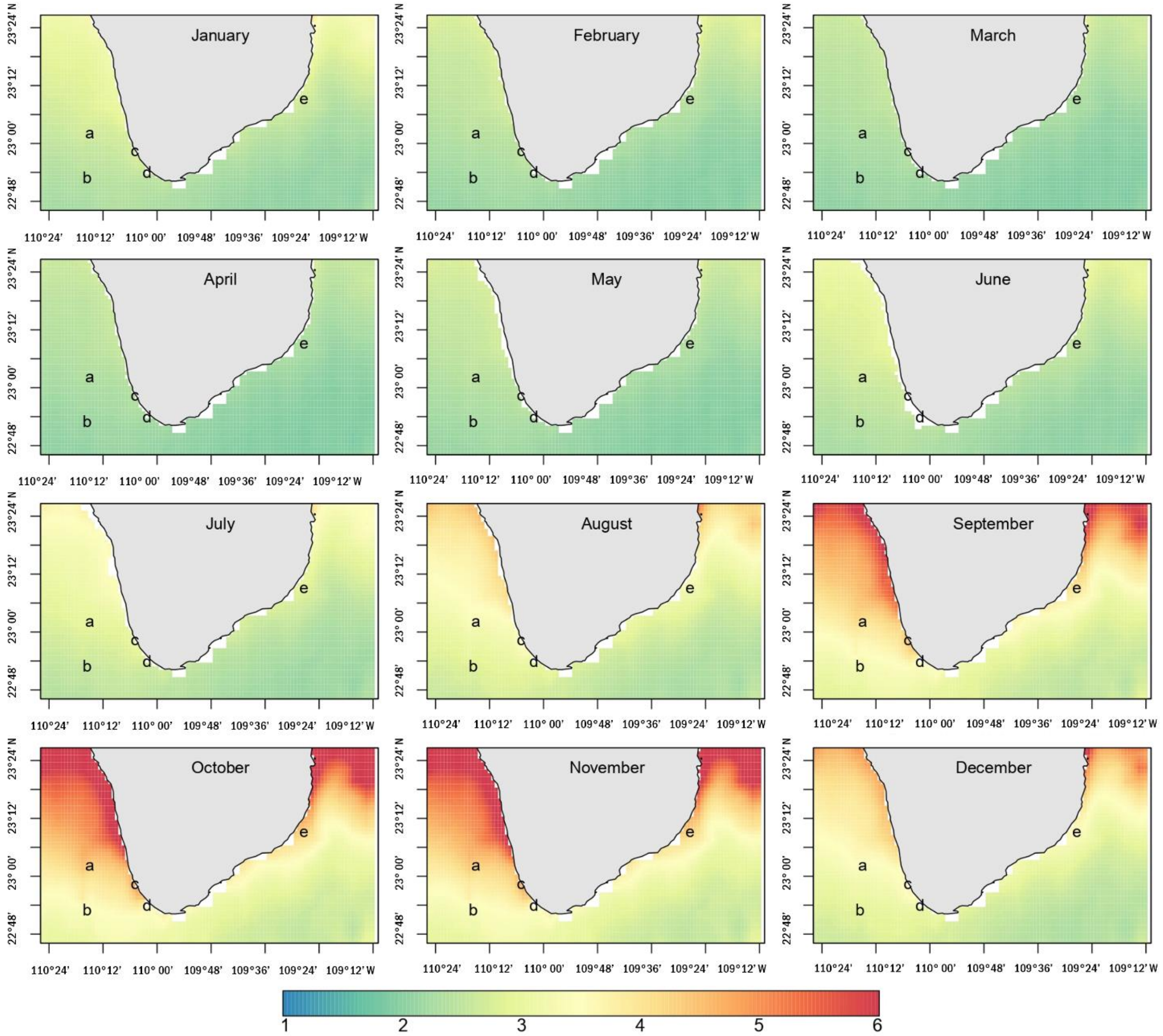

Figure 6. Monthly maps of predicted dolphinfish catch rates (number of individuals per trip) in the Cabo San Lucas area, Baja California Sur, Mexico, during the period 2008-2011.

January and a secondary peak between June and September (Alejo-Plata et al. 2014). The overall mean CR observed in this study (1.55 ind trip^{-1}) is comparable to that reported by Zúñiga-Flores et al. (2008) from 1990 to 2000 (1.33 ind trip^{-1}), suggesting that the resource in the region remained relatively stable over time.

The highest monthly CR was recorded in September 2008 (7.76 ind trip^{-1}). Although fishing effort in this region typically decreases during September (Ortega-García et al. 2006), September effort was 14% above the long-term average, while it remained approximately 60% below average during the rest of the study period.

Interannual variability in CR was not statistically significant; however, the highest and lowest annual mean CRs coincided with the 2009 El Niño and the 2010 La Niña events, respectively. Similar patterns have been reported previously, with higher CRs observed during moderate El Niño events (1992-1993) and reduced CRs during strong El Niño conditions (1998), likely due to northward shifts in dolphinfish distribution (Zúñiga-Flores et al. 2008). Such displacement during intense El Niño events has also been documented by the occurrence of dorado in waters off California (Norton & Crooke 1994, Hammann et al. 1995).

The relationship between SST and dolphinfish CRs was strong. Although dolphinfish was present even during the coldest months with average SSTs around 22°C, the highest CRs were recorded at SSTs ranging from 28 to 31°C. The species' preference for warm waters has been documented by several authors in both the study area and the EPO, highlighting its pronounced seasonality across its distribution, with higher catch rates during summer months in both hemispheres (Norton & Crooke 1994, Santana-Hernández 2001, Zúñiga-Flores et al. 2008, Martínez-Rincón et al. 2009, Solano-Sare et al. 2015).

The correlation between Chl-*a* and CRs was positive with a lag of five months, which agrees with what was previously reported by Zúñiga-Flores et al. (2008) in the same study area for the 1990-2000 period, and which may reflect temporal stability in energy flow from the base of the food web towards the dolphinfish. For the same study area, Ortega-García et al. (2015) reported a six-month lag between striped marlin (*Kajikia audax*) CRs and Chl-*a*. Given that dolphinfish has a lower trophic level than striped marlin (Torres-Rojas et al. 2014), it is expected that energy flow from the base of the food web occurs more quickly than for striped marlin.

Primary productivity is a key factor influencing abundance in large marine ecosystems (Pauly & Christensen 1995), with Chl-*a* serving as an indirect indicator of this productivity. In this study, a cross-correlation analysis revealed a significant five-month lag between Chl-*a* and dolphinfish CRs. However, this pattern was not evident in 2010, when a peak in CR was recorded despite low Chl-*a* levels (the lowest of the entire study period), suggesting that even with reduced Chl-*a*, the ecosystem can still support increases in dolphinfish CRs, likely due to their high mobility and opportunistic feeding habits (Tripp-Valdez et al. 2010, Torres-Rojas et al. 2014).

The distribution of CRs showed two patterns: one reduced and confined to the south, and another in which CRs were distributed throughout the study area, with higher values in the west. This pattern of expansion and contraction persisted throughout the study period, suggesting that the dolphinfish exhibits clear migratory behaviors, moving from south to north in spring and from north to south in autumn and winter. These movements are likely influenced by the interaction of the California Current and the Mexican Coastal Current (MCC), which generate warm-water intrusions on the west side of the study area, as well as the seasonal formation of current convergence fronts and mesoscale eddies (Pantoja et al. 2012).

Various studies have reported that floating objects function as aggregators for dolphinfish (Massutí et al. 1999, Castro et al. 2002, Kleisner 2009, Farrell et al. 2014). Unfortunately, in this study, it was not possible to analyze their relationship with CRs, as there are no records indicating whether dolphinfish captures were associated with floating objects. However, considering that the highest frequency of hurricanes in the Pacific is recorded in September (Yáñez-Arancibia 2014), it is reasonable to expect a greater number of natural floating objects during this month (although no official records exist), which coincides with higher CRs.

The monthly distribution of CRs exhibited high variability; however, the highest values were consistently concentrated in the western portion of the study area, particularly around Golden Gate Bank and adjacent coastal zones. This region has been identified as a high-importance area for striped marlin catches (Ortega-García et al. 2015), as has the Outer Gorda Bank during certain months, reinforcing the ecological and fisheries significance of seamounts. Seamounts are known to support diverse and productive ecosystems (Pitcher & Bulman 2007) by enhancing current velocity and promoting the upward transport of nutrient-rich waters, like upwelling systems (Genin et al. 1986, Boehlert 1988, Zaytsev et al. 2003). This process increases prey availability (Tseitlin 1985, Genin et al. 1986, Koslow 1997), making these features preferred habitats for large pelagic species such as tunas, sharks, and marlins (Holland et al. 1999, Itano & Holland 2000, Sibert et al. 2000, Morato et al. 2010, Ortega-García et al. 2015). In this context, SST plays a key role by directly influencing prey availability. For example, *Dosidicus gigas*, one of the main prey items of dolphinfish in the study area, is more abundant in the diet during periods of lower sea surface temperature and less abundant during warmer conditions (Torres-Rojas et al. 2014).

There are no studies specifically addressing the spatiotemporal distribution of dolphinfish in the region; however, Perle et al. (2020) used satellite and conventional spaghetti-type tags off Bahía Magdalena, Baja California Sur, and found that dolphinfish move south during autumn. It appears that the species takes advantage of seasonal flows of currents in the area during its movements, as also suggested by Marin-Enriquez et al. (2018) and Ortega-García et al. (2022). During its northward movement, Santana-Hernández (2001) associated the presence of dolphinfish with the waters of the MCC. Similar patterns of movement following coastal currents have been reported in the eastern central Atlantic, where Merten et al. (2014b) documented dolphinfish moving along the coast from south to north and back again in response to coastal current dynamics.

The selected model explained 29.32% of the total deviance. SST and depth were the only environmental variables included, as the model showed concurvity with ASSH. This phenomenon can lead to parameter overestimation, increasing the risk of type I errors by underestimating model variance, resulting in overly narrow confidence intervals that may alter the statistical significance of the variables (Wood 2004, Amodio et al. 2014). To address the concurvity problem, several alternatives have been proposed, such as using modified GAM algorithms or Partial Generalized Additive Models (Amodio et al. 2014).

The selected model leaves 70% of the deviance unexplained. While this percentage of unexplained variance might appear high in other disciplines, it is consistent with the standards of marine ecological modeling. According to Wood (2017), biological systems are inherently noisy and influenced by complex, non-linear interactions that are often difficult to capture entirely within a single modeling framework. From an ecological perspective, this 70% of unexplained variance is significant as it likely reflects the influence of fine-scale processes and stochasticity inherent to the marine environment. Factors such as biotic interactions (e.g. predation, competition), prey availability, and submesoscale oceanographic features -which were not included as covariates in this study- may play a substantial role in determining the species' distribution. Furthermore, the remaining variance suggests a degree of ecological plasticity in dolphinfish, indicating that its distribution is not strictly constrained by the abiotic variables measured. Consequently, a 30% deviance explained is considered a robust result that successfully identifies the primary environmental drivers of the species' abundance in a highly dynamic ecosystem.

The partial effects plots of the selected model show that CR concentrations are high on the western side of the study area, forming a corridor between two seamounts (Golden Gate and San Jaime) that extends toward the coast. Another area of high CRs was observed near the Outer Gorda Bank on the eastern side of the study area. Additionally, the plots revealed elevated CRs at higher SSTs (26-30°C) and during September. Both the high temperatures and the timing of peak CRs align with previous studies conducted in the EPO, which found that elevated CRs were associated with SSTs between 25 and 31°C and were commonly observed during the summer-autumn months (Santana-Hernández 2001, Zúñiga-Flores et al. 2008, Martínez-Rincón et al. 2009).

Interannual phenomena (e.g. ENSO events) can influence CRs, with positive trends typically observed during El Niño and negative trends during La Niña. However, Zúñiga-Flores et al. (2008) did not observe high CRs during the most intense El Niño of the last two decades (1997-1998), suggesting a non-linear relationship between CRs and these interannual events. When El Niño events are particularly strong, they can lead to a northward expansion of suitable habitat due to changes in the flow of the California Current, resulting in the presence of dolphinfish in waters off California (Hammann et al. 1995) and a corresponding decrease of CRs in the Cabo San Lucas region. The expression of ENSO events in the southern Gulf of California is frequently regionally modulated and temporally offset from equatorial Pacific conditions, potentially obscuring direct links between large-scale climate forcing and local Chl-*a* variability. Longer time series, including multiple ENSO cold phases, would therefore be necessary to evaluate lagged productivity-catch relationships robustly.

In the study area, no CRs were recorded in SSTs below 19°C or above 31°C, suggesting that these temperatures may define the thermal distribution of dolphinfish. This finding aligns with previous reports indicating that temperatures around 19-20°C appear to restrict the distribution and movement of dolphinfish in California waters (Palko et al. 1982, Goldberg & Aguilar 1985, Norton & Crooke 1994).

The information generated in this study, together with existing knowledge on the species' population dynamics (e.g., age structure, individual growth, and reproductive cycle), can support the development of management strategies to improve resource use and help resolve conflicts between commercial and sport fishing fleets. However, because the analyzed period is limited to a few years and the study area is small relative to the overall distribution of dolphinfish, the results of the present study may not be conclusive and should be interpreted with caution.

Credit author contribution

U. Jakes-Cota: analysis, interpretation, writing-original draft, review and editing; H. Yoshida-Hernández: conceptualization, analysis and writing-original draft; R.O. Martínez-Rincón: methodology, analysis, interpretation and writing-original draft; S. Ortega-García: conceptualization, interpretation, supervision, writing original draft, review and editing.

Conflict of interest

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

The authors would like to thank the sport fishing fleets that provided their logbooks, particularly the Pisces fleet, for its invaluable support. Ulianov Jakes-Cota and Sofía Ortega-García are supported by the Programa de Estímulos al Desempeño de los Investigadores. Sofía Ortega-García is also supported by a COFAA (Comisión de Operación y Fomento de Actividades Académicas) fellowship. The authors also thank the Sistema Nacional de Investigadoras e Investigadores de la Secretaría de Ciencia, Humanidades, Tecnologías e Innovación.

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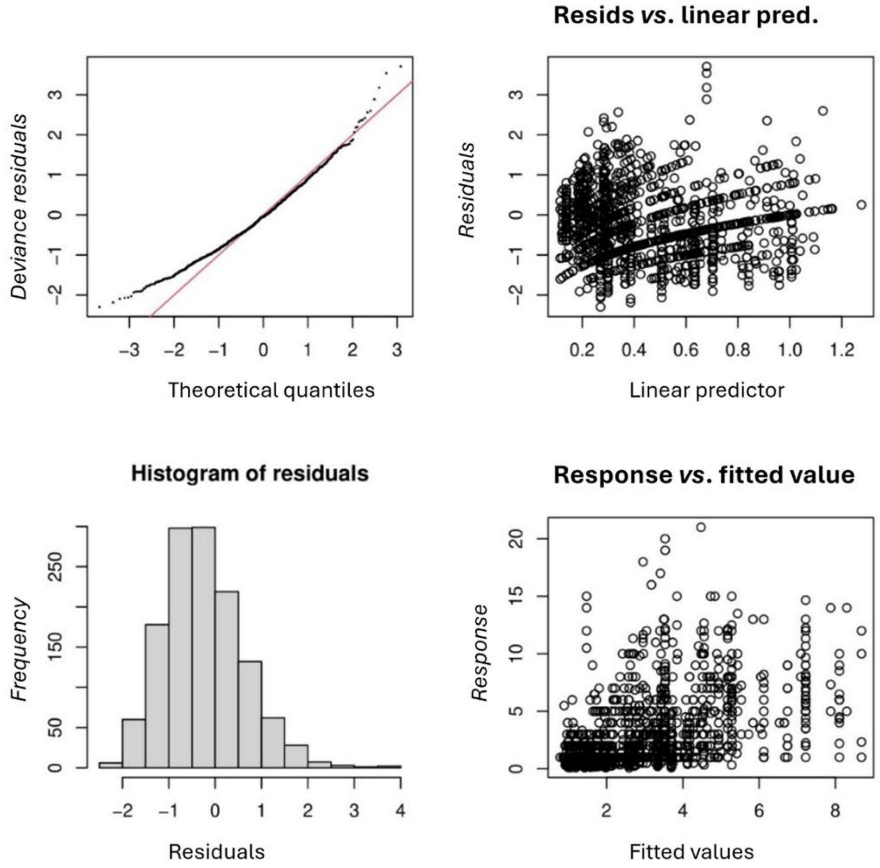
Received: August 18, 2025; Accepted: February 3, 2026

SUPPLEMENTARY MATERIAL



Resids *vs*. linear pred.

Histogram of residuals

Response *vs*. fitted value

Figure S1. Diagnostic plots of the fitted generalized additive model.