Check for updates

Aquatic Conservation: Marine and Freshwater Ecosystems

WILEY

ARTICLE OPEN ACCESS

Responses of Reef Fish Populations to Similar Environmental Changes Across Distant Oceanic Islands

Thamíris C. Karlovic[1] | Amanda R. Rodrigues[1] | Leeann Henry[2] | Sergio R. Floeter[3] | Kirsty L. Jones[2] | Carlos E. L. Ferreira[4] | Paulo S. Polito[5] | Olga T. Sato[5] | Maria A. Gasalla[1]

[1]Fisheries Ecosystems Laboratory, Oceanographic Institute, University of São Paulo, São Paulo, Brazil | [2]Environmental Management Division, St Helena Government, Jamestown, St Helena, Brazil | [3]Marine Macroecology and Biogeography Laboratory, Federal University of Santa Catarina, Florianópolis, Brazil | [4]Reef Systems Ecology and Conservation Laboratory, Universidade Federal Fluminense, Niterói, Brazil | [5]Oceanographic Institute, University of São Paulo, São Paulo, Brazil

Correspondence: Thamíris C. Karlovic (thamykarlovic@usp.br)

Received: 5 October 2025 | **Revised:** 7 March 2026 | **Accepted:** 13 March 2026

Keywords: climate change | environmental convergence | marine protected areas | population dynamics | reef fishes | South Mid-Atlantic Ridge

ABSTRACT

Oceanic islands are among the most remote and understudied regions of the planet, yet they harbour unique reef fish communities that are increasingly vulnerable to global environmental change. Because these islands are geographically isolated, their populations are often assumed to respond mainly to local environmental conditions. However, by analysing temporal patterns in oceanographic variables across two distant systems (3204 km apart) in the South Mid-Atlantic Ridge (both encompassed by marine protected areas—MPAs), we found that temporal alignment in environmental conditions was associated with coordinated shifts in counts of nine reef fish populations in each study area. Among the evaluated variables, pH emerged as the most influential factor. Despite the divergent responses among reef fishes, possibly reflecting differences in physiological plasticity, shared temporal patterns in pH appeared central to parallel population patterns observed across assemblages. Increases in sea surface height and chlorophyll-a played secondary roles, potentially benefiting some populations, although such effects may be transient. These results suggest that climate-driven convergence in environmental conditions can override geographic isolation, promoting similar biological responses that may reduce resilience and increase extinction risk. Given that both islands are legally protected, our findings highlight that even MPAs are not insulated from large-scale oceanographic stressors, underscoring the need for long-term monitoring and adaptative conservation strategies for remote reef systems.

1 | Introduction

Climate change poses great risks to marine ecosystems, altering water properties, habitat structure, ecosystem functioning and biodiversity patterns (Nagelkerken et al. 2016, 2018; Sunday et al. 2017; Lenoir et al. 2020). These impacts are particularly concerning in oceanic islands, whose reef ichthyofauna is typically of high endemicity, species-poor, range-restricted and low in functional redundancy (Ferrari et al. 2023; Floeter et al. 2023). Such communities, shaped by biogeographic isolation, evolved under relatively stable conditions (Escobar-Camacho et al. 2021) and exhibit low connectivity among populations (Luiz et al. 2015), which leads to high self-recruitment (Robertson 2001) and density dependence (Hixon et al. 2012). These population-level dynamics are associated with reduced physiological plasticity (Rummer and Munday 2017), potentially limiting species' ability to adapt to rapid environmental shifts.

Extreme heating events and ocean acidification could harm individual performance and behaviour (Johansen and Jones 2011; Nagelkerken and Munday 2016), influencing life-history traits (e.g., growth, fecundity, survivorship) and consequently

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). *Aquatic Conservation: Marine and Freshwater Ecosystems* published by John Wiley & Sons Ltd.

population dynamics (Rummer and Munday 2017; Marquez et al. 2023). Population declines, through increased mortality or distribution shifts, are expected especially for populations living close to their thermal limits (Rummer and Munday 2017). High latitude reef fish are adapted to greater temperature variation in comparison to low-latitude ones, increasing feasibility to thrive under global warming scenarios (Rummer and Munday 2017). Likewise, populations exposed to daily and seasonal variations of CO_2 exhibited higher tolerance to pH decreases (Kwan et al. 2017; Rummer and Munday 2017).

Indirect effects may also constrain species' resilience. Ocean acidification can reduce habitat complexity (Sunday et al. 2017), which sometimes affects fish populations more strongly than pH per se (Nagelkerken et al. 2016). Modifications in marine habitats are also promoted by increases in sea surface temperature (SST). Increases in sea surface height (SSH), from ice melt and thermal expansion (IPCC 2019), shift zonation and benthic composition in rocky ecosystems (Kaplanis et al. 2020; Rilov et al. 2021). Additionally, enhanced upper-ocean stratification reduces vertical mixing, limiting primary production (D'Alelio et al. 2020). Because chlorophyll-a concentrations (Chl), a proxy for primary production, correlate positively with reef fish biomass, its reduction may ultimately affect reef fish communities through bottom-up processes, particularly in isolated oceanic systems where productivity is already limited (Williams et al. 2015; Quimbayo et al. 2019).

To explore how oceanographic constraints influence reef fish assemblages, we investigated two remote systems along the South Mid-Atlantic Ridge (Figure 1): the Archipelago of Saint Peter and Saint Paul (the archipelago) and Saint Helena Island (the island). These areas encompass a broad latitudinal gradient, with the archipelago in the equatorial zone (0.91°N, 29.35°W), and the island in the southern tropical Atlantic (5.96°S, 5.70°W), 3204km apart, reflecting contrasting oceanographic regimes (Pacheco et al. 2022). The equatorial region is influenced by interactions between the South Equatorial Current and the Equatorial Undercurrent, as well as the high rainfall rates promoted by the intertropical convergence zone. Together these forces increase SST, decrease sea surface salinity and suspend allochthonous nutrients, enhancing productivity in the archipelago's waters (Viana et al. 2009; Vaske et al. 2010; Pinheiro et al. 2020). In contrast, the island is mainly influenced by the northern branch of the subtropical gyre, persistent anti-clockwise winds and high-pressure systems, which promote downwelling and lead to net evaporation (Talley et al. 2011). Additionally, the presence of the Eastern South Atlantic Central Water contributes to cooler sea surface waters

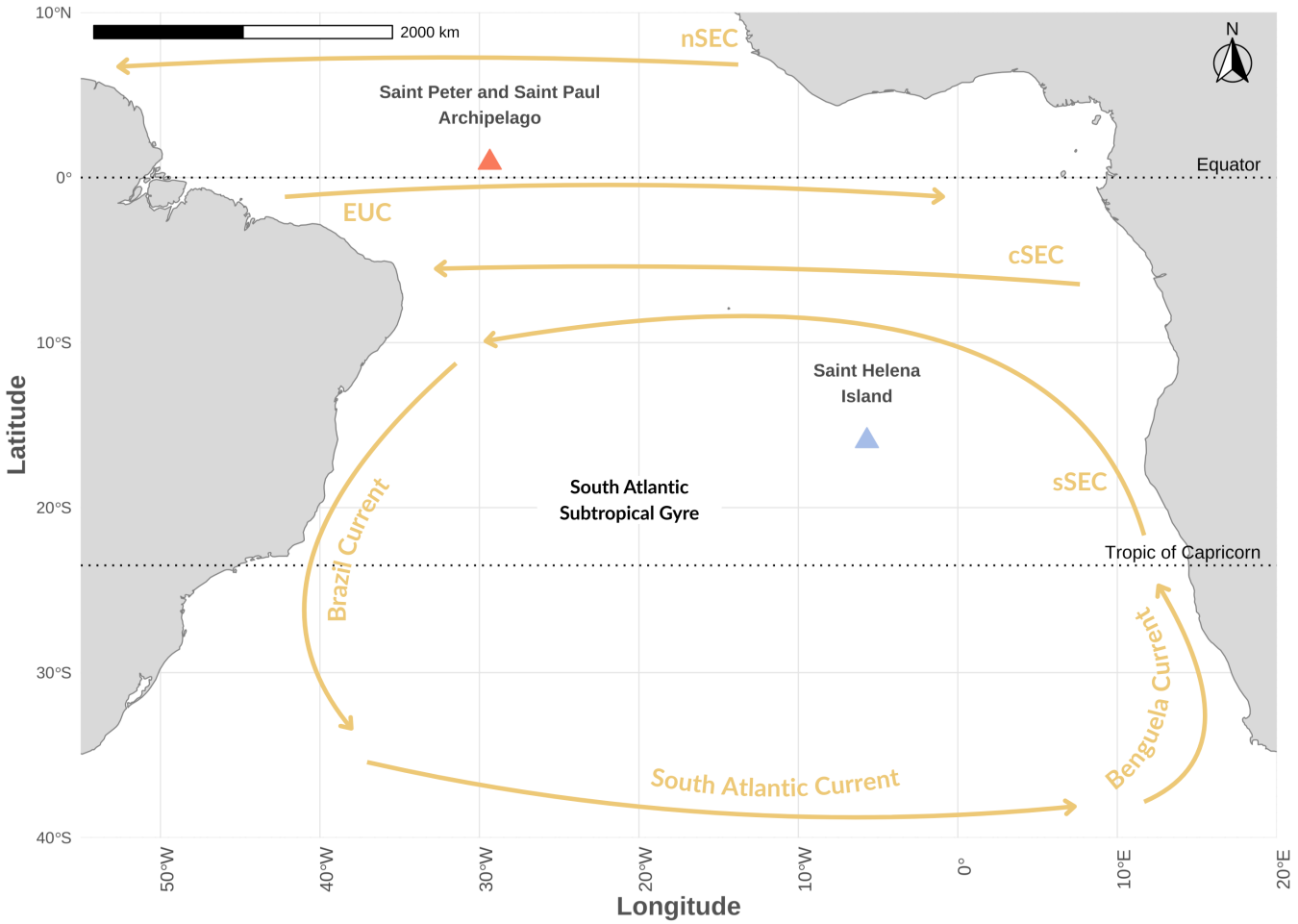

FIGURE 1 | Location of Saint Peter and Saint Paul Archipelago and Saint Helena Island in the South Atlantic Ocean. The map illustrates the main oceanographic system influencing each system, including the north, central and south branches of the South Equatorial Current (nSEC, cSEC and sSEC), the Equatorial Undercurrent (EUC), the Brazil Current, the South Atlantic Current, the Benguela Current and the South Atlantic Subtropical Gyre.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

(Feistel et al. 2003; Liu and Tanhua 2021; SHG 2022), resulting in elevated salinity and reduced local productivity (Demetris and Hall-Spencer 2012; Goes et al. 2014). Such characteristics have resulted in distinctive reef fish assemblages, even compared with other oceanic islands (Cowburn et al. 2021).

Therefore, given that both areas shelter isolated populations of shared species exposed to contrasting environmental conditions, we did not expect similar temporal dynamics in population pattern between them. To explore this, we investigated temporal patterns in population counts of nine reef fish species shared between the two areas and four oceanographic variables (SSH, SST, pH and Chl), applying a combination of time-series analyses and modelling to annual data. We expected both biological and environmental variables to exhibit distinct temporal patterns across the two areas, with weak or non-significant lagged correlations among time series. We also anticipated that environmental anomalies, particularly for SST, SSH and Chl would be more pronounced in the archipelago due to the influence of the intertropical convergence zone, equatorial upwelling and mesoscale eddies. Consequently, we expected reef fish assemblages to exhibit greater temporal concordance (i.e., aligned temporal variation in species counts) within areas than between them, forming distinct clusters. Finally, we fitted models to assess associations between fish counts and environmental variability, evaluating whether the influence of key oceanographic factors differed between the areas.

2 | Methods

2.1 | Data Source and Preparation

Counts of reef fishes from each assemblage were provided by the Long-Term Monitoring Program of Reef Communities at the Brazilian Oceanic Islands and by the Marine and Fisheries Conservation Section of the St Helena Government. Both datasets were generated through underwater visual surveys, conducted independently under region-specific monitoring protocols. At the archipelago, 506 surveys were conducted annually from 2009 to 2019 (except in 2010) using 40 m^2 transects at depths of up to 36 m. At the island, 401 surveys were carried out from 2014 to 2022 using 100 m^2 transects at depths of up to 21 m, with variable monthly sampling effort across years (from biannual surveys to uneven seasonal coverage).

Across both areas, a total of 16 reef fish species were recorded in common during the survey campaigns. However, only nine species were consistently observed across multiple years in both locations, providing sufficient temporal coverage to support comparative time series analyses. Species that were sporadically recorded or absent in several years were excluded to avoid spurious patterns driven by data gaps or the need for extensive data imputation.

To derive annual values while minimizing potential under or overestimation due to uneven sampling effort, mean counts were first calculated for each semester (i.e., January–June corresponding to the first semester and July–December to the second semester) and subsequently averaged to obtain yearly estimates for the island data. This procedure was applied to reduce the influence of variable sampling frequency and seasonal coverage. The missing 2010 value in the archipelago data was estimated using the 'impute' function from the R package *IEAtools*, based on the 5-year moving average method (Otto 2023). This method was applied to the full time series (2009–2019), with the window centred on the missing year and adjusted at the series boundaries as implemented in the function.

Because the objectives of this study focus on temporal patterns, concordance and population responses to environmental variability, rather than on comparisons of absolute abundance or density between areas, differences in spatial sampling effort (e.g., number of surveys and depth) were not explicitly standardized. Such differences are inherent to independent long-term monitoring programmes and were assumed to exert consistent effects on species counts through time within each area. To evaluate whether temporal changes in sampling design during the overlapping period (i.e., 2014–2019) could bias observed patterns, we tested for interannual differences in survey effort between areas using a chi-squared test and found no significant difference ($\chi^2 = 6.96$, df = 5, $p = 0.22$). Additionally, variation in mean transect depth was assessed using a linear model including the interaction between area and year (depth ~area*year), with no significant effects detected (all $p > 0.05$), indicating that depth-related sampling differences are unlikely to have biased temporal patterns.

Monthly pH data was obtained from the global hindcast product by Mercator Ocean International (10.48670/moi-00019), based on the PISCES biogeochemical model within the NEMO framework, with a horizontal resolution of 0.25° × 0.25° and 75 vertical levels. SST and Chl were sourced from NASA's Aqua-MODIS Level 3 monthly composites at 9 km resolution (NASA 2024). Daily anomalies of SSH were obtained from the Copernicus Marine Environmental Monitoring Service (CMEMS; 10.48670/moi-00148), also at 0.25° × 0.25° resolution. To obtain the environmental aspects of each area, shapefiles of the exclusive economic zones (EEZs) were obtained from marineregions.org repository (Flanders Marine Institute 2024). The EEZs were treated as circular polygons with a 200 NM radius. All pixels within each EEZ were selected from the original-resolution satellite and model-derived products. These values were averaged spatially at each time step to produce monthly time series for each area from 2002 to 2022.

2.2 | Time Series Analysis and Statistical Models

To prevent biased results due to temporal autocorrelation, which could lead to erroneous interpretations in the subsequent analysis (Olden and Neff 2001), autocorrelation and partial autocorrelation analyses were performed (Figures S1–S3). This preliminary step helped to better understand the temporal structure of the data and guided the selection of appropriate analytical methods for each objective.

Our analyses followed three main steps. First, temporal patterns of species counts were evaluated comparing the overlapping period (i.e., 2014–2019) between areas. To evaluate temporal concordance between assemblages, Hellinger-transformed species counts (Borcard et al. 2011) were used in hierarchical clustering with dynamic time warping (DTW) (Giorgino 2009; Kassambara and Mundt 2020). The resulting DTW matrix was

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

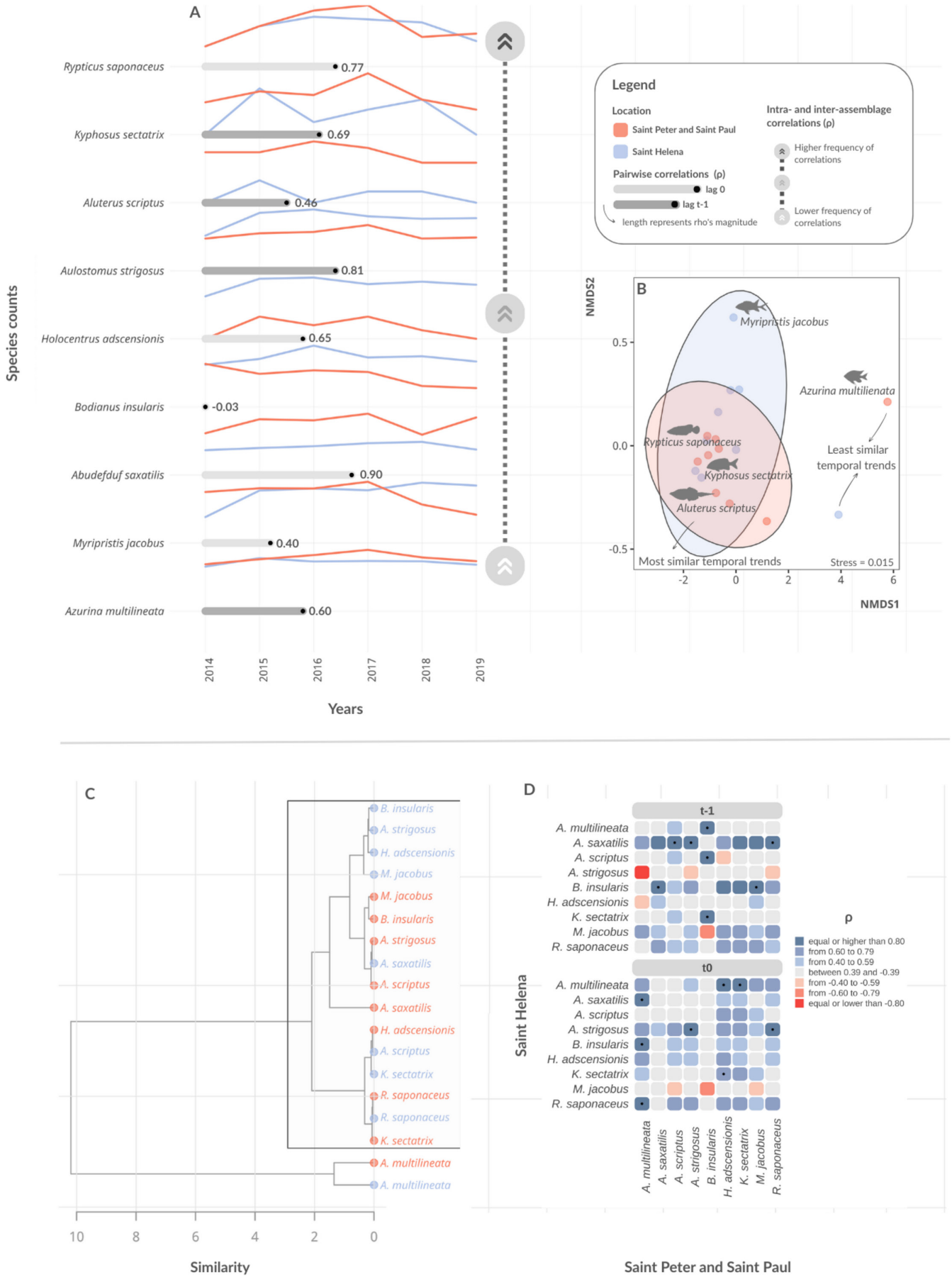

FIGURE 2 | Legend on next page.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

FIGURE 2 | Integrated visualization of temporal dynamics among reef fish populations from 2014 to 2019. The figure combines (A) ridgeline plots showing temporal trajectories of species counts in each location, where the y-axis indicates species identity and ridge height represents relative variation in counts through time (for visualization of counts magnitudes, see Figure S4); strongest pairwise correlations (regardless of lag) shown as connecting bars beneath the time series and a frequency gradient of intra- and inter-assemblage correlations, (B and C) grouping of populations based on dynamic time warping (DTW) distances represented via non-metric multidimensional scaling (NMDS) and hierarchical cluster dendrogram and (D) complete Spearman cross-correlation matrix.

also used to generate a non-metric multidimensional scaling (NMDS) ordination, providing a visual representation of temporal similarities across populations. Temporal covariation was quantified using the index of Loreau and De Mazancourt (2008) and cross-correlation analyses evaluated the strength and direction of relationships between current and lagged values of species populations. The significance of the estimated index and correlation coefficients were assessed by 10,000 random permutations (Manly 2006).

Second, we aimed to assess whether the areas have experienced similar environmental changes over the last 21 years (2002–2022), thus characterizing long-term background variability and patterns in oceanographic conditions at each site. Quarterly data of the four oceanographic variables were decomposed using locally weighted scatterplot smoothing (Cowpertwait 2006). Anomalous semesters were identified based on the interquartile range of the residual component of each time series. This procedure allowed us to detect unusual environmental fluctuations and compare the timing and frequency of anomalies between the island and the archipelago. We then estimated the Spearman correlation coefficients among the annual means of the oceanographic variables considering a shorter time window (i.e., 2014–2019), corresponding to the full period of overlap with the biological data.

Finally, relationships between species counts and oceanographic variables were assessed to identify potential associations underlying population patterns. Generalized additive models (GAMs) with a negative binomial distribution were fitted (Zuur et al. 2009), considering the available time window for each area (the archipelago = 2009–2019; the island = 2014–2022). This distribution was appropriate given the overdispersion and skewness of count data. When GAM smoothers were approximately linear (effective degrees of freedom close to 1), they were removed to simplify model structure. To minimize multicollinearity and reduce the risk of overfitting, only uncorrelated or weakly correlated predictors (Spearman's $\rho < 0.35$) were combined, and no more than two predictors per model were included. Models that explained more than 10% of the variation in species counts and showed significant predictor effects were ranked using the second order Akaike information criterion (AICc), with ΔAICc < 2 as a threshold to evaluate them regarding their descriptive capacity (Burnham and Anderson 2002). Residual diagnostics (Figures S6–S14) were performed to check for misspecification and heteroscedasticity (Zuur et al. 2009). All analyses were performed in R environment (R Core Team 2025) using functions from the following packages: *factoextra*, *dtw*, *synchrony*, *stats, mgcv* and *MuMIn* packages (Giorgino 2009; Gouhier and Guichard 2014; Wood 2017; Bartoń 2020; Kassambara and Mundt 2020).

3 | Results

3.1 | Species Population Dynamics

To explore shared temporal dynamics across areas, we focused on the overlapping period of reef fish data from 2014 to 2019. During this interval, most species showed similar temporal patterns across areas, characterized by coherent peaks and declines through time, with slight variation in magnitude or timing (Figures 2A and S4). Overall, species counts tended to increase during the first 2 years, followed by delayed peaks between 2016 and 2017, and abrupt declines thereafter.

Despite this general pattern, species differed in the degree of temporal concordance among populations and in their similarity to other species. For instance, the greater soapfish (*Rypticus saponaceus*) exhibited temporal fluctuations that closely tracked not only between areas but also aligned with patterns observed in several other species (e.g., the Bermuda sea chub, *Kyphosus sectatrix*, and the scrawled filefish, *Aluterus scriptus*). In contrast, the brown chromis (*Azurina multilineata*) showed strong temporal concordance between populations but a more distinct trajectory relative to the remaining reef fishes, regardless of location. These patterns were consistent with the clusters identified through DTW and their ordination in a NMDS space (Figure 2B,C), with the two identified groups comprising populations that shared similar temporal trajectories.

Cross-correlation analyses supported these findings, revealing a high frequency of moderate to strong temporal associations ($\rho \geq 0.4$), not only between populations of the same species but also among different assemblages (Figure 2A,D). Most of these correlations were positive, reflecting similar temporal phases at lag 0 (i.e., coincident peaks and valleys) and delayed responses at lag −1. Although not all pairwise correlations were statistically significant due to limited power from short time series (Manly 2006), the temporal coherence index remained high (~70%, $p < 0.05$), indicating consistent covariation among populations and assemblages.

3.2 | Environmental Patterns and Anomalies

Similar patterns were observed between the areas in the temporal variation of oceanographic variables from 2002 to 2022 (Figure S5). SSH showed a consistent increasing trend, whereas pH exhibited a gradual decline over time. Peaks and valleys in Chl, pH and SST occurred simultaneously in both areas, suggesting that populations have experienced similar environmental conditions despite differences in magnitude (e.g., higher temperatures in the archipelago's waters). Anomaly analyses revealed a general decline in anomaly magnitude across all oceanographic variables,

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

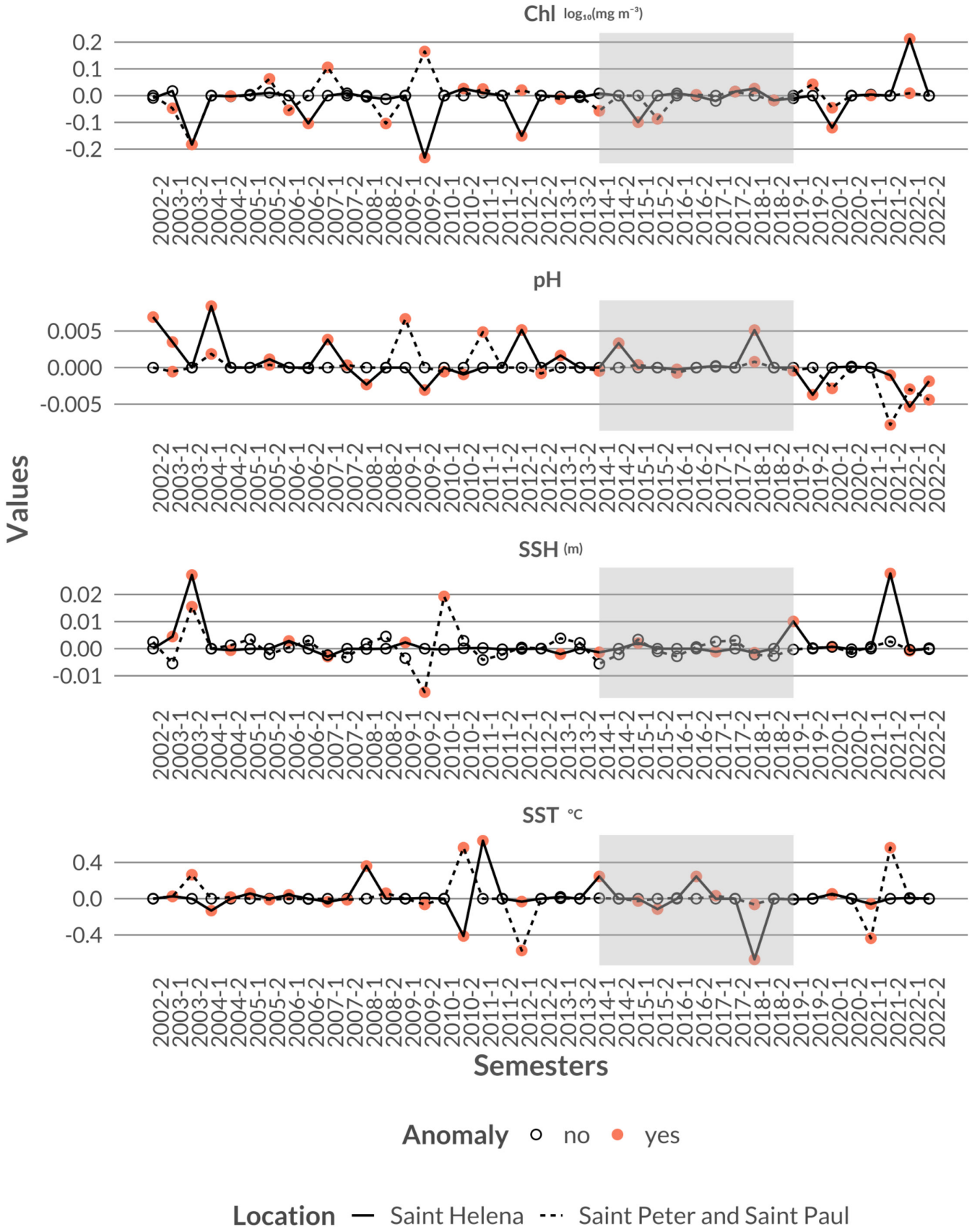

FIGURE 3 | Semestral anomalies of oceanographic variables depicting environmental conditions in Saint Helena Island and Saint Peter and Saint Paul Archipelago from 2002 to 2022. The shaded area highlights the period during which synchrony between reef fish assemblages was detected (2014–2019). SSH and SST values are in metres and °C, respectively, and Chl as $\log_{10}(\text{mg m}^{-3})$.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

starting around 2009 and becoming particularly marked between 2014 and 2019 (Figure 3). This suggests a shift toward more stable environmental conditions during the same period when parallel population patterns were observed between the island and the archipelago assemblages. During this time window, SSH and Chl anomalies decreased in both areas, with anomalies in the archipelago becoming nearly absent. Similar variations in positive and negative anomalies became more evident, especially for Chl and pH, with fluctuations occurring simultaneously or within a one-semester lag across regions. Except for SSH, these variables showed strong positive correlations between areas ($\rho \geq 0.6$), with pH displaying an almost perfect correlation ($\rho = 0.94$, $p < 0.05$).

3.3 | Environmental Associations With Populations Dynamics

The evaluated oceanographic variables explained between 23% and 89% of the variation in the counts of most fish (Table S1). Approximately 72% of the populations showed significant associations with at least one variable. Among them, pH was the most influential predictor across areas, appearing in half of the best ranked models, followed by SSH, Chl and SST. In the island, pH exhibited an inverse effect, with species counts increasing sharply above a threshold of 8.055. Conversely, in the archipelago, pH had a direct effect, with species counts decreasing from 8.040 onwards. SSH displayed similar effects in both areas, with an increase in species counts observed from 0.03 m in the archipelago and −0.07 m in the island. Chl influenced only the population of the Island hogfish (*Bodianus insularis*) in the island, whose species counts increased from −2.50 ($\log_{10}(\text{mg m}^{-3})$) onwards (Figures 4 and 5; Tables S2 and S3).

4 | Discussion

Although the overlap between the island and the archipelago datasets is relatively short and the focus on species consistently recorded across years limits inference about longer-term dynamics and the full assemblage, our results revealed a complex scenario in which reef fish populations from both areas exhibited similar temporal patterns under comparable environmental conditions. This alignment was particularly evident for

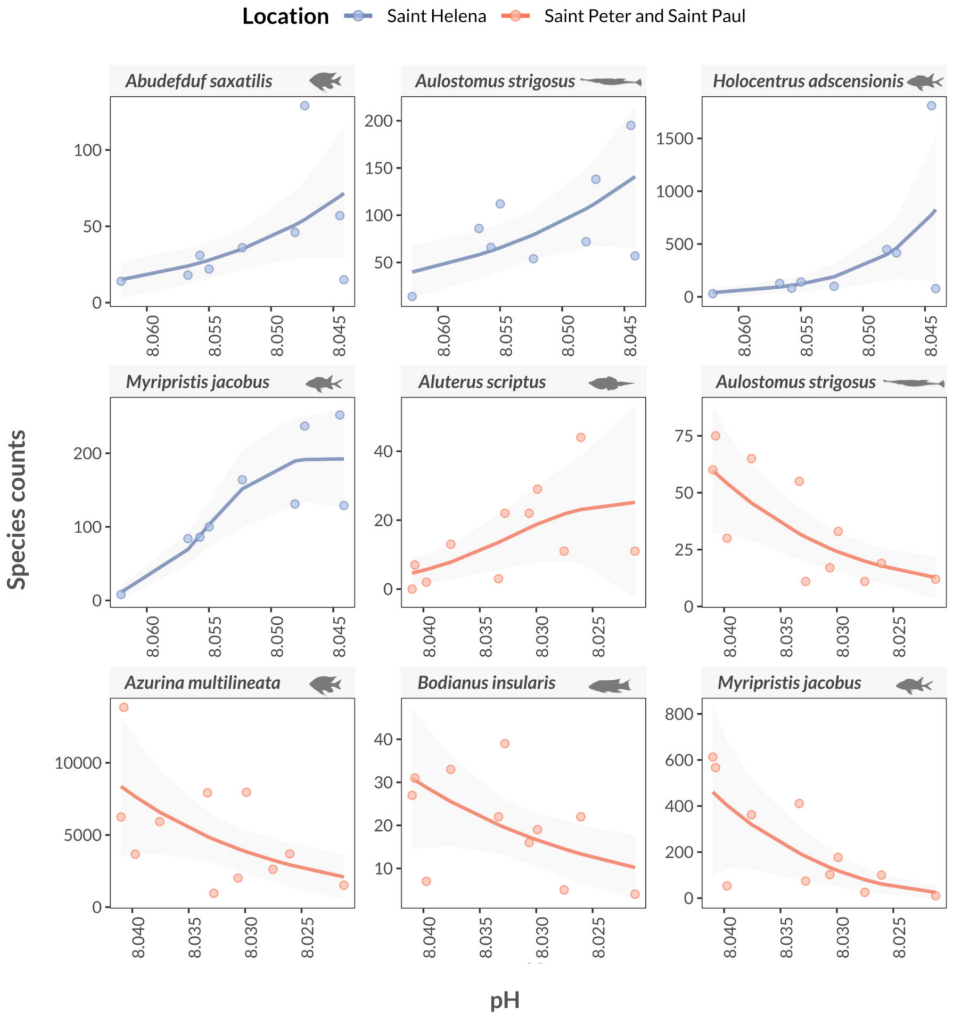

FIGURE 4 | Comparisons among partial effects of pH on the species counts of reef fish populations from Saint Helena Island and Saint Peter and Saint Paul Archipelago, as estimated by generalized additive models (GAMs). Effects were extracted from the single best-supported model (i.e., model with the lowest AICc) for each population. Shaded areas indicate 95% confidence intervals and dots represent observed values of species counts. Populations not displayed did not include pH as an explanatory variable in their best-supported models.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

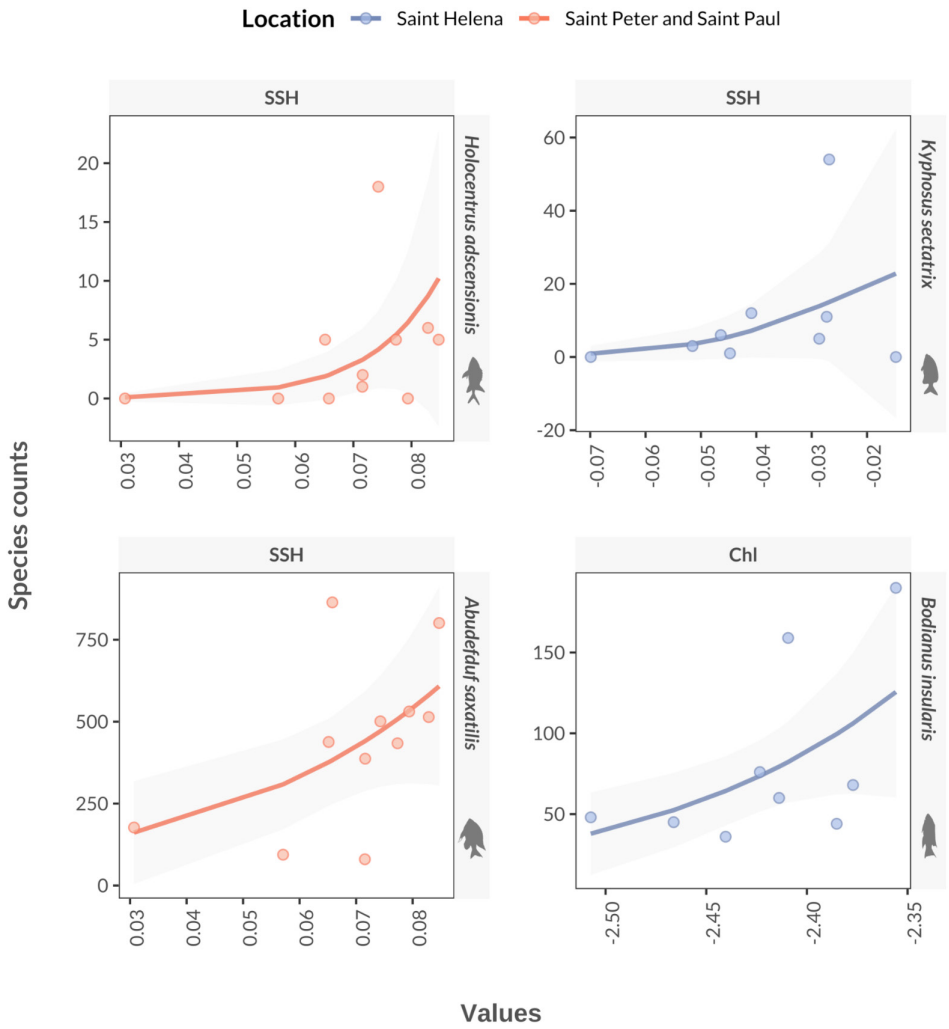

FIGURE 5 | Partial effects of sea surface height (SSH) and concentrations of chlorophyl-a (Chl) on the species counts of reef fish populations from Saint Helena Island and Saint Peter and Saint Paul Archipelago, as estimated by generalized additive models (GAMs). Effects were extracted from the single best-supported model (i.e., model with the lowest AICc) for each population. Shaded areas indicate 95% confidence intervals and dots represent observed values of species counts. SSH values are in metres and Chl as $\log_{10}(\text{mg m}^{-3})$.

oceanographic variables, which displayed strong correlations and convergence in anomalies. The concurrent patterns between 2014 and 2019 may coincide with perturbations related to the El Niño–Southern Oscillation (ENSO). Large-scale ocean–atmosphere processes are known to generate spatially coherent environmental variability, synchronizing SST and Chl across distant regions (Muñoz et al. 2023). Moreover, the observed patterns exhibited by reef fishes were consistent with theoretical and empirical evidence, showing that correlated environmental variability can lead to concordance in population dynamics across broader scales (Hudson and Cattadori 1999; Hansen et al. 2020; Marquez et al. 2023), particularly when spatial correlations among environmental processes are high.

pH emerged as a key factor, with contrasting effects on species counts between areas. Although mechanisms remain unclear, these differences may relate to species-specific traits and adaptive capacity. In damselfishes, reproductive performance (Welch and Munday 2016) and CO_2 tolerance vary markedly, with greater acclimatization in populations exposed to naturally variable CO_2 (Kwan et al. 2017). The broader seasonal variability in temperature and pH around the island (Figure S5) may help explain the increase of the sergeant major (*Abudefduf saxatilis*) despite declining pH, contrasting with the brown chromis decline in the archipelago (Figure 4).

Beyond direct physiological effects, fish responses to variations in pH should be interpreted within the broader environmental context in which it varied, as pH often varies with temperature and productivity that differ regionally (Goldenberg et al. 2017). In both areas, pH showed negative correlations with SST and SSH and a weak positive association with chlorophyll-a. However, the strength of these relationships differed markedly between regions, particularly for SSH, which was more strongly correlated with pH in the island than in the archipelago. This suggests that similar pH trends may reflect distinct underlying processes across sites, such as differences in upper-ocean heat content and circulation regimes. Although additive or interactive effects among predictors were not explicitly modelled due to the limited length of biological time series, these context-dependent associations may help explain the contrasting population responses observed between areas.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Whitin this broader environmental framework, thermal conditions emerged as an additional factor influencing population responses. SST and SSH increased in both areas, with the latter becoming particularly pronounced from 2014 onwards (Figure S5). Although SST is widely recognized as a key driver of reef fish dynamics (Ferrari et al. 2024; Silva et al. 2025), it reflects only surface conditions, whereas SSH is tightly correlated with the integrated heat content above the thermocline (Polito et al. 2000) and may therefore better capture subsurface thermal processes relevant to reef ecosystems. In this context, the absence of SST among the majority of the best-supported models likely reflects its limited explanatory power relative to SSH, rather than a lack of thermal influence per se.

This interpretation is further supported by contrasting physical oceanographic regimes between the two regions. In the island, SSH and SST exhibited closely aligned temporal patterns, consistent with the dominance of the first baroclinic mode typical of mid-latitudes, where variability in SSH largely reflects changes in upper ocean heat content. In contrast, in the archipelago, the annual SSH signal arises from seasonal changes in the volume and slope of the thermocline, influenced by opposing current systems: the northern branch of the South Equatorial Current, at the surface, and Equatorial Undercurrent, just below. Although the former more strongly affects SST, the latter exerts greater control on SSH (Bunge and Clarke 2009), resulting in a partial decoupling between these variables. This physical contrast is consistent with the weak temporal correlation observed between SSH anomalies in the island and the archipelago, indicating that sea-level variability in each region is governed by distinct regional dynamics.

Such decoupling may reduce the ability of SST alone to capture thermally driven processes in equatorial environments. Consistently, populations in the archipelago, such as the squirrelfish (*Holocentrus adscensionis*) and the sergeant major, showed positive responses to SSH, whereas populations in the island, including the Bermuda sea chub and the Atlantic cornetfish (*Aulostomus strigosus*), increased with warmer waters or higher sea surface height (Figure 5 and Tables S2 and S3). Together, these patterns suggest that thermal effects on reef fish populations in oceanic systems may be mediated by broader upper-ocean heat content than surface temperature alone, potentially reflecting adaptation to local thermal regimes.

Responses to thermal changes are strongly related to species' niche characteristics. Species from warmer and more stable temperatures, such as those in the archipelago, tend to increase under heating according to their thermal-niche midpoint (Day et al. 2018). Conversely, species from cooler and more seasonal temperatures, like the island, often display greater thermal tolerance (Stuart-Smith et al. 2017). In the island, the most abundant species also exhibited wider thermal niches (Ferrari et al. 2024), consistent with this adaptive pattern and providing a potential explanation for the observed responses.

These oceanographic changes can also indirectly affect populations by altering benthic habitats and food resources. Rising sea levels can enlarge underwater areas by shrinkage of intertidal zones, initially increasing benthic coverage by sessile invertebrates and macroalgae (Kaplanis et al. 2020). Similarly, ocean acidification may favour turf algae growth (Nagelkerken et al. 2016, 2018). Over time, such changes may benefit diet generalists (i.e., sergeant major) and more specialized consumers, such as invertivores (i.e., squirrelfish) and macroalgivores (i.e., Bermuda sea chub). In addition, larger carnivores also benefit from expanded foraging grounds (Rasher et al. 2017; Sartori et al. 2021), which may similarly explain the observed increase in species counts of the Atlantic cornetfish.

Besides these possible changes in habitat structure and resource availability, shifts in ocean productivity can also influence reef fish assemblages. Chl is a well-recognized determinant of reef fish dynamics in oligotrophic oceanic systems (Williams et al. 2015; Gove et al. 2016; Quimbayo et al. 2019). In the island, Chl increases were positively related to the island hogfish species counts (*B. insularis*) (Figure 5). This association was most evident in 2016 (Figure 2A), when slightly elevated Chl levels (Figure S5) coincided with a marked population peak. This followed the strong 2015 El Niño event, which has been reported to enhance upwelling and primary productivity in the northern Benguela system, with potential spillover to the island (Rouault and Tomety 2022; Brandt et al. 2024). Increases in Chl can influence multiple trophic levels by directly supporting planktivores and other primary consumers (Williams et al. 2015) and, through phytodetritus deposition, enriching benthic habitats and promoting the growth of invertebrate fauna (Gove et al. 2016)—key prey items for this species.

5 | Implications for Conservation

Our findings reveal potential disruptions in these isolated rocky reefs influenced by ongoing environmental change. Globally, reef ecosystems are vital service providers, regulating, provisioning and offering cultural services (Wong et al. 2005; Brander et al. 2007; Spalding et al. 2017; Balzan et al. 2018). In oceanic islands, however, these services are particularly at risk, as ecological challenges are magnified by geographic isolation and are expected to intensify under climate change (Wong et al. 2005). Although their remoteness limits exposure to direct human activities, particularly in the archipelago, it also hampers effective monitoring to mitigate environmental impacts (Soares 2018; Rodrigues et al. 2023). Therefore, despite the legal protection of both areas as marine protected areas under Brazilian and British jurisdictions, they remain exposed to large-scale oceanographic and climatic processes.

For instance, evidence that the gyre-scale circulation in the South Atlantic is intensifying and shifting southward, along with the wind stress (Roemmich et al. 2007; Marcello et al. 2018) suggests future alterations in regional regimes that reflect to local communities. Losses in reef fauna have been reported across the South Atlantic as consequences of concurrent heat stress events (Destri et al. 2025). Additionally, temporal concordance among populations may elevate extinction risk, as uniform responses reduce the community's resilience to future stressors (Hudson and Cattadori 1999;

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Hansen et al. 2020; Marquez et al. 2023). Thus, the observed links between regional oceanographic processes, especially ocean acidification, and biological responses reinforce their vulnerability.

The dimension of impacts on the local role as well as services provided to surrounding areas, such as nutrient cycling and fisheries support remains uncertain. Economically, these areas compose one of the most affected zones regarding marine fisheries revenue (Lam et al. 2020), which exposes the sensitivity of the local and export markets of the island (SHG 2022). Within the constraints of the temporal coverage and spatial scope of this study, strengthening long-term monitoring, integrating environmental and biological indicators and ensuring adaptive conservation strategies that account for indirect and synergistic effects are crucial to safeguard the resilience of these vulnerable reef systems against compounded global and regional stressors.

Author Contributions

Thamíris C. Karlovic: conceptualization, visualization, formal analysis, methodology, writing – original draft, writing – review and editing. **Amanda R. Rodrigues:** formal analysis, writing – original draft, writing – review and editing. **Leeann Henry:** investigation, methodology, writing – review and editing. **Sergio R. Floeter:** funding acquisition, investigation, methodology, writing – review and editing. **Kirsty L. Jones:** investigation, methodology, writing – review and editing. **Carlos E. L. Ferreira:** investigation, methodology, writing – review and editing. **Paulo S. Polito:** investigation, methodology, writing – original draft, writing – review and editing. **Olga T. Sato:** investigation, methodology, writing – original draft, writing – review and editing. **Maria A. Gasalla:** funding acquisition, conceptualization, writing – original draft, writing – review and editing, supervision.

Acknowledgements

The authors thank Doctor Saskia A. Otto (University of Hamburg, Germany) for providing R-codes containing initial concepts of time-series analyses. M.A.G. acknowledges support from CNPq (Brazilian National Council for Scientific) and FUSP (Foundation of Support to the University of São Paulo) for funding management. We thank the PELD-ILOC and SISBIOTA-Mar teams for fieldwork support at Saint Peter and Saint Paul's archipelago. Funding was provided by CNPq through the grants SISBIOTA–Mar (CNPq 563276/2010-0; PI: S.R.F.) and Long-Term Ecological Research of Reef Communities at Oceanic Islands—PELD ILOC (CNPq 441327/2020-6; PI: C.E.L.F.). This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 862428 (MISSION ATLANTIC). No AI-assisted technologies were used in creating this article. The Article Processing Charge for the publication of this research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) (ROR identifier: 00x0ma614).

Funding

This work was supported by the CNPq (CNPq 563276/2010-0, CNPq 441327/2020-6), and the European Union's Horizon 2020 (862428).

Ethics Statement

No ethical approval or specific permits were required for this study. All analyses were based on previously collected data obtained from long-term reef monitoring programmes conducted by governmental and institutional initiatives in each study area. No animals were handled or captured during this study.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data are available in the Zenodo data repository (10.5281/zenodo.16905567).

References

Balzan, M. V., M. Potschin-Young, and R. Haines-Young. 2018. "Island Ecosystem Services: Insights From a Literature Review on Case-Study Island Ecosystem Services and Future Prospects." *International Journal of Biodiversity Science, Ecosystem Services and Management* 14, no. 1: 71–90. https://doi.org/10.1080/21513732.2018.1439103.

Bartoń, K. 2020. "MuMIn: Multi-Model Inference." https://cran.r-project.org/web/packages/MuMIn/index.html.

Borcard, D., F. Gillet, and P. Legendre. 2011. In *Numerical Ecology With R*, edited by R. Gentleman, K. Hornik, and G. G. Parmigiani. Springer.

Brander, L. M., P. Van Beukering, and H. S. J. Cesar. 2007. "The Recreational Value of Coral Reefs: A Meta-Analysis." *Ecological Economics* 63, no. 1: 209–218. https://doi.org/10.1016/j.ecolecon.2006.11.002.

Brandt, P., M. H. Bordbar, P. Coelho, et al. 2024. "Physical Drivers of Southwest African Coastal Upwelling and Its Response to Climate Variability and Change." In: *Sustainability of Southern African Ecosystems Under Global Change*. von Maltitz G. P., G. F. Midgley, J. Veitch, et al. (eds). 1–973. Springer.

Bunge, L., and A. J. Clarke. 2009. "Seasonal Propagation of Sea Level Along the Equator in the Atlantic." *Journal of Physical Oceanography* 39, no. 4: 1069–1074. https://doi.org/10.1175/2008JPO4003.1.

Burnham, K. P., and D. R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. 2nd ed. Springer.

Cowburn, B., J. Graham, M. Schratzberger, et al. 2021. "Rocky Reefs of St Helena and the Tropical Atlantic: How the Lack of Coral and an Isolated Oceanic Location Drive Unique Inshore Marine Ecology." *Marine Ecology Progress Series* 663: 31–49. https://doi.org/10.3354/meps13633.

Cowpertwait, P. S. P. 2006. *Introductory Time Series With R*. Springer Science + Business.

D'Alelio, D., S. Rampone, L. M. Cusano, et al. 2020. "Machine Learning Identifies a Strong Association Between Warming and Reduced Primary Productivity in an Oligotrophic Ocean Gyre." *Scientific Reports* 10, no. 1: 3287. https://doi.org/10.1038/s41598-020-59989-y.

Day, P. B., R. D. Stuart-Smith, G. J. Edgar, and A. E. Bates. 2018. "Species' Thermal Ranges Predict Changes in Reef Fish Community Structure During 8 Years of Extreme Temperature Variation." *Diversity and Distributions* 24, no. 8: 1036–1046. https://doi.org/10.1111/ddi.12753.

Demetris, K., and J. M. Hall-Spencer. 2012. "Threats to Ultraoligotrophic Marine Ecosystems." In *Marine Ecosystems*. InTech.

Destri, G., A. Z. Güth, A. L. Luza, et al. 2025. "The Thermal Stress History of South Atlantic Reefs Reveals Increasing Intensity, Duration, Frequency, and Likely Undocumented Bleaching Episodes." *Global Change Biology* 31, no. 4: e70162. https://doi.org/10.1111/gcb.70162.

Escobar-Camacho, D., P. Rosero, M. Castrejón, C. F. Mena, and F. Cuesta. 2021. "Oceanic Islands and Climate: Using a Multi-Criteria Model of Drivers of Change to Select Key Conservation Areas in Galapagos." *Regional Environmental Change* 21: 47. https://doi.org/10.1007/s10113-021-01768-0.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Feistel, R., E. Hagen, and K. Grant. 2003. "Climatic Changes in the Subtropical Southeast Atlantic: The St. Helena Island Climate Index (1893-1999)." *Progress in Oceanography* 59: 321–337.

Ferrari, D. S., S. R. Floeter, F. Leprieur, and J. P. Quimbayo. 2023. "A Trait-Based Approach to Marine Island Biogeography." *Journal of Biogeography* 50, no. 3: 528–538. https://doi.org/10.1111/jbi.14549.

Ferrari, D. S., L. T. Nunes, K. L. Jones, C. E. L. Ferreira, and S. R. Floeter. 2024. "Thermal Tolerance as a Driver of Reef Fish Community Structure at the Isolated Tropical Mid-Atlantic Ridge Islands." *Marine Environmental Research* 199: 106611. https://doi.org/10.1016/j.marenvres.2024.106611.

Flanders Marine Institute. 2024. "MarineRegions.org." www.marineregions.org.

Floeter, S. R., H. T. Pinheiro, and L. A. Rocha. 2023. "Biogeography and Evolution of Brazilian Reef Fishes." In *Brazilian Reef Fishes*, edited by S. R. Floeter, J. P. Krajewski, T. M. J. Fiuza, L. A. Rocha, and A. Carvalho-Filho, 1–320. EDITORA CRV.

Giorgino, T. 2009. "Computing and Visualizing Dynamic Time Warping Alignments in R: The dtw Package." *Journal of Statistical Software* 31, no. 7: 1–24.

Goes, M., I. Wainer, and N. Signorelli. 2014. "Investigation of the Causes of Historical Changes in the Subsurface Salinity Minimum of the South Atlantic." *Journal of Geophysical Research: Oceans* 119, no. 9: 5654–5675. https://doi.org/10.1002/2014JC009812.

Goldenberg, S. U., I. Nagelkerken, C. M. Ferreira, H. Ullah, and S. D. Connell. 2017. "Boosted Food Web Productivity Through Ocean Acidification Collapses Under Warming." *Global Change Biology* 23, no. 10: 4177–4184. https://doi.org/10.1111/gcb.13699.

Gouhier, T. C., and F. Guichard. 2014. "Synchrony: Quantifying Variability in Space and Time." *Methods in Ecology and Evolution* 5, no. 6: 524–533. https://doi.org/10.1111/2041-210X.12188.

Gove, J. M., M. A. McManus, A. B. Neuheimer, et al. 2016. "Near-Island Biological Hotspots in Barren Ocean Basins." *Nature Communications* 7: 10581. https://doi.org/10.1038/ncomms10581.

Hansen, B. B., V. Grøtan, I. Herfindal, and A. M. Lee. 2020. "The Moran Effect Revisited: Spatial Population Synchrony Under Global Warming." *Ecography* 43, no. 11: 1591–1602. https://doi.org/10.1111/ecog.04962.

Hixon, M. A., T. W. Anderson, K. L. Buch, D. W. Johnson, J. B. Mcleod, and C. D. Stallings. 2012. "Density Dependence and Population Regulation in Marine Fish: A Large-Scale, Long-Term Field Manipulation." *Ecological Monographs* 82, no. 4: 467–489. https://doi.org/10.1890/11-1525.1.

Hudson, P. J., and I. M. Cattadori. 1999. "The Moran Effect: A Cause of Population Synchrony." *Trends in Ecology & Evolution* 14, no. 1: 1–2.

IPCC. 2019. *Summary for Policymakers. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, 3–35. Cambridge University Press.

Johansen, J. L., and G. P. Jones. 2011. "Increasing Ocean Temperature Reduces the Metabolic Performance and Swimming Ability of Coral Reef Damselfishes." *Global Change Biology* 17, no. 9: 2971–2979. https://doi.org/10.1111/j.1365-2486.2011.02436.x.

Kaplanis, N. J., C. B. Edwards, Y. Eynaud, and J. E. Smith. 2020. "Future Sea-Level Rise Drives Rocky Intertidal Habitat Loss and Benthic Community Change." *PeerJ* 2020, no. 5: e9186. https://doi.org/10.7717/peerj.9186.

Kassambara, A., and F. Mundt. 2020. "Factoextra: Extract and Visualize the Results of Multivariate Data Analyses".

Kwan, G. T., T. J. Hamilton, and M. Tresguerres. 2017. "CO_2-Induced Ocean Acidification Does Not Affect Individual or Group Behaviour in a Temperate Damselfish." *Royal Society Open Science* 4, no. 7: 170283. https://doi.org/10.1098/rsos.170283.

Lam, V. W. Y., E. H. Allison, J. D. Bell, et al. 2020. "Climate Change, Tropical Fisheries and Prospects for Sustainable Development." *Nature Reviews Earth and Environment* 1, no. 9: 440–454.

Lenoir, J., R. Bertrand, L. Comte, et al. 2020. "Species Better Track Climate Warming in the Oceans Than on Land." *Nature Ecology and Evolution* 4, no. 8: 1044–1059. https://doi.org/10.1038/s41559-020-1198-2.

Liu, M., and T. Tanhua. 2021. "Water Masses in the Atlantic Ocean: Characteristics and Distributions." *Ocean Science* 17, no. 2: 463–486. https://doi.org/10.5194/os-17-463-2021.

Loreau, M., and C. De Mazancourt. 2008. "Species Synchrony and Its Drivers: Neutral and Nonneutral Community Dynamics in Fluctuating Environments." *American Naturalist* 172, no. 2: E48–E66. https://doi.org/10.1086/589746.

Luiz, O. J., T. C. Mendes, D. R. Barneche, et al. 2015. "Community Structure of Reef Fishes on a Remote Oceanic Island (St Peter and St Paul's Archipelago, Equatorial Atlantic): The Relative Influence of Abiotic and Biotic Variables." *Marine and Freshwater Research* 66, no. 8: 739–749. https://doi.org/10.1071/MF14150.

Manly, B. F. J. 2006. *Randomization, Bootstrap and Monte Carlo Methods in Biology*. 3rd ed. Chapman & Hall/CRC.

Marcello, F., I. Wainer, and R. R. Rodrigues. 2018. "South Atlantic Subtropical Gyre Late Twentieth Century Changes." *Journal of Geophysical Research: Oceans* 123, no. 8: 5194–5209. https://doi.org/10.1029/2018JC013815.

Marquez, J. F., I. Herfindal, B. E. Sæther, S. Aanes, A. Salthaug, and A. M. Lee. 2023. "Effects of Local Density Dependence and Temperature on the Spatial Synchrony of Marine Fish Populations." *Journal of Animal Ecology* 92, no. 11: 2214–2227. https://doi.org/10.1111/1365-2656.14008.

Muñoz, R., C. Lara, J. Arteaga, et al. 2023. "Temporal Synchrony in Satellite-Derived Ocean Parameters in the Inner Sea of Chiloé, Northern Patagonia, Chile." *Remote Sensing* 15, no. 8: 2182. https://doi.org/10.3390/rs15082182.

Nagelkerken, I., S. U. Goldenberg, E. O. C. Coni, and S. D. Connell. 2018. "Microhabitat Change Alters Abundances of Competing Species and Decreases Species Richness Under Ocean Acidification." *Science of the Total Environment* 645: 615–622. https://doi.org/10.1016/j.scitotenv.2018.07.168.

Nagelkerken, I., and P. L. Munday. 2016. "Animal Behaviour Shapes the Ecological Effects of Ocean Acidification and Warming: Moving From Individual to Community-Level Responses." *Global Change Biology* 22, no. 3: 974–989. https://doi.org/10.1111/gcb.13167.

Nagelkerken, I., B. D. Russell, B. M. Gillanders, and S. D. Connell. 2016. "Ocean Acidification Alters Fish Populations Indirectly Through Habitat Modification." *Nature Climate Change* 6, no. 1: 89–93. https://doi.org/10.1038/nclimate2757.

Olden, J. D., and B. D. Neff. 2001. "Cross-Correlation Bias in Lag Analysis of Aquatic Time Series." *Marine Biology* 138, no. 5: 1063–1070. https://doi.org/10.1007/s002270000517.

Otto S. 2023. "IEAtools: R Package for Integrated Ecosystem Assessments."

Pacheco, M. M., P. S. Polito, O. T. Sato, and M. R. Rocha. 2022. "Evolution of Physical and Biological Patterns Along the Tropical and South Atlantic Western Boundary: A Satellite Perspective." *Journal of Geophysical Research: Oceans* 127, no. 3: e2021JC017714. https://doi.org/10.1029/2021JC017714.

Pinheiro, H. T., B. C. L. Macena, R. B. Francini-Filho, et al. 2020. "Fish Biodiversity of Saint Peter and Saint Paul's Archipelago, Mid-Atlantic Ridge, Brazil: New Records and a Species Database." *Journal of Fish Biology* 97, no. 4: 1143–1153. https://doi.org/10.1111/jfb.14484.

Polito, P. S., O. T. Sato, and W. T. Liu. 2000. "Characterization and Validation of the Heat Storage Variability From TOPEX/Poseidon at

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Four Oceanographic Sites." *Journal of Geophysical Research: Oceans* 105, no. C7: 16911–16921. https://doi.org/10.1029/1999jc000048.

Quimbayo, J. P., M. S. Dias, M. Kulbicki, et al. 2019. "Determinants of Reef Fish Assemblages in Tropical Oceanic Islands." *Ecography* 42, no. 1: 77–87. https://doi.org/10.1111/ecog.03506.

R Core Team. 2025. "R: A Language and Environment for Statistical Computing." R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Rasher, D. B., A. S. Hoey, and M. E. Hay. 2017. "Cascading Predator Effects in a Fijian Coral Reef Ecosystem." *Scientific Reports* 7, no. 1: 15684. https://doi.org/10.1038/s41598-017-15679-w.

Rilov, G., N. David, T. Guy-Haim, D. Golomb, R. Arav, and S. Filin. 2021. "Sea Level Rise Can Severely Reduce Biodiversity and Community Net Production on Rocky Shores." *Science of the Total Environment* 791: 148377. https://doi.org/10.1016/j.scitotenv.2021.148377.

Robertson, D. R. 2001. "Population Maintenance Among Tropical Reef Fishes: Inferences From Small-Island Endemics." *PNAS* 98, no. 10: 5667–5670.

Rodrigues, A. R., S. R. Floeter, V. Gomes, et al. 2023. "Integrated Ecosystem Assessment Around Islands of the Tropical South Mid-Atlantic Ridge." *Frontiers in Marine Science* 10. https://doi.org/10.3389/fmars.2023.1001676.

Roemmich, D., J. Gilson, R. Davis, P. Sutton, S. Wijffels, and S. Riser. 2007. "Decadal Spinup of the South Pacific Subtropical Gyre." *Journal of Physical Oceanography* 37, no. 2: 162–173. https://doi.org/10.1175/JPO3004.1.

Rouault, M., and F. S. Tomety. 2022. "Impact of El Niño-Southern Oscillation on the Benguela Upwelling." *Journal of Physical Oceanography*: 2573–2587. https://doi.org/10.1175/JPO-D-21-0219.1.

Rummer, J. L., and P. L. Munday. 2017. "Climate Change and the Evolution of Reef Fishes: Past and Future." *Fish and Fisheries* 18, no. 1: 22–39. https://doi.org/10.1111/faf.12164.

Sartori, G., M. L. Taylor, P. Sebastian, and R. Prasetyo. 2021. "Coral Reef Carnivorous Fish Biomass Relates to Oceanographic Features Depending on Habitat and Prey Preference." *Marine Environmental Research* 172: 105504. https://doi.org/10.1016/j.marenvres.2021.105504.

SHG. 2022. "Marine Management Plan St Helena Government".

Silva, F. C., J. P. Quimbayo, M. Lindegren, and S. R. Floeter. 2025. "Reef Fish Community Structure Across an Ecological Transition Zone." *Marine Environmental Research* 212: 107496. https://doi.org/10.1016/j.marenvres.2025.107496.

Soares, M. d. O. 2018. "Climate Change and Regional Human Pressures as Challenges for Management in Oceanic Islands, South Atlantic." *Marine Pollution Bulletin* 131: 347–355. https://doi.org/10.1016/j.marpolbul.2018.04.008.

Spalding, M., L. Burke, S. A. Wood, J. Ashpole, J. Hutchison, and P. zu Ermgassen. 2017. "Mapping the Global Value and Distribution of Coral Reef Tourism." *Marine Policy* 82: 104–113. https://doi.org/10.1016/j.marpol.2017.05.014.

Stuart-Smith, R. D., G. J. Edgar, and A. E. Bates. 2017. "Thermal Limits to the Geographic Distributions of Shallow-Water Marine Species." *Nature Ecology and Evolution* 1, no. 12: 1846–1852. https://doi.org/10.1038/s41559-017-0353-x.

Sunday, J. M., K. E. Fabricius, K. J. Kroeker, et al. 2017. "Ocean Acidification Can Mediate Biodiversity Shifts by Changing Biogenic Habitat." *Nature Climate Change* 7, no. 1: 81–85. https://doi.org/10.1038/nclimate3161.

Talley, L. D., G. L. Pickard, W. J. Emery, and J. H. Swift. 2011. "Atlantic Ocean." In *Descriptive Physical Oceanography*, 245–301. Elsevier.

Vaske, T., M. F. de Nóbrega, F. M. Santana, S. R. M. O'Brien, and F. M. D. Amaral. 2010. "Características Locais." In *Arquipélago de São Pedro e São Paulo: Histórico e Recursos Naturais*, edited by T. Vaske, R. P. Lessa, M. F. Nóbrega, F. M. D. do Amaral, S. R. M. O'Brien, and F. A. P. da Costa, 1–241. NAVE/LABOMAR UFC.

Viana, D. d. L., F. H. V. Hazin, and M. A. C. de Souza. 2009. In *O Arquipélago de São Pedro e São Paulo: 10 Anos de Estação Científica*, edited by F. H. V. Hazin. SECIRM.

Welch, M. J., and P. L. Munday. 2016. "Contrasting Effects of Ocean Acidification on Reproduction in Reef Fishes." *Coral Reefs* 35, no. 2: 485–493. https://doi.org/10.1007/s00338-015-1385-9.

Williams, I. D., J. K. Baum, A. Heenan, K. M. Hanson, M. O. Nadon, and R. E. Brainard. 2015. "Human, Oceanographic and Habitat Drivers of Central and Western Pacific Coral Reef Fish Assemblages." *PLoS ONE* 10, no. 4: e0120516. https://doi.org/10.1371/journal.pone.0120516.

Wong, P., E. Marone, P. Lana, et al. 2005. "Island Systems." In *Ecosystems and Human Well-Being: Current State and Trends*, 663–680. lsIand Press.

Wood, S. N. 2017. *Generalized Additive Models: An Introduction With R*. 2nd ed. Chapman and Hall/CRC.

Zuur, A. F., E. N. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith. 2009. *Mixed Effects Models and Extensions in Ecology With R*. Springer.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Autocorrelations (ACF) and partial autocorrelations (PACF) of species populations of (A) Saint Helena Island (sh) and (B) Saint Peter and Saint Paul's Archipelago (sp), between 2014 and 2019. Dashed blue lines are the upper and lower limits of the 95% confidence interval. Correlations significantly different from zero are above or under dashed blue lines. Initials' correspondence of species scientific names are: *Abudefduf saxatilis* (abu_sax), *Aluterus scriptus* (alu_scr), *Aulostomus strigosus* (aul_str), *Azurina multilineata* (azu_mul), *Bodianus insularis* (bod_ins), *Holocentrus adscensionis* (hol_ads), *Kyphosus sectatrix* (kyp_sec), *Myripristis jacobus* (myr_jac) and *Rypticus saponaceus* (ryp_sap). **Figure S2:** Autocorrelations (ACF) and partial autocorrelations (PACF) of oceanographic variables of Saint Helena Island (sh) and Saint Peter and Saint Pauls Archipelago (sp), between 2014 and 2019. Dashed blue lines are the upper and lower limits of the 95% confidence interval. Correlations significantly different from zero are above or under dashed blue lines. Initials correspondence of oceanographic variables are: sea surface temperature (sst), chlorophyl-a (chl) and sea surface height (ssh). **Figure S3:** Autocorrelations (ACF) and partial autocorrelations (PACF) of oceanographic variables of Saint Helena Island (sh; 2014–2022) and Saint Peter and Saint Pauls Archipelago (sp; 2009–2019). Dashed blue lines are the upper and lower limits of the 95% confidence interval. Correlations significantly different from zero are above or under dashed blue lines. Initials correspondence of oceanographic variables are: sea surface temperature (sst), chlorophyl-a (chl) and sea surface height (ssh). **Figure S4:** Temporal fluctuations in species counts of reef fishes from Saint Helena Island and Saint Peter and Saint Pauls Archipelago between 2014 and 2019. Species counts were $\log_{10}(x+1)$ transformed to improve visualization and facilitate comparison of intraspecific trends between regions. **Figure S5:** Semestral fluctuations of oceanographic variables in Saint Helena Island and Saint Peter and Saint Pauls Archipelago from 2002 to 2022. The shaded area highlights the period during which temporal concordance between reef fish assemblages was detected (2014–2019). Initials correspondence of oceanographic variables are: sea surface temperature (SST), chlorophyl-a (Chl) and sea surface height (SSH). SSH and SST values are in metres and °C, respectively, and Chl as $\log_{10}(\text{mg m}^{-3})$. **Figure S6:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Abudefduf saxatilis* from Saint Helena Island. **Figure S7:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Aluterus scriptus* from Saint Peter and Sait Pauls Archipelago. **Figure S8:** Diagnostic

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

plots of residuals for the model containing pH as a predictor of changes in counts of *Aulostomus strigosus* from Saint Helena Island. **Figure S9:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Aulostomus strigosus* from Saint Peter and Sait Pauls Archipelago. **Figure S10:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Azurina multilineata* from Saint Peter and Sait Pauls Archipelago. **Figure S11:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Bodianus insularis* from Saint Peter and Sait Paul Archipelago. **Figure S12:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Holocentrus adscensionis* from Saint Helena Island. **Figure S13:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Myripristis jacobus* from Saint Helena Island. **Figure S14:** Diagnostic plots of residuals for the model containing pH as a predictor of changes in counts of *Myripristis jacobus* from Saint Peter and Sait Pauls Archipelago. **Table S1:** Best ranked models according to the second order Akaike Information Criterion (AICc) of generalized aditive models for counts of reef fishes in Saint Helena Island (SH) and Saint Peter and Saint Pauls Archipelago (SPSP). **Table S2:** Effects of oceanographic variables generalized aditive models for counts of reef fishes in Saint Helena Island (SH) and Saint Peter and Saint Pauls Archipelago (SPSP). Shown are the coefficient estimates of linear terms (without smoothers) from the best-ranked models. **Table S3:** Effects of oceanographic variables generalized aditive models for counts of reef fishes in Saint Helena Island (SH) and Saint Peter and Saint Pauls Archipelago (SPSP). Shown are the effective degrees of freedom (edf) and significance of smoothing terms from the best-ranked models.

10990755, 2026, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aqc.70362 by Capes, Wiley Online Library on [01/04/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License