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Critical Status of the Endangered Limpet *Patella candei* in the Canary Islands: Historical Population Trend and Environmental Stressors

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Received: 22 September 2025 | **Revised:** 15 December 2025 | **Accepted:** 22 June 2026

Keywords: Atlantic | conservation | endangered | mollusca | ocean warming | Patellogastropoda | temperature anomalies

ABSTRACT

The Macaronesian endemic limpet *Patella candei*, also known as the ‘majorera limpet’, is an endangered species with a restricted distribution limited to Fuerteventura (Canary Islands) and the Selvagens Islands (Madeira). This study assessed its current distribution and conservation status in Fuerteventura through field surveys conducted in 2022, complemented by a historical comparison with previously published data. The results revealed that the species has become extinct in Lobos Islet and along the northern and eastern coasts of Fuerteventura, with only a relict population persisting in the southern region of the Jandia peninsula. Although the number of individuals in this area has increased in recent years, the population remains very low and insufficient for successful reproduction. This population also shows a broad size distribution, possibly linked to the area’s strong wave exposure, which may reduce harvesting pressure by limiting accessibility. Despite the implementation of a recovery plan in 2015, the species continues to decline, suggesting that current conservation efforts have been insufficient. To explore whether oceanographic variables may have influenced this decline, anomalies in air temperature and sea surface temperature were analysed, revealing a warming trend over recent decades. These findings highlight the poor conservation status of *P. candei* in Fuerteventura and underscore the urgent need for enhanced management and conservation measures to prevent further population decline and potential extinction.

1 | Introduction

The genus *Patella* Linnaeus, 1758 (Patellidae) encompasses marine gastropods that belong to the true limpets within the subclass Patellogastropoda. These organisms inhabit rocky coastal areas, ranging from intertidal zones to shallow subtidal regions. The distribution of this genus is limited to the Northeastern Atlantic Ocean and Mediterranean Sea (Ridgway et al. 1998; Nakano and Ozawa 2004). In the Northeastern Atlantic Ocean, particularly in the Atlantic archipelagos of the Azores, Madeira and the Canaries, limpets

are exploited for consumption as a valued component of local seafood gastronomy and consequently hold important commercial value (Riera et al. 2016; Castejón et al. 2022; Sousa et al. 2023).

There are several species present across the Atlantic islands, *Patella aspera* Röding, 1798, *Patella piperata* A. Gould, 1846 and the *Patella candei* complex, which comprises *P. gomesii* Drouët, 1858, *P. tenuis* Gmelin, 1791, *P. ordinaria* Mabilie 1888 (syn. *P. candei crenata*) and *P. candei* A. d’Orbigny, 1840 (syn. *P. candei candei*), (Titselaar 2019; Quinteiro et al. 2022; World Register of

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Marine Species 2025; Aliende-Hernández et al. 2025). Although the harvesting of these species is regulated in the Azores, Madeira and the Canary Islands (Núñez et al. 1994; Ferraz et al. 2001; González-Lorenzo 2016; Sousa et al. 2019), the Macaronesian endemic limpet *P. candei*, whose distribution is restricted to Fuerteventura (Canary Islands) and the Selvagens Islands (Madeira), is the only Atlantic limpet species listed as 'Endangered' in the Spanish National Catalogue of Threatened Species (Real Decreto 139/2011, BOE-2011-3582). This conservation status reflects the multiple pressures faced by *P. candei*. It typically inhabits upper to mid-intertidal zones (Núñez et al. 2003), which makes it particularly susceptible to harvesting, its main threat. Other major threats include habitat degradation and coastal pollution, exacerbated by the island's tourist development, as evaluated for this species by Núñez-Fraga and Brito-Castro (2006).

The distribution of this species has been previously assessed. The first records came from the examination of museum collections, leading to uncertainty about its true range. According to what Christiaens (1973) reported, *P. candei* was abundant in the Selvagens, nearly extinct in Madeira and the Azores, and fragmented across the Canaries. Titselaar (1998) described its distribution throughout the Selvagens and Fuerteventura, but expressed doubts about its presence in Lanzarote, Tenerife and the Azores. However, Dorta (1992), who sampled across all the Canary Islands, only found specimens in Fuerteventura. Later, archaeological analysis of pre-Hispanic deposits by González-Lorenzo et al. (2015) confirmed that *P. candei* was only present in Lanzarote and Fuerteventura during early human settlement, suggesting that natural colonization and speciation processes shaped its current distribution.

In recent years, a clear decline in relict populations of *P. candei* has been observed, with the species now restricted to certain areas of Fuerteventura and the Selvagens, where it remains much more abundant (Núñez et al. 2003, 2005; González-Lorenzo et al. 2015). As a result, a recovery plan was implemented in Fuerteventura in 2015 (Decreto 161/2015, BOC 136). This plan proposed three critical areas to enhance the conservation of *P. candei*: one area on the northern coast of Fuerteventura (at Lobos Islet) and two areas in the south, specifically in Jandia (Jorós and Punta de Jandia). Activities such as harvesting, construction and recreational use were strictly regulated or prohibited. Conservation measures have also included habitat restoration, monitoring of populations and awareness campaigns targeting local communities and tourists. The recovery plan also considered the possibility of reinforcing reduced populations in Fuerteventura using individuals from the Selvagens Islands. However, subsequent genetic analyses revealed significant population differentiation between these two regions, indicating limited connectivity and suggesting that translocation between populations may not be an appropriate conservation strategy (Quinteiro et al. 2022).

This study aims to evaluate the actual distribution of *P. candei* in Fuerteventura, identify the most resilient populations and explore whether environmental factors could also be contributing to its decline, a key step in the conservation of endangered species under changing climatic conditions.

2 | Material and Methods

2.1 | Study Site and Actual Distribution

In June 2022, fieldwork was carried out on Fuerteventura and Lobos Islet, situated in the eastern part of the Canarian archipelago. The sampling covered 23 sites (Figure 1) where the abundance of *P. candei* populations was quantified. At each site, three replicate transects measuring 10×2 m were established parallel to the shoreline, across three tidal zones (upper, middle and lower) following the standard methodology used in previous surveys on the island (e.g., González-Lorenzo et al. 2015). Additionally, to assess the size of individuals, the longest axis of each shell was measured using a calliper with a precision of 0.05 mm. All data collected for this study is available in Zenodo at [doi:10.5281/zenodo.20799161](https://doi.org/10.5281/zenodo.20799161).

2.2 | Historical Changes in Distribution

After reviewing previous literature on *P. candei* in Fuerteventura, historical abundance data were compiled to allow comparison with the current results. The available data were obtained from Núñez et al. (2003), sampled during 2003, and González-Lorenzo et al. (2015), with data collected during 2011 and 2013. Since most sampling sites differed between studies, we divided Fuerteventura into three sectors: North and Lobos Islet, Eastern and Jandia in the south, as shown in Figure 1. The western coast of Fuerteventura was excluded from the analysis due to the absence of historical data and the lack of individuals observed during this study (Núñez et al. 2003; González-Lorenzo et al. 2015).

To visualize changes in population abundance and distribution across Fuerteventura and Lobos Islet over the past 20 years, a comparative heatmap graph was created using Geographic Information System QGIS. A permutational ANOVA analysis was performed with two fixed factors: 'Sector' (North-Lobos, Eastern and Jandia) and 'Year' (2002, 2013, 2015, 2022) to assess differences in *P. candei* abundance over time. Abundance data were square root transformed prior to analysis to reduce the influence of extreme values and zero inflation. The analysis was performed using the *adonis* function from the *vegan* package (Oksanen et al. 2024), applying Euclidean distance as the dissimilarity measure in order to maintain comparability with previous studies using historical *P. candei* abundance data. The interaction between the factors was also evaluated. Post hoc pairwise comparisons between levels of the factor 'Sector' within each 'Year' were conducted using the pairwise *Adonis* package (Martínez-Arbizu 2017), allowing us to assess specific temporal differences in each sector. All analyses and visualizations were performed using R Version 4.3.2 (R Core Team 2023).

2.3 | Oceanographic Variables

According to previous studies, air temperature (AT) and sea surface temperature (SST) are key factors influencing changes in the geographical distribution of Atlantic limpets (Lima et al. 2006, 2007). Accordingly, we analysed both parameters over recent decades to explore whether temperature trends may relate to the observed decline in *P. candei* populations.

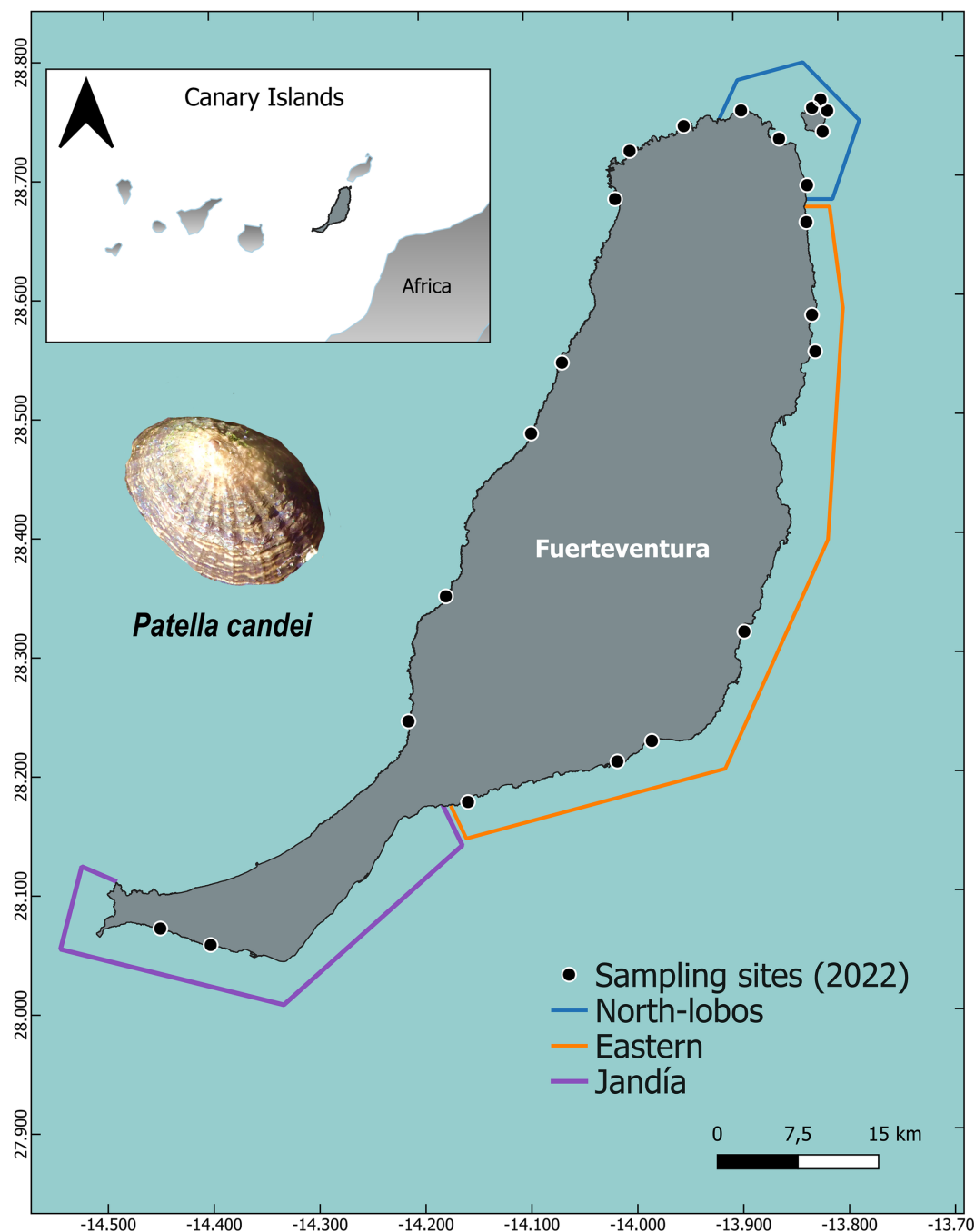


FIGURE 1 | Study area showing the sampling sites for this study. The sectors selected for the historical analysis are indicated with different colours.

Monthly SST data (°C) for the available period 1993–2022 were obtained from the Atlantic-Iberian Biscay Irish-Ocean Physics Reanalysis provided by the E.U. Copernicus Marine Service Information; [doi:10.48670/moi-00029](https://doi.org/10.48670/moi-00029). This dataset provides ocean physical information, using the NEMO v3.6 ocean general circulation model at 1/12° horizontal resolution. Additionally, monthly AT data (°C) were retrieved from AEMET OpenData platform (Agencia Estatal de Meteorología, Spain); <https://opendata.aemet.es/centrodedescargas/productosAEMET>, accessed in April 2025. This open-access service offers validated climatological data from official Spanish

weather stations, specifically from the Fuerteventura Airport station.

To evaluate interannual thermal variability, we calculated annual anomalies for AT and SST relative to the mean temperature for the full period (1993–2022). Anomalies were computed by subtracting the baseline mean from each monthly AT and SST value, enabling detection of years with significantly warmer or cooler conditions. All calculations were performed in R Version 4.3.2 (R Core Team 2023). Temporal patterns were visualized using the ggplot2 package (Wickham 2016),

highlighting warm and cold anomaly years with red and blue markers, respectively.

3 | Results

3.1 | Status of *P. candei*

According to our results, a total of 53 limpets of *P. candei* were registered during this study, all of which were found in the southern sector of Fuerteventura, specifically in Jandia (Figure 2a). Moreover, among the three intertidal levels sampled, the upper tidal level had fewer individuals compared with the middle and lower tidal zones (Figure 2b). Regarding size distribution, all individuals measured between 20 and 65 mm (Figure 2c), with a great notable concentration of large specimens between 40–45 and 50–55 mm size classes.

3.2 | Historical Changes in Distribution

The distribution of the ‘majorera limpet’ has changed over time. In the first surveys conducted in 2003, it was present along most of the coast of Fuerteventura and Islet of Lobos, except for the western side of the island. Over the years, its distribution has shrunk and it is now only found in the southern region of the Jandia peninsula (Figure 3a).

The permutational ANOVA results showed significant interaction effects between the factors ‘Sector’ and ‘Year’ ($F=8.2$, $p<0.05$) on *P. candei* abundance (Table 1; Figure 3b). In the North of Fuerteventura and Lobos Islet, the presence of the species has remained consistently low, with a few individuals observed only in 2002 and 2013. In contrast, the eastern sector harboured the species 20 years ago; however, its abundance has steadily declined over the past decade, culminating in its complete disappearance in the most recent survey (Figure 3b). On

the other hand, the Jandia sector showed more favourable conditions for the species, with an increase in *P. candei* abundance over time. Post hoc pairwise comparisons (Table 2) offered further insight into the temporal and spatial dynamics. After 2011, populations in the Eastern sector began to decline, ultimately disappearing completely by 2022 as mentioned before. In contrast, *P. candei* populations in Jandia started to increase after 2011 (Table 2; Figure 3b). Nonetheless, during the early sampling periods, some locations in Jandia had already recorded high densities (30 ind/100 m²) (Figure 3b).

3.3 | Historical Temperature Data Trends in Fuerteventura

AT anomalies in Fuerteventura have shown a clear warming trend over the past two decades, with most years exhibiting above-average temperatures (Figure 4a). Notably, several years such as 2004, 2008 and 2010 recorded anomalies exceeding +1°C. These particularly warm years preceded marked declines in *P. candei* populations, with a decline of 38% in 2011 and 41% in 2013, as documented by González-Lorenzo et al. (2015).

In contrast, SST anomalies exhibited less pronounced variability over the same period (Figure 4b). While the warming trend in SST was not as strong as in AT, two notable peaks were observed in 1997 and 2010. Temperature records indicate that the 2009–2010 period was particularly warm, as reflected in both AT and SST anomalies. This warmer period also coincided with the decline of *P. candei* populations reported by González-Lorenzo et al. (2015) in 2011.

4 | Discussion

This study highlights the poor conservation status of the Macaronesian endemic and protected limpet, *P. candei* in

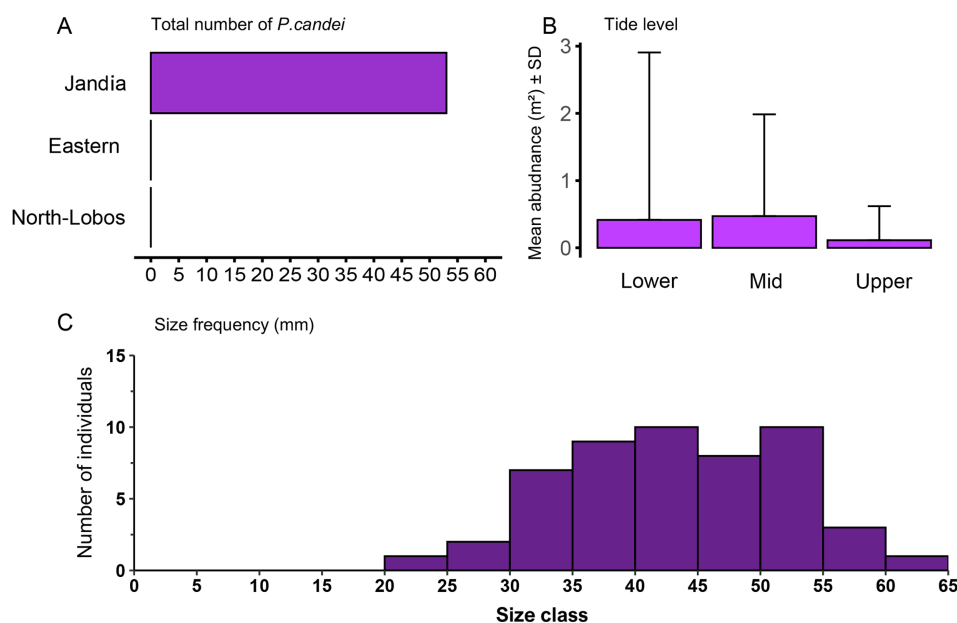


FIGURE 2 | Descriptors of *P. candei* population in Fuerteventura during the 2022 sampling year. (A) Abundance across the different surveyed sectors. (B) Abundance across tidal levels. (C) Size-frequency distribution of individuals sampled in 2022.

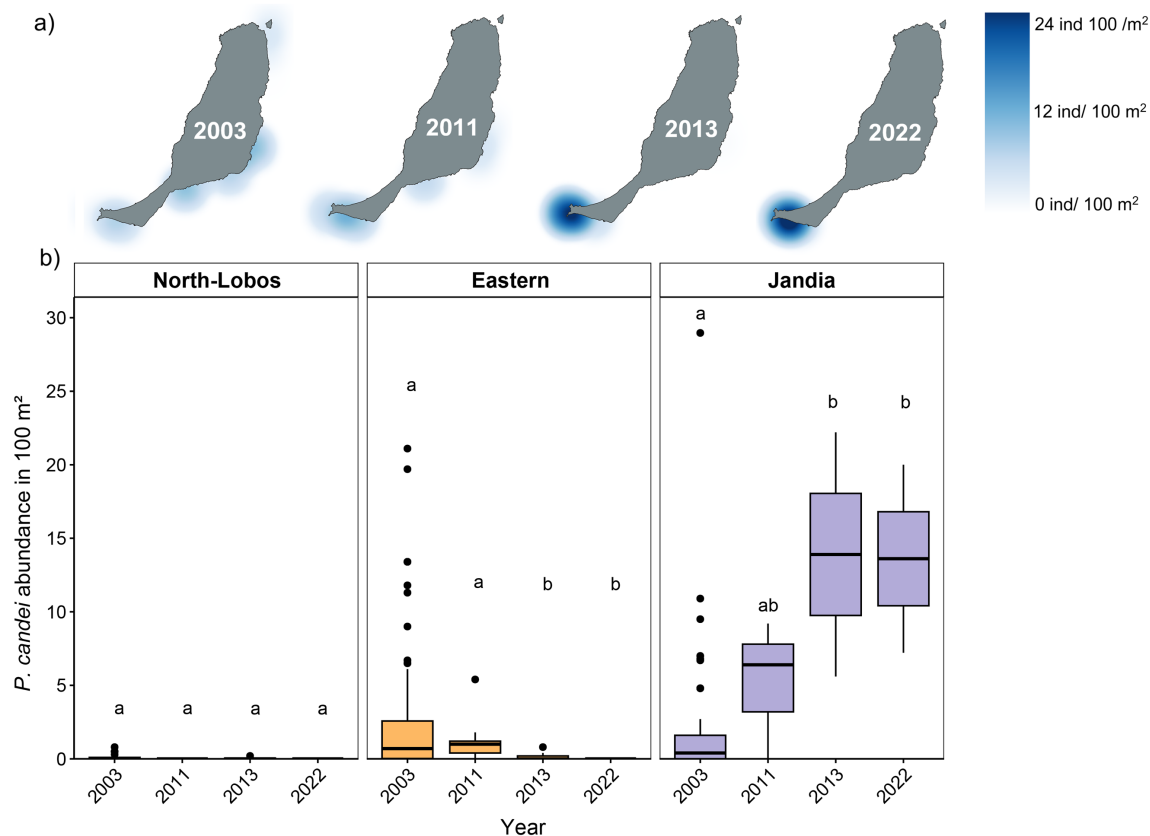


FIGURE 3 | (a) Heatmap showing historical changes in *P. candei* abundance (individuals/100 m²) in Fuerteventura. (b) Boxplots showing the abundance of *P. candei* (individuals/100 m²) in the North—Lobos, Eastern and Jandia sectors over different studied years. Sampling was conducted in 2003 (Núñez et al. 2003), 2011 and 2013 (González-Lorenzo et al. 2015), and 2022 (this study). Black dots represent outliers. Letters denote significantly different groups based on post hoc permutational ANOVA contrasts grouped by sectors ($p \leq 0.05$).

TABLE 1 | Permutational ANOVA analysis for the abundance of *P. candei* sampled at each studied sector in Fuerteventura and Lobos Islet and across different years. Asterisks denote significant differences ($*p < 0.05$).

	Df	Sum Sq	MeanSq	F model	R ²	p value
Sector	2	26.79	13.39	15.71	0.10	0.001*
Year	3	1.19	0.40	0.47	0.00	0.71
Sector × Year	6	41.99	6.99	8.2	0.15	0.001*

Fuerteventura. The results confirm the disappearance of populations along Lobos Islet, northern and eastern coasts of the island. Currently, a single relict population persists in Jandia, the southernmost sector of the island, where more than 50 individuals were recorded, representing the highest abundance observed in 2022. However, previous studies have shown that in externally fertilizing species, gamete concentrations decline sharply with distance, and successful fertilization generally requires individuals to occur in close proximity (Denny and Shibata 1989; Grosberg 1991). In this sector, mean abundance was only 15 ind./100 m² (0.15 ind./m²) as shown in Figure 3b, and consequently, despite being the highest value recorded in our survey, this density still represents a low local abundance for an external breeder. Size distribution data revealed a broad range (from 20 to 65 mm), consistent with previous measurements by Núñez et al. (2003) and González-Lorenzo et al. (2015). However, no individuals between 65 and 75 mm were observed,

contrasting with 2013 data from González-Lorenzo et al. (2015), who associated such sizes with population recovery and protection measures. A reduction in *P. candei* abundance along with a contraction of its range toward the southern region was already evident in 2013 (González-Lorenzo et al. 2015). These alarming signs suggest that the existing Recovery Plan launched in 2015 (Decreto 161/2015, BOC 136) has been either insufficient or inefficient in ensuring the species' survival, as measurable improvements in limpet populations would be expected after a decade of implemented conservation measures (Aliende-Hernández et al. 2025).

Similar challenges have been documented in other limpet species, such as the threatened Mediterranean limpet *Patella ferruginea* Gmelin, 1791, which is listed as endangered under several international agreements and national environmental laws, including Annex IV of the EU Habitats Directive (92/43/

TABLE 2 | Pairwise comparisons of *P. candei* abundance (individuals/100 m²) across sampling years within each sector, based on permutational ANOVA with Bonferroni-adjusted *p* values. Significant differences are highlighted in bold and indicated with an asterisk (**p* ≤ 0.05). NaN values denote comparisons where no variation was detected.

Contrast by years	Sums Sq	F. model	R ²	<i>p</i>
Sector: North-Lobos				
2011 = 2003	0.11	1.64	0.05	0.29
2011 = 2013	0.03	1.00	0.14	1.00
2011 = 2022	0.00	NaN	NaN	NA
2013 = 2003	0.01	0.20	0.01	0.73
2013 = 2022	0.03	2.22	0.18	0.34
2022 = 2003	0.19	3.31	0.09	0.10
Sector: Eastern				
2011 = 2003	0.04	0.04	0.00	0.83
2011 > 2013	2.61	9.71	0.38	0.00 *
2011 > 2022	4.08	18.33	0.55	0.00 *
2013 < 2003	5.78	5.88	0.05	0.02 *
2013 = 2022	0.20	3.16	0.17	0.20
2022 < 2003	8.27	8.41	0.07	0.01 *
Sector: Jandia				
2011 = 2003	2.96	2.37	0.04	0.10
2011 = 2013	3.41	1.27	0.30	0.60
2011 = 2022	3.57	1.56	0.34	0.40
2013 > 2003	14.12	11.51	0.17	0.01 *
2013 vs. 2022	0.00	0.00	0.00	1.00
2022 > 2003	14.55	12.05	0.17	0.01 *

EU), Appendix II of the Bern Convention, the Spanish National Catalogue of Threatened Species (Order of 9 June 1999; BOE No. 148) and the Barcelona Convention (UNEP/MAP-SPA/RAC 2018). Despite years of conservation efforts, this species has shown little to no significant recovery in abundance within protected areas (Cascales-Soler et al. 2023). However, certain locations along the North African coast, such as Ceuta, have been identified as strongholds for *P. ferruginea*, with population densities increasing markedly over the past decade (Espinosa et al. 2014; Ostalé-Valriberas et al. 2023). This localized and exceptional recovery underscores the importance of continuous monitoring to identify potential refuge areas that may play a key role in the long-term conservation of endangered limpet species.

Limpets in the Atlantic archipelagos have been harvested for human consumption since human colonization, and this activity persists to this day, being one of the most important small-scale fisheries activities in these islands (da Silva and de Meneses 1921; Martínez-Escauriaza et al. 2020; Sousa

et al. 2023). In the Canary Islands, conservation regulations impose limits on catch sizes and establish a no-catch period from December to April for commercially harvested species such as *P. ordinaria* and *P. aspera* (BOC n°93, 2011), while harvesting of *P. candei* has been completely prohibited year-round since 2004 (Decreto 182/2004, BOC 004). Nonetheless, conservation measures seem to be inadequate, as limpet extraction during closed seasons has been documented (González-Lorenzo et al. 2015 and authors' personal observation). Furthermore, misidentification by shellfishers may lead to inadvertent harvesting of *P. candei*, hindering recovery efforts for this endangered species.

Temperature-related environmental stressors may also contribute to population declines. Notably, high AT anomalies (some exceeding +1°C), occurred shortly before the 2011 sampling by González-Lorenzo et al. (2015), coinciding with the initial detection of population collapse in all regions except in Jandia. This temporal coincidence suggests that thermal stress could be considered a potential contributing factor, especially as *P. candei* inhabits both upper and mid-shore zones and must cope with long emersion periods during low tide, but this hypothesis cannot be tested with the current dataset. Interestingly, in this study, individuals were also found at lower tidal levels, unlike earlier reports (Núñez et al. 2003). This downward shift may represent a response to avoid extreme heat, a pattern observed in other intertidal species such as *P. vulgata*, *Semibalanus balanoides* (Kendall et al. 2004) and *Gelidium canariense* (Alfonso et al. 2021). While SST anomalies have shown relatively low variability in recent decades, a peak exceeding +0.4°C was recorded prior to the documented population decline around 2010. Nevertheless, the relative importance of temperature in the disappearance of *P. candei* cannot be assessed here, and targeted experimental studies are needed to evaluate the effects of thermal stress on this species as has been demonstrated for other European Atlantic limpet species (Seabra et al. 2016; Freitas et al. 2023).

Although *P. candei* populations in the Selvagens Islands have remained stable in contrast to those in Fuerteventura (González-Lorenzo et al. 2015; Quinteiro et al. 2022), translocation from Selvagens is not recommended due to the significant genetic divergence between populations on different islands (Quinteiro et al. 2022). A more viable strategy could involve relocating juveniles obtained from the remaining adult population in Jandia to other suitable habitats within Fuerteventura. This approach could be implemented using non-invasive techniques, as successfully demonstrated for the endangered Mediterranean limpet *P. ferruginea* (Ferranti et al. 2022). However, as emphasized by Quinteiro et al. (2022), such interventions must be preceded by thorough genetic analyses to ensure compatibility and preserve the species' genetic integrity. This would also require replicating the ecological conditions of Jandia, which appears to offer a favourable environment for the 'majorera limpet'. For example, Jandia is characterized by generally high wave exposure (waves > 1.5 m), unlike the eastern and northern coasts, where wave heights rarely exceed 1 m (<https://portus.puertoes.es/>, accessed May 2025). This factor may contribute to population resilience, as similarly observed for *P. ferruginea* in Plane Island and Melilla (Cascales-Soler et al. 2023). Harvesting activity tends to decrease with increasing wave height and typically occurs only under calmer sea conditions (Branch and Odendaal 2003; Diogo

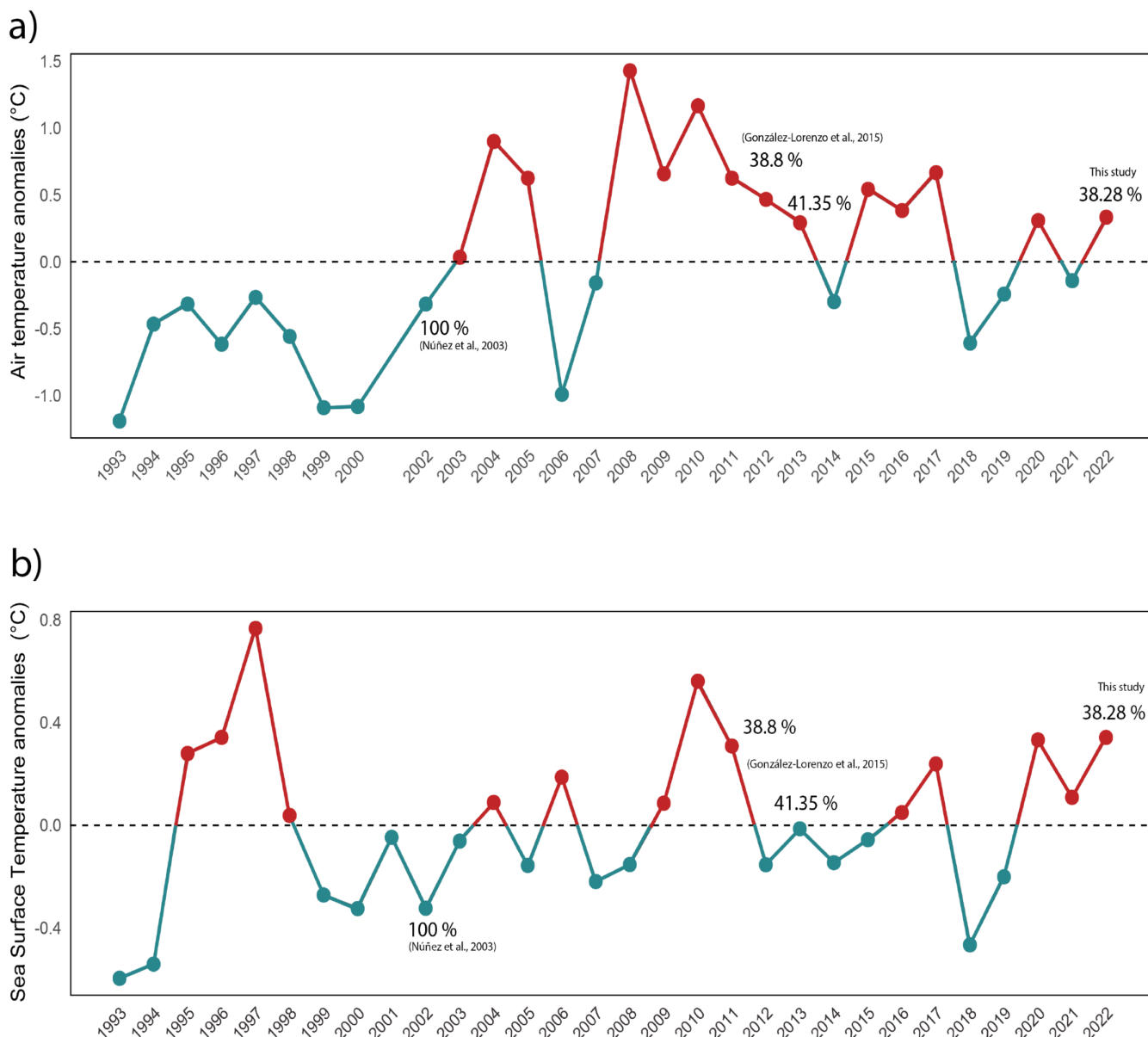


FIGURE 4 | Annual anomalies of (a) air temperature (AT) and (b) sea surface temperature (SST) in Fuerteventura from 1993 to 2022. Red dots represent years with positive anomalies (warmer than average), while blue dots indicate years with negative anomalies (colder than average). Percentages refer to the proportion of *P. candei* individuals remaining in Fuerteventura in each year, using the 2002 population reported by Núñez et al. (2003) as the 100% reference baseline.

et al. 2016). Additionally, wave action has been suggested to play a role in triggering spawning in limpets (Orton et al. 1956; Brazão et al. 2003), potentially enhancing reproductive success.

In conclusion, the current distribution of *P. candei* in the Canary Islands is confined to the southern region of Fuerteventura (Jandia), where a relict population persists. Although the number of individuals has increased in recent years, this recovery has occurred only in this small area, and the population remains very low and insufficient for successful reproduction. Consequently, the species remains highly vulnerable, restricted to a small, isolated part of the island. This localized persistence may be attributed to the area's strong wave exposure, likely reducing illegal harvesting by making access difficult, and the species' apparent shift toward lower tidal levels. Nevertheless, the overall conservation status of *P. candei* remains critical, as it

has disappeared from Lobos Islet and the northern and eastern coasts of Fuerteventura, despite the implementation of a recovery plan. This decline may result from a combination of rising air temperatures and ongoing anthropogenic pressures, including illegal or unintentional harvesting and habitat degradation, leading to population fragmentation and reducing reproductive success. Urgent and targeted conservation measures are essential to safeguard the remaining population and to promote the recovery of this endangered Macaronesian limpet.

Author Contributions

Marina Aliende-Hernández: writing – original draft, methodology, writing – review and editing, data curation, investigation. **Beatriz Alfonso:** methodology, supervision, writing – review and editing, investigation. **Jorge Núñez:** methodology, supervision, writing – review and

editing, investigation. **José Carlos Hernández:** funding acquisition, methodology, supervision, writing – review and editing, investigation.

Acknowledgements

This work is framed in the thesis of Marina Aliende Hernandez financed by the Agencia Canaria de Investigación, Innovación y Sociedad de la Información de la Consejería de Universidades, Ciencia e Innovación y Cultura and Fondo Social Europeo Plus (FSE+), Programa Operativo Integrado de Canarias 2021-2027, Eje 3 Tema Prioritario 74 (85%), (FPI2024010161). It was also supported by the agreement “Recursos Marinos Pesqueros de Canarias: punto de referencia histórico y estado actual” from the Consejería de Agricultura, Ganadería y Pesca del Gobierno de Canarias. Fieldwork was carried out with the authorization of the Secretaría de Medio Ambiente (Permit No. SGBTM/BDM/AUTSPP/70/2022). No artificial intelligence tools were used in the preparation of this manuscript. We would like to thank Sara González-Delgado and Iván Cano for their assistance with field sampling.

Funding

This work was supported by Agencia Canaria de Investigación, Innovación y Sociedad de la Información, FPI2024010161; Gobierno de Canarias, Consejería de Agricultura, Ganadería y Pesca.

Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The supplementary datasets supporting the findings of this study have been deposited in the Zenodo repository and are publicly accessible at <https://doi.org/10.5281/zenodo.20799161>. These data include field sampling records of *P. candei* from Fuerteventura (June 2022), organized into two components: Sheet 1 provides abundance data, and Sheet 2 provides size data (shell measurements in mm of individual limpets by site).

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