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Occurrence of the subtropical fish *Pomacanthus paru* (Pomacanthidae, Acanthuriformes) in Uruguay, Southwestern Atlantic

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Abstract: Climate change is affecting marine ecosystems worldwide; shifts in the distribution of fish species are common. The southern Brazilian and Uruguayan oceanic region is considered one of the largest marine warming hotspots in the world. *Pomacanthus paru* is a subtropical fish distributed from Florida (USA) to Santa Catarina (Brazil). However, this species was recorded in the Rio de la Plata estuary in 2013. Here we report the first records of *Pomacanthus paru* in Uruguay with citizen science contributions. Eight records of dead stranded individuals were obtained during 2017-2023. Four fish were preserved as voucher specimens. The arrival of *P. paru* in Uruguay may have occurred during the warmer months and may have been favored by positive SST anomalies during the summers of the years prior to the strandings. All strandings occurred after a succession of extratropical cyclones in late fall and winter that caused abrupt drops in SST (≤15ºC). The frequency of occurrence of *P. paru* at latitudes beyond its distribution is uncertain; this highlights that citizen science will contribute to long-term monitoring of changes in the distribution of tropical species and would be one of the main drivers in documenting these phenomena in the context of global ocean warming.

Key words: French angelfish, citizen science, ocean warming, tropicalization, southwestern Atlantic.

Occurrencia del pez subtropical *Pomacanthus paru* (Pomacanthidae, Acanthuriformes) en Uruguay, Atlantico Sudoccidental. Resumen: El cambio climático afecta los ecosistemas marinos globalmente, generando cambios en la distribución de las especies de peces. La región oceánica del sur de Brasil y Uruguay se considera uno de los mayores focos de calentamiento global. *Pomacanthus paru* es un pez subtropical distribuido desde Florida (EEUU) hasta Santa Catarina (Brasil). Sin embargo, la especie fue registrada en el Río de la Plata en 2013. Aquí reportamos los primeros registros de *Pomacanthus paru* en Uruguay con contribuciones de ciencia ciudadana. Se obtuvieron ocho registros de individuos varados muertos durante 2017-2023. Cuatro peces fueron preservados como especímenes voucher. La llegada de *P. paru* a Uruguay pudo ocurrir durante meses cálidos y posiblemente estuvo favorecida por anomalías positivas de la TSM durante los veranos previos a los varamientos. Éstos, ocurrieron después de una sucesión de ciclones extratropicales en las estaciones frías que causaron caídas abruptas de la TSM (≤15ºC). La ocurrencia de *P. paru* en latitudes superiores a las de su distribución es incierta; destacando que la ciencia ciudadana contribuirá al seguimiento a largo plazo de los cambios en la distribución de las especies tropicales y será un conductor para documentar estos fenómenos en el contexto del calentamiento global de los océanos.

Palabras clave: pez ángel francés, ciencia ciudadana, calentamiento de los océanos, tropicalización, Atlántico sudoccidental.

Introduction

Climate change is impacting global ocean ecosystems (Bindoff *et al.* 2019) and may lead not only to the extinction of species, but also to profound changes in their abundance, distribution, and species assemblages, compositions, and interactions with other species (Pecl *et al.* 2017, Antão *et al.* 2020). This, in turn, can affect the life cycle, seasonality, and distribution of marine species (Perry *et al.* 2005, Poloczanska *et al.* 2013, 2016). Therefore, a higher rate of ocean warming could affect the distribution, abundance, and life history traits of fishes (Cheung *et al.* 2013, Pauly & Cheung 2018).

A warming trend in the upper ocean has been observed in the South Atlantic (Kolodziejczyk *et al.* 2014). Over the past three decades, there has been a systematic increase in sea surface temperature (SST) over the southwestern Atlantic (Ortega *et al.* 2012). In particular, the oceanic region of southern Brazil and Uruguay is considered one of the largest ocean´s warming hotspots in the world (Hobday & Pecl 2014). At the same time, positive sea surface temperature anomalies (SSTA) off the Uruguayan coast have increased since 1997 (Ortega *et al.* 2016), and in the last decade they have become more intense, with longer durations and higher values (Martínez *et al.* 2017). Furthermore, in 2017, the area between Rio Grande do Sul (Brazil) and Mar del Plata (Argentina), up to 200 km offshore, experienced the most intense marine heat wave (MHW) in the last 30 years (Manta *et al.* 2018). In turn, Gianelli *et al.* (2019) reported a shift from cool-water to warm-water species caught by the Uruguayan industrial fishery in recent decades. This provides the first quantitative evidence of the long-term impact of ocean warming on local landings. Similarly, in response to climate change, Araújo *et al.* (2018) reported shifts in the abundance and distribution of shallow-water fish fauna along the southeastern coast of Brazil. In addition, Perez & Sant'Ana (2022) found evidence of tropicalization of demersal megafauna in the Brazilian Meridional Margin between 2013 and 2019. Even more remarkable is the strong scientific evidence that the Brazil Current has been intensifying and shifting southwards in response to changes in near-surface wind patterns in recent decades. This has led to intense ocean warming along the path of the Brazil Current and the South Brazil Bight (Franco *et al.* 2020, 2022, Li *et al.* 2022). All these facts promote the occurrence of tropical and subtropical marine species of different taxa along the Uruguayan and northern Argentinean continental shelves, associated with an extended presence of warm subtropical waters derived from the Brazil Current (e. g. Segura *et al.* 2008, Solari *et al.* 2010, Leoni *et al.* 2016, Martínez *et al.* 2017, De Wysiecki *et al.* 2018, Pereyra *et al.* 2019, Laporta *et al.* 2021a, Silveira *et al.* 2022, Bovcon *et al.* 2022).

Within the framework described above, citizen science has proven to be a powerful and cost-effective method for detecting and monitoring rare native and non-native fish species (Vann-Sander *et al.* 2016, Champion *et al.* 2018, Tiralongo *et al.* 2020, Agostini *et al.* 2021, Deidun *et al*. 2021). In fact, data collected by citizens were often easily verifiable and can be considered as reliable as those collected by scientists, as already highlighted in the relevant literature (e.g. Bonney *et al.* 2014, Danielsen *et al.* 2014, Lewandowski & Specht 2015, Martin *et al.* 2016, Smith & Nimbs 2022). Recently, previously unreported marine fish species have been documented in Uruguay thanks to the contribution of citizen science (De Wysiecki *et al.* 2018, Laporta *et al.* 2018, 2021a,b, 2022, Pereyra *et al.* 2019, Fabiano *et al.* 2021, Vidal *et al.* 2021). This demonstrates how transdisciplinary research can contribute to knowledge on diversity, especially in countries with scarce resources for marine science studies.

To date, 13 species of the genus *Pomacanthus* Lacepède, 1802 are known from the oceans (Nelson *et al.* 2016), but only two species, the French angelfish *Pomacanthus paru* (Bloch, 1787) and the gray angelfish *Pomacanthus arcuatus* (Linnaeus, 1758), occur in the Western Atlantic (Fricke *et al.*

2022). *Pomacanthus paru* is distributed in tropical waters from Florida (USA) to southern Brazil and *P. arcuatus* is commonly found from New England (USA) to Brazil (Menezes *et al.* 2003). Both species occur in the Gulf of Mexico, the Bahamas and the Caribbean (Smith 1997, Burgess 2002). *Pomacanthus paru* has also been reported in St. Paul's Rocks and Ascension Island in the Central Atlantic and Gulf of Guinea (Feitoza *et al.* 2003), while *P. arcuatus* is common in the Caribbean and less common in Brazil (Hostim-Silva *et al.* 2006). Although Santa Catarina (Brazil) was considered the southern distributional limit for *P. paru* (Carvalho-Filho 1999, Hostim-Silva *et al.* 2006), a single specimen was recorded in the Rio de la Plata estuary (Argentina, 36°13′S, 56°33′W) in 2013, associated with a southward warm coastal drift (Milessi *et al.* 2013).

This work presents the first record of the subtropical fish *Pomacanthus paru* in Uruguay with the contribution of citizen science. At the same time, it discusses whether its occurrence could be as a visitor or as a possible resident depending on the oceanographic conditions prevailing in these latitudes due to global ocean warming.

Study area: The southwestern Atlantic surface winds drive an open ocean circulation characterized by intense western boundary currents, with a poleward flowing warm and saline Brazil Current and an equatorward flowing cold and relatively fresh Falklands/Malvinas Current (Peterson & Stramma 1991). These two currents converge on the slope at about 38.8°S, generating the highly energetic and productive Brazil/Falklands-Malvinas Confluence (Olson *et al.* 1988). These currents in turn influence the continental shelf circulation, which is also influenced by the outflow from the Rio de la Plata estuary and the northward flow of the Subantarctic Shelf waters. At about 30°S, these waters meet the Subtropical Shelf Waters in a density-compensated front that extends toward the slope and continues to the Brazil-Falklands/Malvinas Confluence (Piola *et al.* 2000). The Uruguayan shelf hydrography is characterized by a pronounced seasonality related to the southward shift of the South Atlantic anticyclone, with a seasonal amplitude of 12°C and a reversal of the prevailing winds, which blow from the NE during most of the year, except in winter, when they also blow from the SW with similar frequency (Manta *et al.* 2021). However, the interannual variability is also high and strongly related to the El Niño-Southern Oscillation (ENSO). El Niño years tend to be warm and wet, with large discharges from the Rio de la Plata, while La Niña years tend to be dry and cooler (e.g., Barreiro 2010).

Materials and methods

Records of *P. paru* were obtained from fishers and citizens who reported stranded specimens to researchers from the Unidad de Gestión Pesquera Atlántica, Dirección Nacional de Recursos Acuáticos (UGEPA-DINARA) and Facultad de Ciencias, Universidad de la República (FCIEN-UdelaR). The data recorded included: date, stranding location, collector, photographs of the specimens and, when possible, total length, weight, sex, and stomach contents. Muscle tissue samples were also collected for genetic studies. Specimens were identified using the key proposed by Carvalho-Filho (1999) and Hostim-Silva *et al.* (2006). Whenever possible, stranded specimens were collected and used to confirm identity, and later preserved and deposited as voucher specimens in the Ichthyological Collection of the Museo Nacional de Historia Natural, Montevideo (MNHN) and in the Fish Collection of the Facultad de Ciencias (Universidad de la República, Uruguay; institutional code ZVCP).

According to Carvalho-Filho (1999) and Hostim-Silva *et al.* (2006), adults of *P. paru* can be distinguished from *P. arcuatus* by the following characteristics: general coloration is marine blue to black (vs. brown); 10 dorsal spines (vs. 9); 29 - 31 dorsal soft rays (vs. 31 - 33); 22 - 24 anal soft rays (vs. 23 - 25); black body scales except those anteriorly from nape to abdomen rimmed in golden yellow (vs. beige rim and grayish brown center); yellow dorsal filament; pectoral-fin base, circle around eyes, and opercle and preopercle borders, bright yellow (vs. only upper border axil of pectoral fin is light yellow); whitish chin (vs. pale gray around mouth).

The guts of the collected individuals were preserved in 95% alcohol for later analysis. The stomach and intestinal contents were analyzed under a stereomicroscope. All prey items were identified to the lowest taxonomic level possible, counted and their absolute volume (mm^3) was measured using Hyslop's standardized indirect volumetric method (Hyslop 1980). The proportion of each prey item consumed was calculated.

Monthly sea surface temperature anomaly images from the National Oceanic and Atmospheric Administration (NOAA NCEP EMC CMB GLOBAL Reyn_SmithOIv2) were used for December, January, and February 2017, 2020, and

2022; and November, December, and January 2023 for the coastal region of the southwestern Atlantic Ocean (61ºW - 40ºW, 10ºS - 41ºS). The SST fields have been updated from version 1 with more COADS data, a new sea ice to SST conversion algorithm, and 1971-2000 climatology (Reynolds *et al.* 2002, updated to March 22, 2023).

Daily data on SST and salinity at La Paloma, Uruguay (34.6°S - 54.1°W) were collected *in situ* as part of the Environmental Data Monitoring Program carried out by DINARA since 1996 (Santana *et al.* 2022). The equipment used to measure SST and salinity was an YSI EcoSense EC300A conductivity meter. To identify each *P. paru* occurrence event in relation to the distribution of salinity and temperature, plots were made of the values of these two variables at La Paloma between July 2016 and July 2023, and the mean values of the last 25 years of both variables in winter, using the R software version 4.0.5 (R Core Team, 2021), package ggplot2 version 3.4.3 (Wickham, 2016) . Information from the National Meteorological Institute web (https://www.inumet.gub.uy/) on the presence of extratropical cyclones in the region was considered in the interpretation of each *P. paru* record.

Results

From July 2017 to July 2023, eight records of *Pomacanthus paru* were obtained along the Uruguayan coast (Table I, Figs. 1 and 2). Three of them were recorded in late fall, and the other five were recorded in winter. All specimens were adults, as described by Feitosa *et al.* (2016), with the observed length range at sexual maturity being 15-25 cm TL for females and 25-35 cm TL for males.

Four specimens were preserved in 4% formalin solution and deposited in scientific collections, three of them in the MNHN's ichthyology collection (MHNM-5401; MHNM-5402; MHNM-5403) and one specimen in the fish collection of the Facultad de Ciencias (Universidad de la República, Uruguay; ZVCP-15529) (Figure 2).

Only one specimen out of two *P. paru* recorded from Cabo Polonio in July 2017 was collected; it was deposited in the MNHN collection (Table I, Figure 2 A-B, MHNM-5401). This specimen was quite decomposed when it was found stranded on the beach, so the collector (MNGV) dried it. For the second individual, only a photograph is available (Table I, Figure 3 A). Regarding the records at Isla de Flores, Lagomar and José Ignacio (June 2022, June and July 2023, respectively), specimens could not be collected and only photos of the stranded specimens were taken at the site where they were found (Table I, Figures 3 B, C, E, respectively).

Two of the collected individuals had stomach contents. Individual MHNM-5402, collected during July 2017, preyed on local species of green (*Ulva*

Table I. Biological data of *Pomacanthus paru* specimens collected in Uruguay: () measured dry; *measured from photographs including a size reference; ** dry weight; *** eviscerated weight; - no data.

Date	Locality	Coordinates	Lt (cm) / Lst (cm) / W (g) / Sex	Collection code	Photo
21 July 2017	Cabo Polonio (CP)	34°24'6.6"S 53°46'48.4"W	33* (27) / (23) / 322,05** / -	MHNM-5401	Figs. 2 A - B
21 July 2017	Cabo Polonio (CP)	34°24'6.6"S 53°46'48.4"W	33* / - / - / -	not collected	Fig. 3
21 July 2017	Playa Hermosa (PH)	34°50'37.5"S 55°18'8.5"W	35,5 / 29 / 1063,48 / F	MHNM-5402	Figs. 2 C - D
18 June 2020	La Paloma (LP)	34°39'44.3"S 54°10'33.3"W	37 / 31 / 954,9*** / -	MHNM-5403	Figs. 2 E -F
03 June 2022	Playa Grande (PG)	34°51'17.4"S 55°17'55.4"W	34,5 / 28 / 1293 / F	ZVCP-15529	Figs. 2 G - H
03 June 2022	Isla de Flores (IF)	34°56'28.5"S 55°55'35.5"W	30* / - / - / -	not collected	Fig. 3 B
21 June 2023	Lagomar (LM)	34°50'54.7"S 55°58'26.3"W	35* / - / - / -	not collected	Fig. 3 C
22 July 2023	José Ignacio (JI)	34°50'11.0"S 54°37'50.0"W	30* / - / - / -	not collected	Fig. 3 D

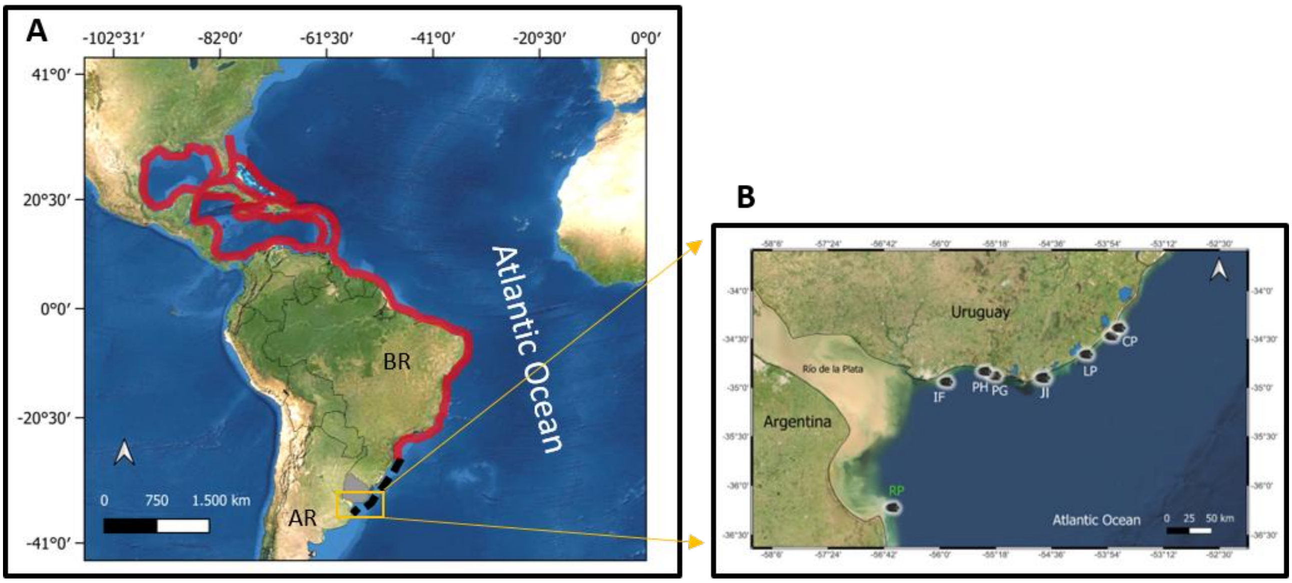

Figure 1. (A) Map of historical distribution of *Pomacanthus paru* in the Atlantic Ocean (in red). **(B)** Locations of stranded specimens along the Uruguayan Atlantic coast recorded in the present study, from 2017 to 2023 (LM, IF, PH, PG, LP, JI, CP in white; see locations acronyms in Table I); record of *P. paru* from Argentina in 2013 (Milessi *et al.* 2013) (RP: Río de la Plata, in green).

spp.) and coralline macroalgae (25% and 75%, respectively). However, the individual collected in June 2022 (ZVCP-15529) fed on crustaceans and mollusks (shrimp 35%, crabs 38%, and mollusks 27%). These results partially agree with those found by Batista *et al.* (2012) for specimens observed in Brazil, where their diet consisted mainly of algae (63.2 ± 32.1%) and sponges (31.5 ± 32.1%). However, we also found crustaceans and mollusks in the stomach contents of one of the specimens analyzed, which represents a new prey item for a spongivorous fish species.

All stranded specimens of *P. paru* were found between 11.5 ºC and 15.5 ºC SST during winter months (June-July) below the usual optimum water temperature range for the species (Froese 2020). Six of these were near and below the 25-year winter mean salinity (24.84 psu), three of which were at SSTs below the winter mean (12.59 ºC) during cold events recorded at La Paloma (34.6°S - 54.1°W). (Santana et al. 2022) (Figure 5).

In all years of strandings, extratropical cyclones reached the Uruguayan coast days before the strandings, resulting in abrupt drops in SST and salinity (e.g. INUMET 2022, INUMET 2023a,b). In July 2023, this decrease in SST is consistent with what was observed by spearfishers in the José Ignacio locality, where they personally recorded this decrease in SST in their diving watches, from 15°C in the days before the extratropical cyclone arrived to 11°C in the days after (González pers. comm[1].).

Discussion

This work represents the first record of *P. paru* for Uruguay and of the occurrence of a species of tropical and subtropical distribution in waters far from its usual range, carried out through citizen science. The presence of this species in different and recurrent years in Uruguay is evidence that it is not an isolated event and its occurrence along the Uruguayan coast may be a consequence of atmospheric, climatic, oceanographic and biological processes in scenarios of variability and climate change.

Pomacanthus paru specimens may have arrived in Uruguayan waters during the summer months (December, January, and February), when SST is warmer than other seasons (Figure 5) (Santana *et al.* 2022). This is supported by the observation of two live specimens by a recreational spearfisher in January 2017, six months before the 2017 stranding events, while free diving in the breakwater of La Paloma harbor. Both specimens were swimming freely together and in good health inside a large cave at the time they were observed by the spearfisher (Chañ pers. comm.[2]).

1 Gabriel González, Spearfisher, Federación Uruguaya de Actividades Subacuáticas, FUAS, Montevideo, Uruguay.
2 Daniel Chañ, Spearfisher, Federación Uruguaya de Actividades Subacuáticas, FUAS, Montevideo, Uruguay.

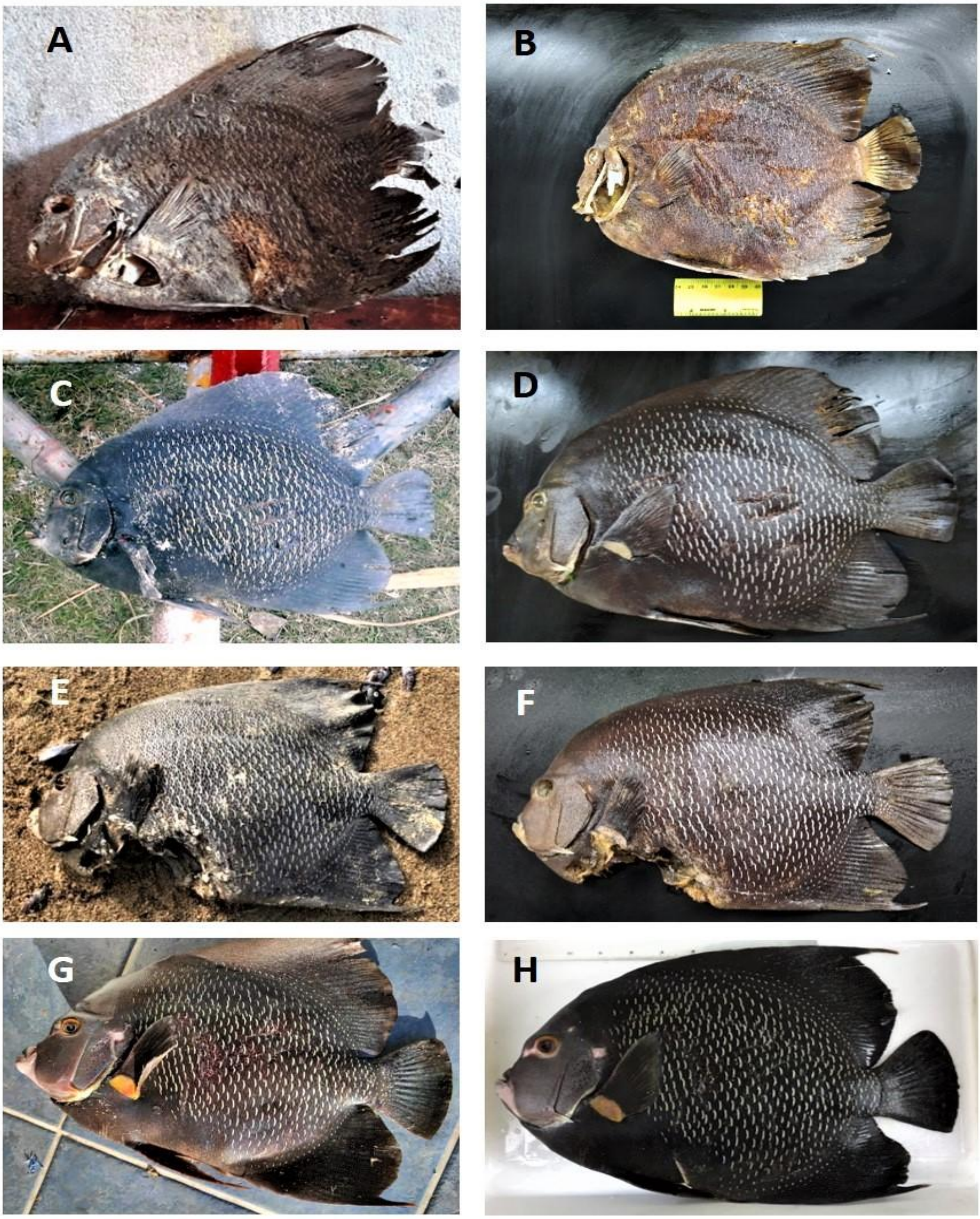

Figure 2. Photographs of stranded *Pomacanthus paru* specimens collected by citizens (left) and the same specimens preserved (right) at five coastal locations in Uruguay. A-B (Cabo Polonio, 2017, MHNM-5401); C-D (Playa Hermosa, 2017, MHNM-5402); E-F (La Paloma, 2020, (MHNM-5403); G-H (Playa Grande, 2022, ZVCP-15529).

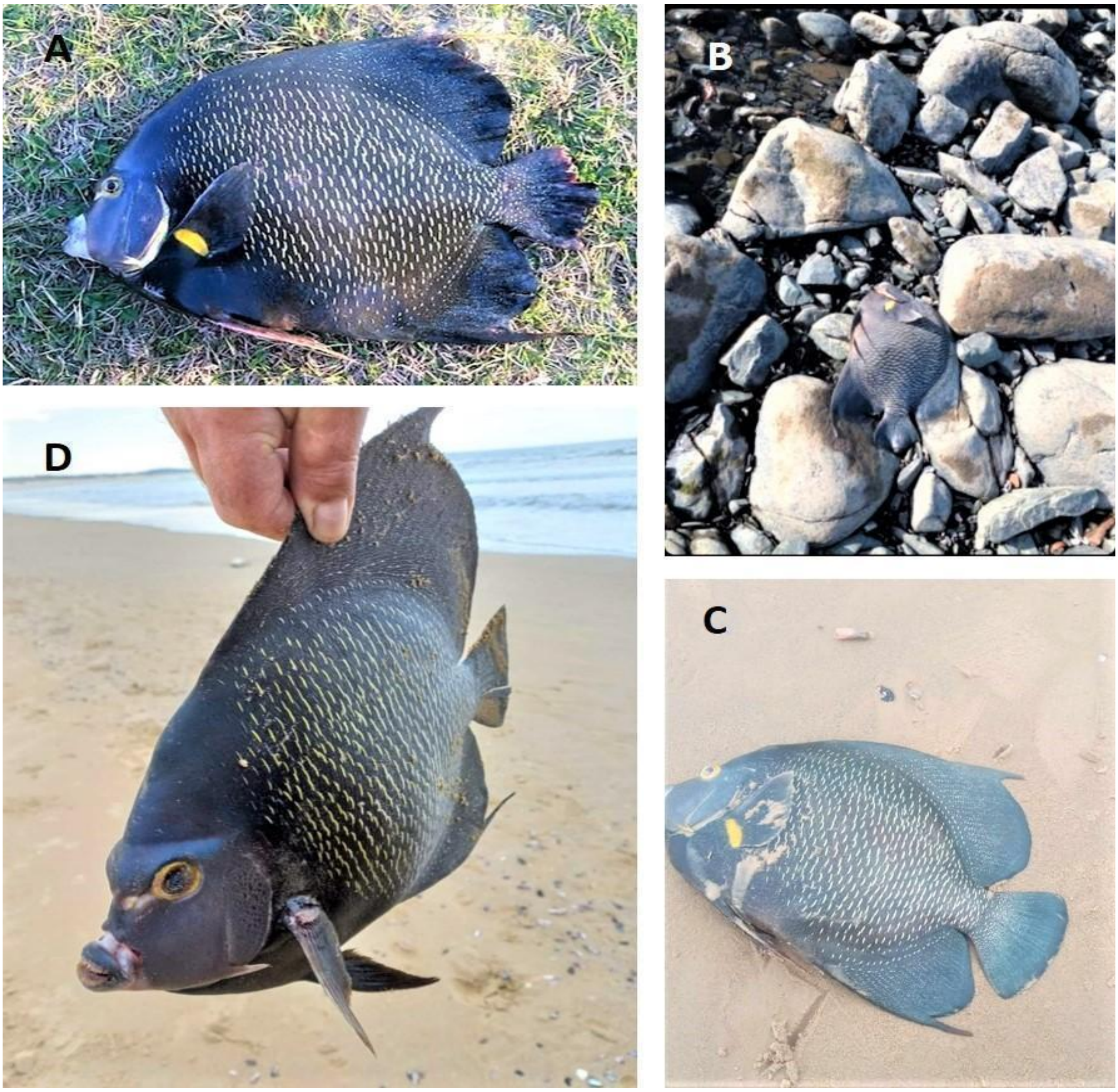

Figure 3. Photographs of stranded *Pomacanthus paru* specimens taken by citizens: A) Cabo Polonio, 2017; B) Isla de Flores, 2022; C) Lagomar, 2023; D) José Ignacio, 2023.

This is consistent with what Lieske & Myers (1994) described for this species, where they mentioned that it is usually observed in pairs. Furthermore, positive SSTA for the coastal region of the southwestern Atlantic (61ºW - 40ºW, 10ºS - 41ºS) were recorded in December, January and February 2017, 2020 and 2022, and in November, December and January 2023 (Figure 4). These events could also have facilitated the arrival of the species to the Uruguayan coast.

Cyclones are pronounced low-pressure centers that bring rains and winds and are more common in winter (Barreiro et al. 2021). Uruguay is one of the most cyclogenic regions in South America, which means that extratropical cyclones develop frequently. It should be noted that in all the years in which strandings were recorded (2017, 2020, 2022 and 2023), extratropical cyclones occurred over the Uruguayan coast days before the strandings, causing abrupt decreases in SST in particular, but also in salinity (Figure 5). These abrupt changes within a few days, especially the rapid decrease in SST and the effect of strong winds over the coast, could have caused the death and subsequent stranding of the specimens reported in this study.

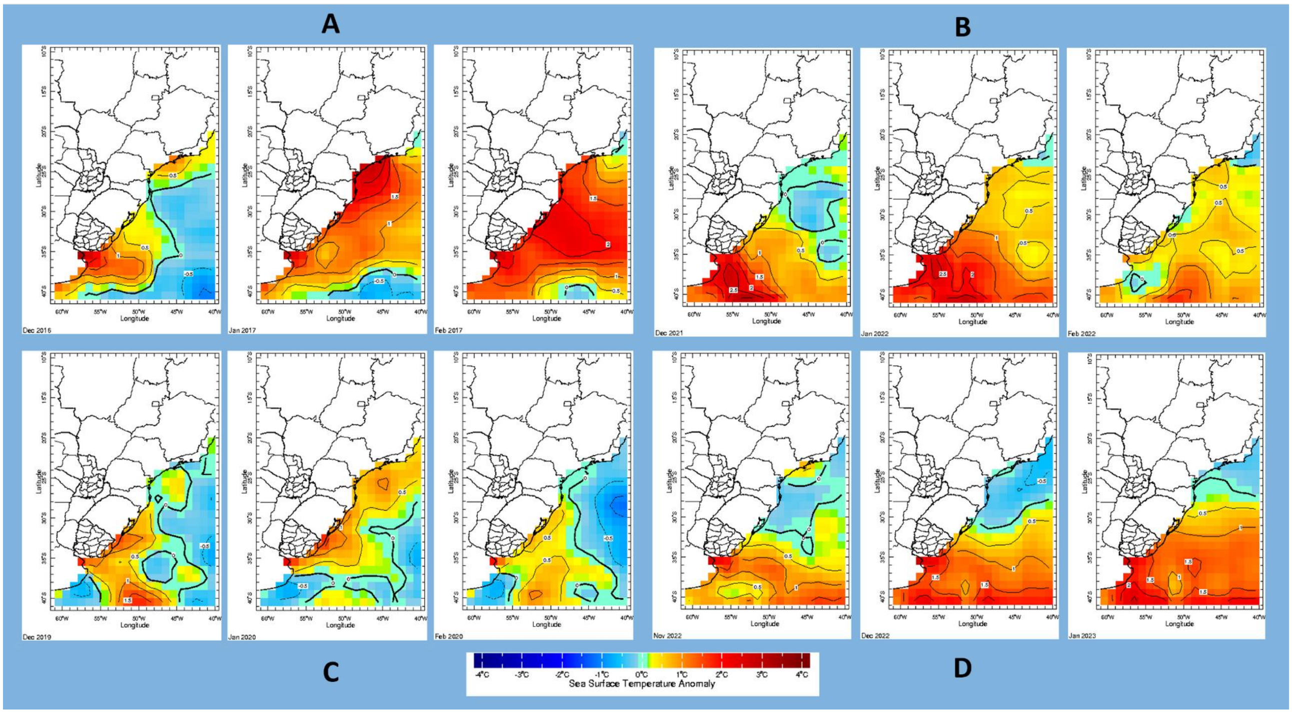

Figure 4. Images of monthly SSTA from NOAA (NOAA OI SST V2) for December, January and February 2017 **(A)**, 2020 **(B)** and 2022 **(C)**; and November, December and January 2023 **(D)** for the coastal region of the southwestern Atlantic Ocean (61ºW - 40ºW, 10ºS - 41ºS).

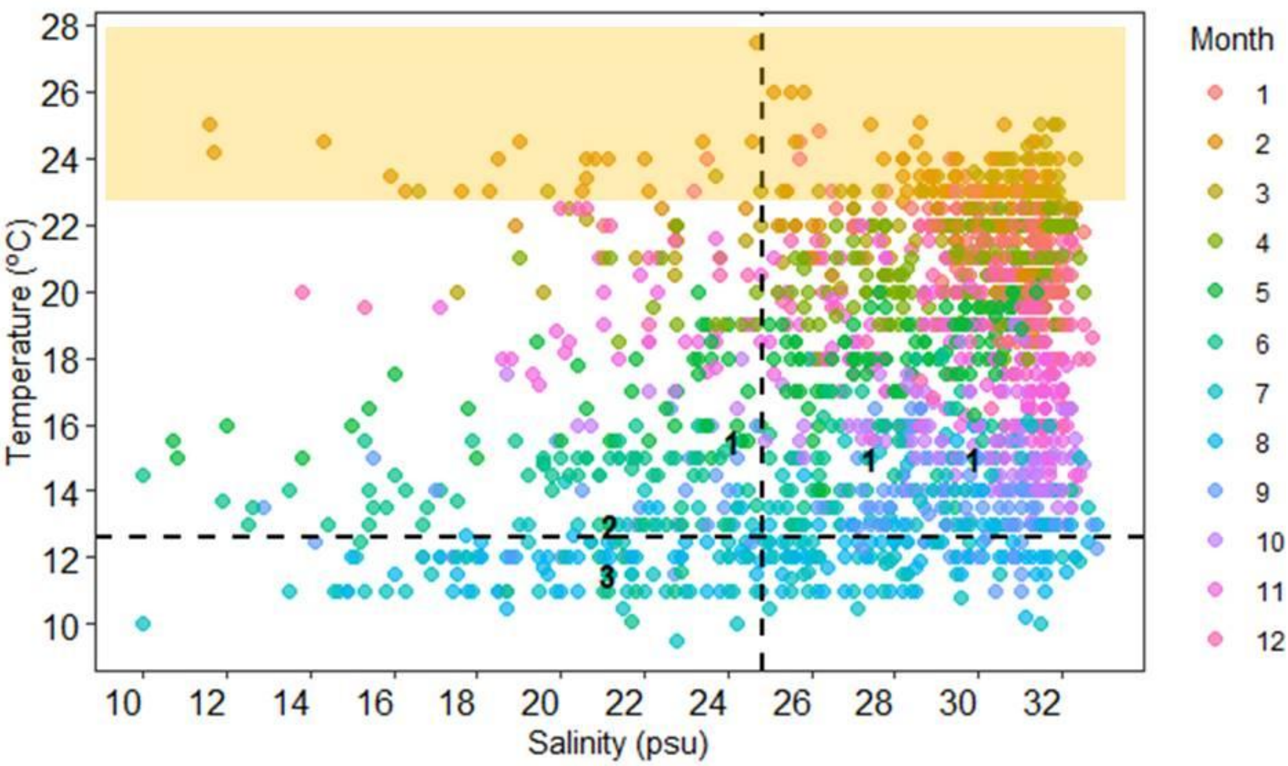

Figure 5. Detailed plot of daily salinity and temperature by month between July 2016 and July 2023 at La Paloma (34.6°S - 54.1°W). The number of *Pomacanthus paru* specimens collected is indicated in relation to these two variables. The dotted lines show mean winter temperature and salinity over 25 years (Santana *et al.* 2022), respectively. In orange, the range of optimal temperature values where the species commonly occurs is highlighted.

It is worth noting that in the Reserva Biológica Marinha do Arvoredo (27°17'57"S - 48°18'30"W, Santa Catarina, Brazil), the southern limit of the reported distribution of *Pomacanthus paru* (Hostim-Silva *et al.* 2006), the SST varies between 15°C and 26°C (Carvalho *et al.* 1998). Presumably, the survival of this species is compromised at temperatures below 15°C, as its preferred temperature range is between 22.9 and 28°C (Froese 2020). All stranding events reported in this study occurred at temperatures below and near 15°C and after the occurrence of extratropical cyclones that caused abrupt changes in SST mainly and salinity. At the same time, it is also interesting to highlight for this species that, despite not being found in the known range of its distribution, in two specimens recorded in this study we found food items comprising native species of macroalgae and macroinvertebrates in their stomach contents, indicating a feeding activity of the species in Uruguayan waters prior to the stranding events. We were also able to identify new prey items for this species in this study.

In the last decade, Uruguayan waters have shown an increase in new records and occasional occurrences of fish species and other marine organisms of tropical and subtropical distribution (e.g., Martínez *et al.* 2017, Pereyra *et al.* 2019, Laporta *et al.* 2021a,b, Fabiano *et al.* 2021, Silveira *et al.* 2022). In particular, between 2004 and 2022, 32 fish species of tropical and subtropical distribution were recorded in Uruguay, 10 of which were new records between 2014 and 2022 (Laporta *et al.* 2022). All of these new records and the occasional increase in the occurrence of tropical and subtropical species on the Atlantic coast of Uruguay and northern Argentina may be associated with a greater influence of the warm Brazil Current on the continental shelf due to global warming of the oceans as a result of climate change (Franco et al., 2020).

Tropicalization is a term used to describe the transformation of temperate ecosystems by poleward migrating tropical organisms in response to warming temperatures (Vergés et al. 2014). In general, most studies on the effects of global warming focus on the direct physiological effects of climate change. However, one of the most widespread changes being caused by global warming of the oceans is a shift in the distribution of many species, leading to new interactions between previously separated species that have the potential to transform entire ecological communities (Vergés et al. 2016; Fijiwara et al. 2022). A poleward range expansion of many tropical species in the tropical-temperate transition zones of North America has recently been reported by Osland et al. (2021). These authors suggested that climate change-induced decreases in the frequency and intensity of extreme cold events lead to a potential faunal tropicalization of the temperate ecosystem. Although it is difficult to assign this interpretation to what has been observed in Uruguay with this and other species, long-term monitoring of these events and the contribution of citizen science could help provide evidence of permanent or non-permanent changes in species distributions.

During the last three decades, several oceanographic phenomena have occurred in the southwest Atlantic, such as: 1) systematic increases in SST (Ortega *et al.* 2012); 2) positive SSTA intensification (Martínez *et al.* 2017, Castellanos *et al.* 2022, dos Santos *et al.* 2023); 3) historical MHW record (Manta *et al.* 2018, Smith *et al.* 2023); 4) extreme El Niño and La Niña Southern Oscillation episodes (Grimm *et al.* 2011, Santana *et al.* 2015, Valente *et al.* 2023); and 5) Southward extension of the Brazil-Falklands/Malvinas Confluence (Lumpkin and Garzoli 2011; Manta et al., 2022). This oceanographic context, added to the increase in new records of tropical and subtropical fish species, together with the increasing records of other species previously documented in our waters, but with occasional presence in the past and that have become more common in recent years (Laporta *et al.* 2021b, 2022), leads us to think about the possibility of a tropicalization of the fauna towards these latitudes. This has recently been suggested for Argentine Patagonia in the southwest Atlantic, where 27 species have expanded their ranges southward in the last 50 years (Galván et al. 2022), and for other regions of the world (e.g., Cheung et al. 2012, Bates et al. 2014, Hyndes et al. 2016, McLean et al. 2021, Pessarrodona et al. 2022). Future studies to understand the effects of climate change on the South Atlantic circulation and its variability at different scales on the shifts in the distribution of these subtropical and tropical species would help to understand and predict the changes that global warming is causing in coastal marine communities at these latitudes.

At the same time, it is essential to continue with participatory monitoring to learn about these oceanographic changes in our marine diversity and the possible effects they may have on marine fish assemblages in Uruguay (Laporta *et al.* 2021b, 2022: Vidal *et al.* 2021). It is also important to highlight the key role of citizen science in this type of studies and its contribution to the knowledge and development of marine science in Uruguay (Laporta *et al.* 2021a). In impoverished countries with scarce resources to develop large-scale marine research programs, the contribution and engagement by citizens, together with transdisciplinary research and participatory monitoring, strengthens and increases knowledge of the marine environment.

Conclusions

The effects of climate change are affecting pre-existing oceanographic variability in the southwest Atlantic (Li *et al.* 2022). These changes, in turn, are causing shifts in the distribution of tropical fish species, with some adapting to the variability of the region, as recently reported for *Trachinotus carolinus* (Laporta *et al.* 2018, Laporta *et al.* 2022), *Orthopristis rubra* (Laporta *et al.* 2021a), *Elops smithi* (Machado *et al.* 2012, Vidal *et al.* 2021, Bovcon *et al.* 2022), while others species are not able to settle and develop stable populations. The events described in this article try to reflect what happens in this latter case, to species with a subtropical distribution, such as *P. paru*, which are able to survive in Uruguayan waters only during the warm seasons. However, during the cold seasons and the SST abruptly drops below 15°C within a few days after the onset of the extratropical cyclones, the individuals appear dead on the coast. The same pattern was observed in all years in which recently strandings occurred (2017, 2020, 2022 and 2023). It is difficult to predict what will happen in the future with the occurrence of *P. paru* in Uruguayan waters, but if the SST remains above 15°C during winter, it is possible that *P. paru* will be able to survive the round year and turn from to a resident species, as it has happened with the other fishes mentioned above. Nevertheless, it is not clear which environmental variables determine whether this species becomes a resident or an occasional visitor. We do not know, but citizen science could contribute to the long-term monitoring of such shifts in the distribution of these species and be one of the main drivers for documenting these phenomena in the context of global ocean warming.

Ethical statement

The present investigation did not involve regulated animals and did not require approval by an Ethical Committee

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