ATLANTIC PUFFIN *FRATERCULA ARCTICA* MORTALITY ALONG THE PORTUGUESE WEST COAST IN EARLY 2023

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ABSTRACT

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This study presents data about a mortality event involving Atlantic Puffins *Fratercula arctica* in the central region of Portugal, including information on the species' biometrics. More than 2,000 seabirds were collected from beaches between Lisbon and Matosinhos in January and February 2023, as casualties of a massive wreck. In total 444 Atlantic Puffins (171 live, 273 dead) were found and analysed. Leg bands on some birds indicated that these individuals primarily originated from colonies in Scotland. Of the live puffins that entered the Ecomare Marine Animal Rehabilitation Centre, only 18 survived to be successfully released. We conducted 426 post-mortem examinations and collected 271 individual photographs to analyse wing feather condition. Most of the birds were emaciated adult females, with significantly low-fat deposits, presumably having starved to death following extreme weather and ocean conditions. This study also revealed significant differences in wing length and bill depth among various age and sex categories, with adults having larger measurements than younger birds. Further long-term studies are necessary to assess the significance of mortality from this kind of extreme event on population levels.

Key words: biometrics, extreme weather, *Fratercula arctica*, puffin mortality, strandings, rehabilitation

INTRODUCTION

The Atlantic Puffin *Fratercula arctica* is an exclusively marine species found on rocky coasts and offshore islands across the North Atlantic Ocean (Nettleship et al., 2014). As a pursuit diver, the Atlantic Puffin catches most of its prey within 30 m of the water's surface, though it is capable of diving to depths of 60 m (Burger & Simpson, 1986; Piatt & Nettleship, 1985). During winter, it is widely distributed in pelagic habitats (Fayet et al., 2017). In mainland Portugal, it winters and migrates along the coast from October to early April (Catry et al., 2010; Meirinho et al., 2014). As a result, information about this species in Portugal is primarily based on beached bird surveys (Carvalho et al., 2024; Granadeiro & Silva, 1992; Granadeiro et al., 1997; Morley et al., 2016; Teixeira, 1985). According to the IUCN Red List of Threatened Species, the Atlantic Puffin has transitioned from being classified as Least Concern in 2012 to Vulnerable since 2015 (International Union for Conservation of Nature [IUCN], 2018). Major threats to the species include climate change (Dias et al., 2019; Durant et al., 2003; Harris et al., 2013; Melillo et al., 2014; Sandvik et al., 2005), bycatch (Rogan & Mackey, 2007; Tasker et al., 2000), pollution (Harris & Wanless, 2011), predation by introduced species (Barrett, 2015; Mitchell et al., 2004; Stempniewicz & Jensen, 2007), and reduced food availability (Breton & Diamond, 2014; Fumero-Hernández et al., 2023).

Stranding events involving pelagic seabirds such as the Atlantic Puffin provide valuable opportunities to assess mortality rates, population threats, and environmental stressors affecting species that are otherwise difficult to study at sea (Costa et al., 2019; Haman et al., 2013). Such events are often associated with extreme weather, which can cause massive mortality and, depending on their scale and frequency, may significantly impact seabird population demographics (Camphuysen et al., 1999; Clairbaux et al., 2021). The frequency and severity of marine weather events, an emergent consequence of global warming, have led to large-scale disruptions in marine ecosystems (Babcock et al., 2019).

Given that stranding events provide critical insights into the mortality and threats faced by pelagic seabirds, this study aims to present data on a mortality event involving Atlantic Puffins in the central region of Portugal. In so doing, we explore the possible causes of this wreck and use data from necropsies of the stranded birds to enhance reporting on species biometrics.

METHODS

During January and February 2023, over 2,000 seabirds of 20 different species were collected from beaches along the central coast of Portugal as casualties of a massive wreck (Oliveira et al., 2023). We thoroughly analysed 444 Atlantic Puffins (171 live and 273 dead birds) collected during this period. From the 171 live birds, 18 were released, 81 died within 24 hours of arrival, 39 died within 48 hours of arrival, 31 died within 30 days of arrival, and two were euthanized due to very poor prognosis of survival. Birds that died or were euthanized, as well as those collected dead on the

beach by volunteers and local authorities, were transported to the laboratory and frozen at −20 °C. Full post-mortem analyses were eventually performed on 426 individuals according to standard protocols (Work, 2000). Photographs of the beaks and flight feathers were taken for 271 randomly selected birds to confirm age and assess the moult status of the flight feathers.

Because some individuals were missing parts or were otherwise too disfigured to provide reliable data, we assessed each bird to the extent possible for several characteristics. The condition of the flight feathers was assigned to one of five categories according to Harris et al. (2014): old (extreme wear and bleached), new (unworn and shiny), new with slight wear (little wear, likely due to beach sand), worn (some wear and bleaching), and active moult (with growing feathers). Five causes of mortality were inferred according to Simpson & Fisher (2017), namely Confirmed drowning, Unconfirmed drowning, Polyisobutylene pollution, Oil pollution, and Storm wreck. During necropsies, subcutaneous fat, intestinal fat, and pectoral muscle were each scored on a four-point scale (0–3, where "0" indicates extreme emaciation and "3" indicates good body condition; see van Franeker (2004)). We measured exposed culmen (base of feathers to bill tip), bill depth (at base; maximum vertical measurement of the bill at the feather line), wing length (maximum flattened chord), and tarsus length (exposed leg bone between the tibiotarsal joint and the base of the toes). Body weight was recorded for only 163 live birds, due to the high levels of sand and water in dead birds, which would distort measurements. Age classification was based on the number of visible growth grooves on the beak (following Harris et al., 2014) and supplemented by standardized age terminology (Pyle, 2008). Individuals with no beak grooves were classified as first year (approximately 6 months of age), while birds exhibiting one fully formed groove (approximately 18 months) or a fully formed groove with an additional partial groove (1.5 grooves, approximately 30 months) were classified as second/third year. Adults were defined as individuals with two or more fully developed grooves, corresponding to after-third-year or definitive basic plumage (> 42 months of age).

Sex identification was successful in 394 individuals through clear identification of the gonads (ovaries/testes). To reduce possible measurement variation, one researcher conducted all biometric measurements as well as all external and internal assessments of the birds' plumage, state, and condition.

Statistical analyses were performed using IBM SPSS Statistics version 29.0 (IBM Corporation, 2016). Bill length, bill depth, wing length, tarsus length, and body weight were compared by sex within each age class using a *t*-test for unequal variances. Bill length, bill depth, wing length, and tarsus length were compared by age classes using a one-way ANOVA (followed by a Tukey–Kramer post hoc test). Body weight was compared by age classes using a *t*-test for unequal variances after checking for normality and homoscedasticity of distributions. The four exceptions to the parametric tests, *t*-test, and ANOVA were bill depth in males, which was analysed using the Kruskal-Wallis test; bill depth in first-year birds, which was analysed using the Mann-Whitney test; and both bill depth and wing length in adults, which were analysed using the Mann-Whitney test (Tables A1 to A5 in Appendix, available on the website).

RESULTS

Most of the birds inspected were adult females (Table 1). Among the 444 birds collected, seven adult birds were found with coded metal rings originating from four colonies in Scotland: Sule Skerry, Airighean a' Bhàigh, Carnach Mhor, and Garbh Eilean (data provided by the CEMPA[1] Bird Ringing Scheme).

Mean measurements by sex and statistical test results are shown in Tables 2, A1, and A2. In females, significant differences were observed among age categories in mean wing length, bill depth, and bill length, with adults having larger measurements than younger birds. No differences were noted in tarsus length or body weight. In males, significant differences were found in bill depth and bill length among age categories, with adults exhibiting larger bills compared to younger birds, while no differences were observed in wing length or tarsus length.

In the first-year age category, no significant differences between sexes were found in any measurements (Tables 3, A3). In the second/third-year category, significant differences in mean bill depth were noted, with males exhibiting larger bills (Tables 3, A4). In the adult category, significant differences were observed across all measurements, with males showing larger values (Tables 3, A5). Adult males were significantly heavier than adult females and second/third-year males (Tables 4, A1, A2).

Regarding the physical condition of the birds examined, 120 received a score of zero, 286 had a score of one, and only one bird received a score of two. Considering the overall condition index, in which scores of 0–1 indicate mortal emaciation, 2–3 indicate critical emaciation, 4–6 indicate moderate body condition, and 7–9 indicate good body condition (van Franeker, 2004), 99.8% of the analysed birds were classified as mortally emaciated. Most birds had empty stomachs, gastrointestinal ulceration, and atrophy of internal organs. A comparison of body weight at arrival between birds that did not survive rehabilitation and those that were released revealed significant differences ($t = -2.007$; $p < .05$), with the released birds averaging 12.5 g more at admission (Fig. 1). The 18 birds that survived rehabilitation and were successfully released showed an average weight difference of 99.1 g between arrival and release (Fig. 2). This represents an increase of more than 10% in body weight during their time in rehabilitation.

TABLE 1
Age and sex data from 444 stranded Atlantic Puffins *Fratercula arctica* collected from beaches located on the central west coast of Portugal between Lisbon and Matosinhos during January and February of 2023

Number of beak grooves	Total	Age grouping	Total	Female	Male	Undefined
0	34	1st year	34	4	7	23
1	27	2nd/3rd year	48	25	19	4
1.5	21					
2	177	adult	361	212	127	23
2.5	149					
3 or more	36					

[1] Centro de Estudos de Migração e Proteção de Aves, or Portugal's Centre for the Study of Migration and Protection of Birds

TABLE 2
Comparison of bill length, bill depth, wing length, and tarsus length by age category and sex for stranded Atlantic Puffins *Fratercula arctica* collected from beaches located on the central west coast of Portugal between Lisbon and Matosinhos during January and February of 2023. Values are given as mean ± standard deviation (sample size).

		1st year	2nd/3rd year	Adult	*df*	*F*[a]	*p*
Females	Bill length	36.85 ± 0.64 (4)	39.45 ± 1.46 (24)	40.03 ± 1.40 (211)	2	11.629	< .001
	Bill depth	23.58 ± 1.20 (4)	28.15 ± 1.64 (24)	29.49 ± 1.49 (211)	2	37.714	< .001
	Wing length	152.13 ± 3.47 (4)	157.88 ± 2.98 (25)	158.04 ± 3.59 (210)	2	5.519	.005
	Tarsus length	25.79 ± 0.92 (4)	26.51 ± 1.23 (25)	26.44 ± 1.02 (210)	2	0.844	.431
Males	Bill length	36.49 ± 2.98 (7)	40.21 ± 1.31 (19)	41.67 ± 1.96 (125)	2	26.580	< .001
	Bill depth	22.97 ± 4.59 (7)	29.89 ± 2.25 (19)	31.25 ± 1.50 (125)	2	32.109	< .001
	Wing length	153.79 ± 6.59 (7)	158.63 ± 3.32 (19)	160.97 ± 9.86 (124)	2	2.399	.094
	Tarsus length	26.75 ± 1.19 (7)	26.75 ± 0.96 (19)	27.20 ± 0.90 (125)	2	2.628	.076

[a] Analysed using a one-way ANOVA, except for male bill depth, which was analysed using the Kruskal-Wallis test

TABLE 3
Comparison of bill length, bill depth, wing length, and tarsus length between sex in each age category for stranded Atlantic Puffins *Fratercula arctica* collected from beaches located on the central west coast of Portugal between Lisbon and Matosinhos during January and February of 2023. Values are given as mean ± standard deviation (sample size).

		Female	Male	*df*	*t*[a]	*p*
1st year	Bill length	36.85 ± 0.64 (4)	36.49 ± 2.98 (7)	9	0.236	.819
	Bill depth	23.58 ± 1.20 (4)	22.97 ± 4.59 (7)	9	13.0	.927
	Wing length	152.13 ± 3.47 (4)	153.79 ± 6.59 (7)	9	−4.610	.656
	Tarsus length	25.79 ± 0.92 (4)	26.75 ± 1.19 (7)	9	−1.389	.198
2nd/3rd year	Bill length	39.45 ± 1.46 (24)	40.21 ± 1.31 (19)	41	−1.767	.085
	Bill depth	28.15 ± 1.64 (24)	29.89 ± 2.25 (19)	41	−2.947	.005
	Wing length	157.88 ± 2.98 (25)	158.63 ± 3.32 (19)	42	−0.789	.435
	Tarsus length	26.51 ± 1.23 (25)	26.75 ± 0.96 (19)	42	−0.693	.492
Adult	Bill length	40.03 ± 1.40 (211)	41.67 ± 1.96 (125)	334	−8.873	< .001
	Bill depth	29.49 ± 1.49 (211)	31.25 ± 1.50 (125)	334	21,167.5	< .001
	Wing length	158.04 ± 3.59 (210)	160.97 ± 9.86 (124)	332	16,918.0	< .001
	Tarsus length	26.44 ± 1.02 (210)	27.20 ± 0.90 (125)	333	−6.926	< .001

[a] Analysed using a *t*-test for unequal variances except for bill depth for first-year and adult birds, which were analysed using the Mann-Whitney test

TABLE 4
Comparison of body weight between age category by sex, and between sex in each age category, for stranded Atlantic Puffins *Fratercula arctica* collected from beaches located on the central west coast of Portugal between Lisbon and Matosinhos during January and February of 2023. Values are given as mean ± standard deviation (sample size).

	Female	Male	*df*	*t*[a]	*p*
2nd/3rd year	262.5 ± 22.5 (8)	255.0 ± 25.6 (8)	14	.622	.544
Adult	252.8 ± 21.8 (78)	275.4 ± 23.4 (46)	122	−5.457	< .001
	2nd/3rd year	**Adult**	***df***	***t***	***p***
Female	262.5 ± 22.5 (8)	252.8 ± 21.8 (78)	84	1.203	.232
Male	255.0 ± 25.6 (8)	275.4 ± 23.4 (46)	52	−2.253	.028

[a] Analysed using a *t*-test for unequal variances

Of the 271 individuals photographed to assess the moult status of the flight feathers (Fig. 3), 12 birds (11 adults, 1 second/third-year) were in active moult; 52 had old feathers (47 adults, 5 second/third-year); 30 had new feathers (19 adults, 4 second/third-year, 7 first-year); 68 had new feathers with slight wear (47 adults, 9 second/third-year, 12 first-year); and 109 had worn feathers (93 adults, 13 second/third-year, 3 first-year individuals).

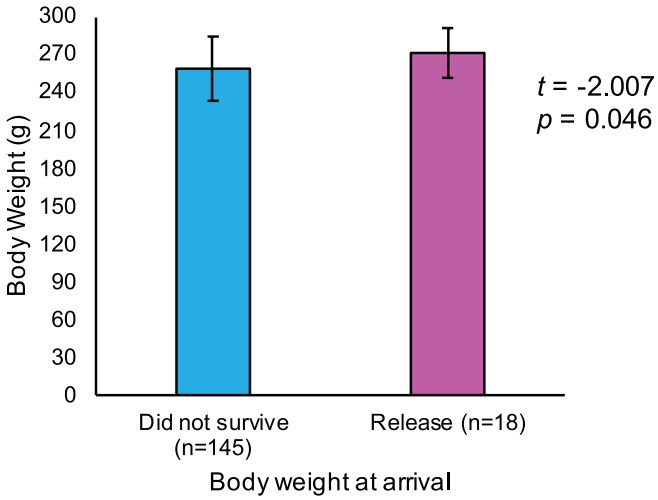

Fig. 1. Comparison of average body weights of stranded Atlantic Puffins *Fratercula arctica* upon arrival at the Ecomare Marine Animal Rehabilitation Centre in Aveiro, Portugal, during January and February of 2023. Results are grouped by survival through the rehabilitation process. The vertical line at the top of each bar graph indicates standard deviation.

DISCUSSION

This study presents data collected on Atlantic Puffins killed during a massive wreck that occurred in the central region of Portugal in early 2023. The analysis is based on over 400 puffins collected and brought to the Ecomare Marine Animal Rehabilitation Centre (Centro de Reabilitação de Animais Marinhos, CRAM) at the University of Aveiro in Portugal. Considering the immense North Sea wintering population of Atlantic Puffins (Stone et al., 1995) and the number of recurrent wreck events in that region (Harris et al., 2022), the fatalities from this wreck may initially appear insignificant. However, for the Portuguese coast, this number is unusually high. Long-term data from beached bird surveys conducted in 1982–1986 (Teixeira, 1985), 1990–1994 (Granadeiro & Silva, 1992; Granadeiro et al., 1997), 2014 (Morley et al., 2016), and 2020–2022 (Carvalho et al., 2024) report an average of ~14 (range: 0–45) Atlantic Puffins found dead annually. This average excludes exceptional seasons during 1984/85 (182 puffins) and 2014 (121 puffins).

In contrast, the current wreck was detected not only along the Portuguese coastline but also across the entire Iberian Peninsula and as far as the Canary Islands, where more than 200 additional Atlantic Puffins were collected (Suárez-Santana et al., 2025); we have no information for the North African coastline. Such a widespread event underscores the scale of the mortality. Furthermore, it is widely recognized that only a small fraction of birds that die at sea eventually wash ashore and are recovered, suggesting the actual death toll was likely much higher.

Importantly, a substantial proportion of the individuals examined in this study were adult females—a demographic cohort of high conservation value. In oil-spill mitigation frameworks and broader seabird conservation strategies, adult females are often prioritized due

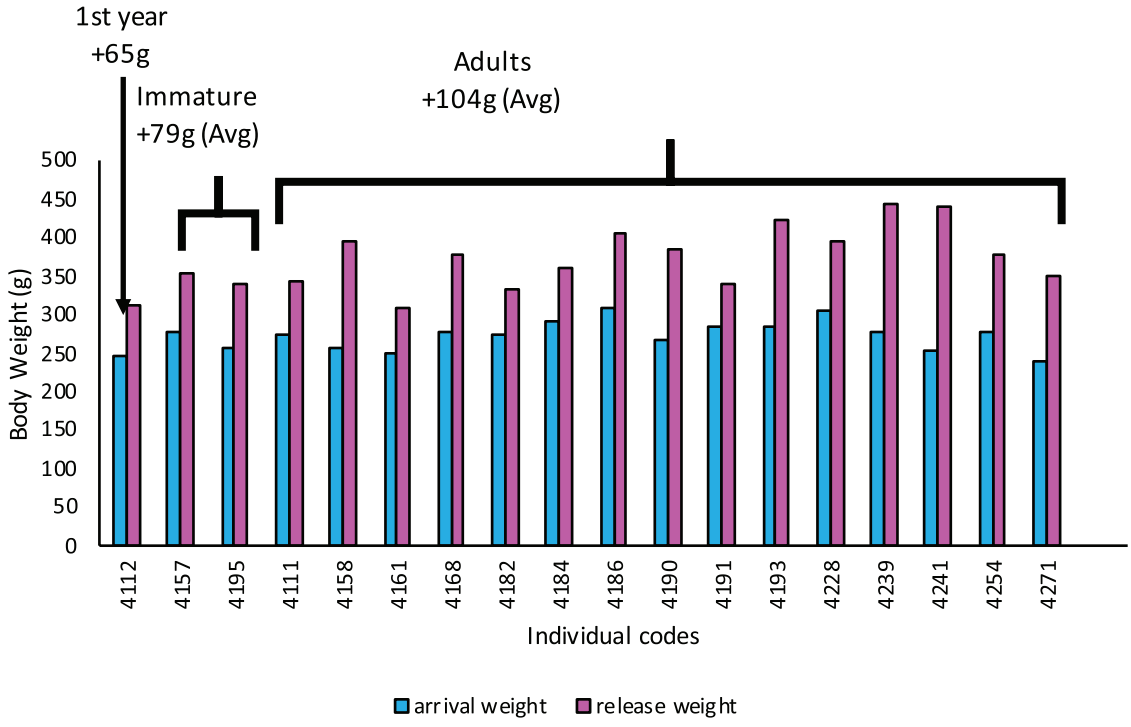

Fig. 2. Body weight comparisons for 18 stranded Atlantic Puffins *Fratercula arctica* upon arrival at (blue) and release from (pink) the Ecomare Marine Animal Rehabilitation Centre in Aveiro, Portugal, in early 2023.

Fig. 3. Examples of flight feather categories for adult Atlantic Puffins *Fratercula arctica* stranded during the wreck of 2023 around the Iberian Peninsula: 1a and 1b show active moult – growing feathers; 2a and 2b show new feathers – unworn and shiny; 3a and 3b show old feathers – extreme wear and bleached; 4a and 4b show worn feathers – some wear and bleach; 5a and 5b show new feathers with slight wear – likely due to beach sand.

to their reproductive role and limited replacement potential within populations (Barros et al., 2014). Therefore, despite the large overall population of Atlantic Puffins, the demographic and geographic context of this wreck highlights its potential ecological significance

The wreck reported herein coincided with unusually intense weather events affecting mainland Portugal in late December 2022 and January 2023, including several depressions that caused harsh conditions, low temperatures, rain, strong winds, and disturbances at sea (Agência Portuguesa do Ambiente, 2023; Instituto Português do Mar e da Atmosfera, 2023). Although the exact causes of wrecks are difficult to determine (Camphuysen et al., 1999; Anker-Nilssen et al., 2003), evidence collected during our necropsies—such as empty stomachs and atrophied internal organs—strongly suggest that the birds likely starved to death. Another indication of starvation is that the body weights of these Atlantic Puffins (260.9 ± 25.2 g) were well below the averages reported by Corkhill (1972; 397.8 g in males and 368.0 g in females) and by Harrison et al., (2021; 380 g). Also, the low body weights we recorded were similar to those found in necropsies of five emaciated Atlantic Puffins collected at the Ecomare CRAM in previous years (2018, 2021, and 2022; personal observation by RAC), with an average weight of 236 g.

Significant differences in body weight were also found between birds that did not survive rehabilitation and those that did, indicating that even small variations in weight can be critical for survival, particularly when individuals approach a physiological "non-return" threshold. This threshold represents the minimum body mass below which recovery becomes unlikely, making it a key prognostic indicator for rehabilitation success (Anker-Nilssen et al., 2003; Montesdeoca et al., 2017). In Anker-Nilssen et al., (2003), emaciated beached birds were found to be 29.1% lighter than the mean weights measured in early May in their colonies, illustrating how substantial weight loss compromises survival. Similar findings across seabird species highlight the importance of body condition as a predictor of survival (Bourgeon & Raclot, 2006; Perrins, 2014).

Maintaining a healthy body weight is crucial for adapting to and surviving in a fluctuating environment. Doing so in this era of rapid and intense climate change, with its increasingly frequent storms (Dias et al., 2019), is likely more difficult because food availability and the timing of food abundance are affected (Gaston et al. 2009), which in turn can reduce foraging efficiency (Clairbaux et al., 2021). Additionally, puffins with insufficient body weight may have weakened immune defenses, making them more susceptible to diseases, parasites, or environmental stressors (Visser et al., 2009).

Our analysis strongly suggests that most Atlantic Puffins we collected originated from breeding colonies in Scotland. Given that the wreck occurred during the wintering season, it is likely that the birds were

from different populations and colonies (Camphuysen et al., 1999; Fayet et al., 2017). This suggestion is supported by the recovery of seven rings from four Scottish colonies and by the average wing length measurements in all adult birds we assessed (males 161.0 ± 9.86 mm, females 158.0 ± 3.59 mm). These measurements are similar to those from colonies at Skomer (159.3 ± 0.23 mm), Isle of May (161.8 ± 0.14), St. Kilda (158.2 ± 0.19), and Hermaness (161.4 ± 0.28) (Harris, 1984; Camphuysen, 2003), but smaller than values from Norwegian breeding colonies (males 174.6 ± 1.45 mm, females 163.8 ± 1.91 mm; Anker-Nilssen et al., 2003).

In terms of species biometrics, our study has revealed significant differences in wing length and bill depth among various age and sex categories, with adults having larger measurements than younger birds. This was consistent with findings by Pyle (2008) and Anker-Nilssen et al. (2017), who found males to exhibit larger measurements than females, and adults to exhibit larger measurements than first-year birds.

Most of the birds assessed exhibited worn and slightly worn flight feathers, indicating that their foraging capacity was likely not directly affected. This suggests that feather condition did not play a role in the wreck. However, it is important to note that the flight and diving abilities of Atlantic Puffins can be severely impaired during the growth of their primary wing feathers (Anker-Nilssen et al., 2017). It remains challenging to assess how long these birds were affected by adverse weather and/or poor food availability, complicating the identification of the actual cause of starvation.

Due to the issues related to avian flu in recent times, several of the stranded puffins were tested for avian flu, all of which returned negative results (Oliveira et al., 2023). Further analyses to determine if the birds had accumulated abnormal levels of contaminants or had underlying diseases could help to discern whether hazardous-compound intake could be a contributing factor to the incident, exacerbated by the physiological stress from severe weather conditions. However, the fact that over 2,000 seabirds of 20 different species stranded in the same period and area point to an acute overarching phenomenon affecting many seabird species at sea. Additionally, a higher-than-usual number of Loggerhead Turtle *Caretta caretta* strandings were registered during the same period and in the same coastal area at the Ecomare CRAM (personal observations by CRAM staff), corroborating the idea that this wreck was caused by an intense weather event. Similar mass stranding events were also reported across other regions of the Iberian Peninsula and beyond, including the Canary Islands, indicating a widespread impact likely linked to adverse environmental conditions (Suárez-Santana et al., 2025).

The birds washed up on the beach may not represent the total number of affected birds, as not all animals can reach the shore or be detected. For example, Anker-Nilssen et al., (2003) estimated that beached birds in Norway accounted for only 30% of the total number of affected birds. Given that the Atlantic Puffin is classified as Vulnerable on the IUCN Red List of Threatened Species (IUCN, 2018), further long-term studies on a larger spatial scale are essential to assess the impact of such extreme events at the population level. The samples collected in this study provide a valuable foundation for future research, and data from the 18 ringed Atlantic Puffins released from the rehabilitation centre could be pivotal in understanding the long-term implications of this event on population dynamics. Additionally, the randomness of such events underscores the importance of regular beach surveys (Granadeiro & Silva, 1992; Granadeiro et al., 1997; Jones et al., 2018; Piatt et al., 2020; Jones et al., 2024), as consistent, long-term, standardised beached bird surveys offer the best evidence to assess the magnitude of wrecks (Harris et al., 2022).

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COMPETING INTERESTS

The authors declare that they have no competing interests.

ETHICS APPROVAL

This study was conducted in accordance with all applicable laws and rules dictated by the Portuguese Government and all licenses granted by ICNF. The present work involves handling stranded live and dead animals. All technicians involved in this work have a licence to capture, handle, transport, mark, and collect samples of wild fauna specimens in mainland Portugal under the terms of decree-law no. 140/99 of 24 April, with the new wording given by decree-law no. 49/2005 of 24 February, as amended by decree-law no. 156-a/2013 of 08 November, and decree-law no. 316/89, of 20 November law no. 316/89, of 22 September. These licences are issued by the ICNF. Live animals were admitted to Ecomare CRAM (licence nº 2017 PT 11/CR) from the National Network of Fauna Rehabilitation Centres, under the terms of the Ordinance 112/2009, of 28 September.

CONSENT FOR PUBLICATION

All authors read and approved the final manuscript.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and analysed during the current study are available from the Ecomare CRAM (cram@cram.org.pt) on reasonable request.

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