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RESEARCH

Four unusual mortality events of seabirds in the Patagonian Sea, 2000–2006: species affected and possible causes

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Abstract

The Patagonian Sea is a highly productive marine ecosystem and a hotspot for seabird diversity and density in the Southwest Atlantic Ocean. Reports of unusual mortality events are relatively scarce in this region, likely due to under detection and investigation. In this study, we report on four unusual mortality events affecting seabirds in the Patagonian Sea from 2000 to 2006. Events 1 and 2 occurred at Golfo Nuevo and Chubut coast, Argentina in September–December 2000, affecting at least 4550 seabirds, mainly Magellanic penguins (*Spheniscus magellanicus*). Event 3 occurred at the Falkland/Malvinas Islands during December 2002–January 2003, affecting at least 3500 seabirds, mainly gentoo penguins (*Pygoscelis papua*). Event 4 occurred at Punta Loma and Punta León, Argentina, in November 2006, affecting at least 57 seabirds, mainly kelp gulls (*Larus dominicanus*). The aetiology of Events 1 and 2 could not be determined, but malnutrition/starvation and paralytic shellfish poisoning, respectively, were identified as potential causes. Pathological findings and toxicological testing supported paralytic shellfish poisoning as the cause of Events 3 and 4. Our results illustrate how identifying the occurrence, cause and extent of unusual mortality events affecting seabirds can present significant challenges. Moreover, our investigations of the events display variations in timeliness and completeness, and our lack of certainty on aetiology reflects the shortcomings often faced in remote locations and low resource settings. Technological advances, such as smartphones, increased public awareness and connectivity, coupled with more and better equipped protected areas and diagnostic laboratories will likely aid in overcoming difficulties from past decades.

Keywords Die-off · Paralytic shellfish poisoning · South America · Southwest Atlantic Ocean · Starvation · Wreck

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Introduction

The Patagonian Sea is an oceanic ecosystem of the Southwest Atlantic Ocean (Fig. 1), comprising coastal and pelagic waters off southern Brazil, Uruguay, Argentina, the Falkland/Malvinas Islands and southern Chile (Falabella et al. 2009). This region is characterized by the interaction of the northbound cold waters of the Malvinas Current, the southbound warm waters of the Brazil Current, and the discharge of nutrient-rich waters by the La Plata River, creating a highly productive marine ecosystem (Piola et al. 2001, 2005). Consequently, the Patagonian Sea is a hotspot for seabird, pinniped and cetacean diversity and density (Falabella et al. 2009; Tittensor et al. 2010). The avian community of the Patagonian Sea comprises both coastal and pelagic species, including penguins, albatrosses, gulls, cormorants, terns, giant petrels, skuas, among others (Yorio et al. 1998; Falabella et al. 2009; Augé et al. 2018; Favero et al. 2024).

Unusual mortality events (UMEs) are infrequent demographic occurrences where an atypical number of individuals die within a short period (Gulland 2006; Fey et al. 2015). Depending on the geographic scale and proportion of the species population affected, UMEs can pose a threat to wildlife conservation (Mangel and Tier 1994; Fey et al. 2015), particularly when they impact populations already exhibiting declining trends and facing high environmental variability (Jones et al. 2018, 2019, 2023; Piatt et al. 2020; Nur et al. 2021). Certain taxa, such as seabirds, have experienced an escalation in both the magnitude and frequency of UMEs in recent decades, notably attributed to a diversity of factors, such as interactions with fisheries, shifts in prey availability (at times resulting from climate change), infectious disease, biotoxicity (e.g. harmful algal blooms) and marine heatwaves (Žydelis et al. 2013; Fey et al. 2015; Crawford et al. 2017; Jones et al. 2018, 2019, 2023; Piatt et al. 2020; Kaler et al. 2022).

Seabird UMEs have been sporadically documented in the Patagonian Sea (Boersma 1987; Shumway et al. 2003; Morgenthaler et al. 2018; Holt and Boersma 2022; Quintana et al. 2022; Cadaillon et al. 2024). However, it is possible that the relative scarcity of reports in this vast coastline, particularly in the early 2000s, is not reflective of a true low frequency of UMEs but rather responds to a low detection probability due to scarce and patchy human presence. In this study, we report on four seabird UMEs we investigated in the Patagonian Sea from 2000 to 2006, encompassing three events in Chubut, Argentina and one in the Falkland/Malvinas Islands. We discuss difficulties faced in investigations and offer recommendations for improvement based on lessons learned.

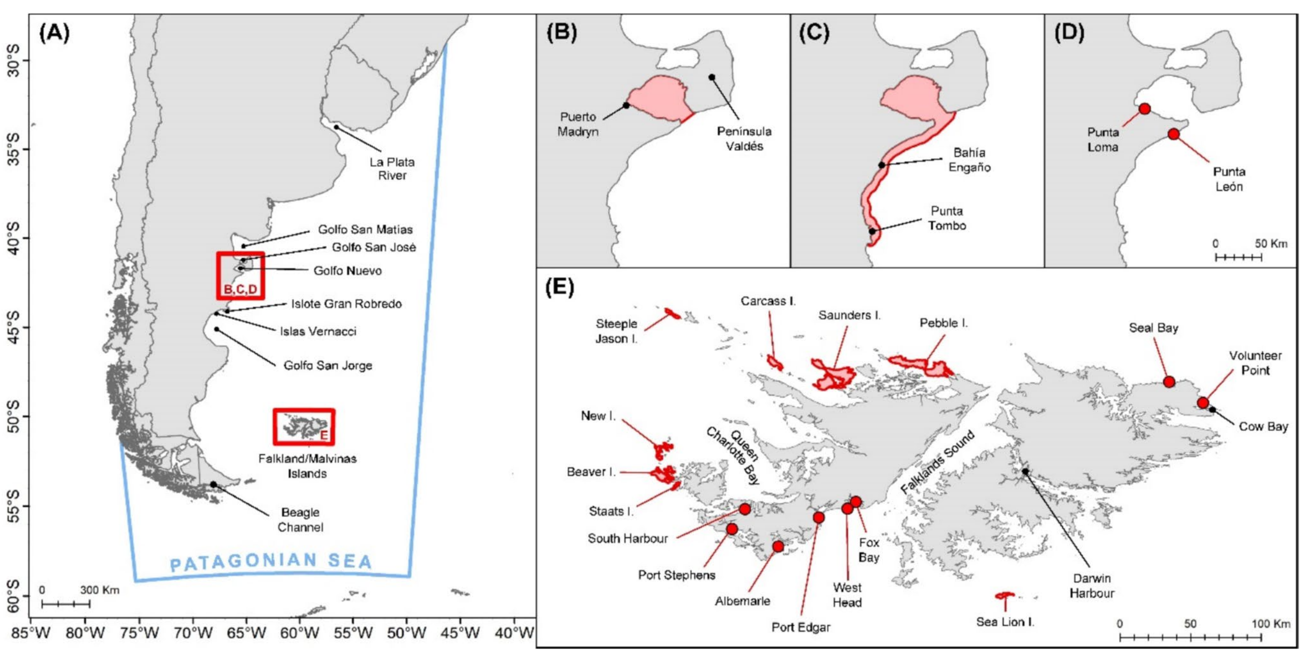

Fig. 1 Maps of the Patagonian Sea, showing the study sites (red areas and points) and other locations mentioned in text. Legend: **A** overview of the Patagonian Sea; **B** Event 1 (September and October 2000); **C** Event 2 (November and December 2000); **D** Event 4 (November 2006), **E** Event 3 (December 2002 and January 2003)

Methods

Our investigations of mortality events were triggered by reports of moribund or deceased seabirds from local residents, which prompted us to conduct targeted beach surveys (by foot) to locate affected birds and carcasses for examination. For Event 1, we conducted surveys on 30 km of beaches near Puerto Madryn (2 October 2000) and an additional 100 km of beaches along the margins of Golfo Nuevo (8 to 11 October 2000; see Fig. 1A and B). For Event 2, we surveyed approximately 80 km of beach from Golfo Nuevo to a few km south of Punta Tombo (28 November to 6 December 2000; see Fig. 1C). For Event 3, residents collected and froze carcasses at New Island (5 December 2002), Volunteer Point (5 December 2022, 11 December 2002, and 20 December 2002), Fox Bay (14 December 2002) and we visited Steeple Jason Island (6 January 2003) and Saunders Island (8 January 2003). Additionally, local researchers and residents at the following locations were contacted by telephone to gather information regarding Event 3: Volunteer Point, New Island, West Point, Staats Island, Beaver Island, Fox Bay, West Heads, Port Edgar, Albemarle, Port Stephens, South Harbour, Sea Lion Island, Carcass Island, Steeple Jason Island, Pebble Island, Saunders Island, Bleaker Island, George Island, Barren Island, Lively Island, Speedwell Island, West Point Island and Seal Bay (see Fig. 1E). For Event 4, we visited the seabird colonies at Punta Loma (16 November 2006) and Punta León (22 November 2006) (see Fig. 1D). Species and age class were determined on the basis of external characteristics (Pearman and Areta 2020).

The preservation condition of field-collected carcasses was assessed based on *rigor mortis*, skin and muscle integrity and visceral coloration and consistency, and carcasses in best preservation condition (scores 2 or 3 sensu Geraci and Lounsbury 1993) were necropsied by veterinarians following standard procedures (Hocken 2002; Munson 2007). Carcasses were weighted using a spring scale (precision = 25 g). Body condition was assessed using a five-level scale (cachectic, poor, fair, good, and excellent) based on pectoral muscles palpation (Hurtado et al. 2020). Stomach contents were visually inspected during necropsy, and food items and parasites were identified by macroscopic examination. Sex was determined through the dissection of gonads. Tissue samples (listed in Supplementary File S1) were preserved in 10% buffered formalin, processed following routine histological methods (Prophet et al. 1992), and hematoxylin–eosin-stained slides were examined under light microscopy. Histopathological findings were considered consistent when observed in ≥ 50% of the individuals for each tissue type. Ancillary histochemical stains such as periodic-acid Schiff for fungi and Prussian blue for hemosiderin were used as needed (Prophet et al. 1992).

In addition, tissues from the birds, including stomach, intestine, liver, kidney, and brain samples, were collected in separate containers and immediately frozen. They were later individually analysed with high-performance liquid chromatography to detect and quantify biotoxins, including domoic acid (DA) and several paralytic shellfish poisoning (PSP) toxins: saxitoxin (STX), neosaxitoxin (NeoSTX) and gonyautoxins 1 to 4 (GTX1–4). Samples collected in Argentina were analysed following Oshima (1995) for PSP toxin detection and Wright and Quilliam (1995) for DA detection. Samples collected at the Falkland/Malvinas Islands were analysed for PSP toxin detection following Franco and Fernández-Vila (1993). To discard false positive results due to fluorescing contaminants, an additional analysis was conducted omitting the oxidizing agent in the post-column derivatization (Montoya et al. 2006). Toxin standards were acquired from the Canadian National Research Council.

Daily meteorological data for Puerto Madryn airport (42° 45′ 20″ S 65° 06′ 00″ W) were obtained from Servicio Meteorológico Nacional. The mean and standard deviation of the mean temperature, precipitation and mean wind speed were calculated for each event (Event 1: 30 September–1 October 2000; Event 2: 27 November–6 December 2000; Event 4: 16–22 November 2006).

Results

The events described here spanned a seven-year period (2000 to 2006, inclusive) and occurred on the coast of Chubut province, Argentina, and the Falkland/Malvinas Islands (Fig. 1). The events are presented chronologically. Table 1 outlines basic information about these events, and Supplementary File S1 offers a comprehensive summary of the clinical, necropsy and laboratory findings.

Event 1 – Golfo Nuevo, Argentina (September–October 2000)

Residents reported finding seabird carcasses on the beaches of Puerto Madryn during the weekend of 30 September and 1 October 2000, coinciding with a windstorm featuring strong southeasterly gusts (M. Uhart, subj. obs.); unfortunately there are no data available for the Puerto Madryn meteorological station in this period, possibly due to the storm. Following these reports, a total of 1042 seabird carcasses were counted in targeted surveys of the beaches near Puerto Madryn (2 October 2000) and along the Golfo Nuevo coastline (8 to 11 October 2000) (Fig. 1B), comprising Magellanic penguins (*Spheniscus magellanicus*, 58%; of which 57% were juveniles and 43% adults), South American terns (*Sterna hirundinacea*, 17%; mostly adults), imperial shags (*Leucocarbo atriceps*, 11%; mostly adults), great

Table 1 Summary of the unusual mortality events reported in this study

Event	Location	Period	Death toll	Species affected	Proposed aetiology
1	Golfo Nuevo, Argentina	September–October 2000	At least 1050 individuals	Mainly Magellanic penguins (*c.* 60%), but also South American terns, imperial shags, great grebes and other species	Undetermined
2	Golfo Nuevo and Chubut coast, Argentina	November–December 2000	At least 3500 individuals	Mainly Magellanic penguins (*c.* 95%), but also great grebes, South American terns and kelp gulls	Undetermined
3	Falkland/Malvinas Islands	December 2002–January 2003	At least 3500 individuals, but potentially as high as 100,000 individuals	Mainly gentoo penguins (*c.* 70%), but also imperial shags, Magellanic penguins, prions, black-browed albatrosses, southern rockhopper penguins and other species	Paralytic shellfish poisoning
4	Punta Loma and Punta León, Argentina	November 2006	At least 57 individuals	Mainly kelp gulls (*c.* 98%), but also royal terns	Paralytic shellfish poisoning

grebes (*Podiceps major*, 8%) and birds of other species (6%) including southern giant petrels (*Macronectes giganteus*), kelp gulls (*Larus dominicanus*), rock shags (*Leucocarbo magellanicus*), southern fulmars (*Fulmarus glacialoides*), prions (*Pachyptila* sp.), storm petrels (Oceanitidae sp.), shearwaters (*Ardenna* sp. or *Puffinus* sp.), a king penguin (*Aptenodytes patagonicus*) and other individuals of unidentified species. Based on the partial or advanced decomposition of the carcasses and the absence of larvae of terrestrial insects or consumption by terrestrial scavengers, it seems probable that the deaths occurred offshore during the preceding week and the carcasses washed ashore due to the storm.

All birds were found deceased, and therefore, no information about *ante-mortem* clinical signs is available. Carcasses varied considerably in their condition of decomposition, with the majority being heavily degraded. Seventy-four carcasses were collected in the field, of which only 18 were considered sufficiently fresh for necropsy (12 Magellanic penguins, five great grebes, one prion). Examined carcasses were in very poor (83%) or poor body condition (17%). Body mass was measured for some Magellanic penguins (mean $\pm$ SD $= 2163 \pm 190$ g, $n = 6$) and great grebes (723 ± 25 g, $n = 3$). All examined carcasses had empty stomachs containing a small quantity of dark mucous liquid (penguins) or feathers and green mucous liquid (grebes and prion), suggesting starvation. Nematodes (macroscopically consistent with *Contracaecum* sp.) were present in the stomach (and at times also in the oesophagus and duodenum) of most penguins (83%). In most examined carcasses (67%), kidneys were pale and drained a yellow liquid when cut; many of these carcasses also showed randomly distributed petechial haemorrhage on the kidney cortex (42%). Reddened lungs with a foamy-oedematous pleura and draining white foam when cut were also frequent findings (50%), suggesting drowning. Other less frequent findings included multifocal pale spots in the ventricular epicardium (25%), hydropericardium (17%), congestive brain vessels (17%) and multifocal white spots on the air sacs (17%).

Tissue samples from four individuals (three great grebes, one prion) were submitted for histopathology. Consistent histopathological findings included diffuse lung congestion (3/4 individuals for which lung samples were examined), multifocal lymphoplasmacytic gastritis (3/4) and liver hemosiderosis (3/4). Other notable findings, recorded in one great grebe each (different individuals), included stomach parasites (macroscopically consistent with *Tetrameres* sp.), muscular protozoal cysts (macroscopically consistent with *Sarcocystis* sp. cysts) and chronic airsacculitis with multiorgan lymphoplasmacytic vasculitis.

Stomach content samples from 20 individuals (11 Magellanic penguins, three southern giant petrels, three great grebes, one rock shag, one king penguin, one shearwater) and intestine samples from six of these individuals (three southern giant petrels, one great grebe, one rock shag, one shearwater) were submitted for biotoxin analyses. None of the samples had detectable levels of DA or PSP toxins. However, samples for toxicological testing were heavily decomposed when found and their preservation was suboptimal due to logistical contingencies (an unreliable field base freezer was suspected to have thawed and refrozen these samples multiple times).

Event 2 – Golfo Nuevo and Chubut coast, Argentina (November–December 2000)

Residents along the coast of Chubut province, especially near the cities of Puerto Madryn and Rawson, reported an unusual number of carcasses washing ashore starting 27 November 2000. Weather conditions at the time were relatively warm, dry and without strong winds (mean temperature 21.5 $\pm$4.7 °C, daily precipitation 0 mm, mean wind speed 7.4 $\pm$1.5 m/s). We surveyed 80 km of coastline (Fig. 1C) and counted approximately 3,500 seabird carcasses. Magellanic penguins were by far the most affected, accounting for 95% of the carcasses (3,399 individuals, mostly adults), the remaining carcasses comprised great grebes, South American terns, kelp gulls and other birds of unidentified species. Because many carcasses (especially Magellanic penguins) were seen afloat in the region, the death toll is believed to have been substantially greater. A few Magellanic penguins and kelp gulls were still alive when found ashore and showed signs of disorientation, lack of connection with their surroundings, refusal to move, eat or drink and some were comatose. Two birds (a Magellanic penguin and a kelp gull) were transferred to a rehabilitation facility but died shortly after arrival.

Nineteen carcasses were collected near Puerto Madryn (17 Magellanic penguins, one great grebe, one South American tern), in addition to the carcasses of the two birds that died in rehabilitation. All necropsied individuals did not have fresh food items in their stomach (either empty or small quantities of squid beaks or algae), and yet most were in fair or good body condition.

Tissue samples from three Magellanic penguins were submitted for histopathology. Consistent histopathological findings included spleen congestion (3/3 individuals for which spleen samples were examined), liver congestion (3/3), multifocal perivascular mononuclear hepatitis (3/3), diffuse mononuclear enteritis (3/3), diffuse mixed ulcerative esophagitis (2/2), kidney congestion and glomerular atrophy (2/3) and lung multifocal haemorrhages (2/3). Brain samples were opportunistically collected from additional Magellanic penguins, revealing multifocal congestion (4/6) and focal gliosis (2/6).

Stomach content samples from 10 individuals (eight Magellanic penguins, one great grebe, one kelp gull) and liver samples from 14 individuals (11 Magellanic penguins, one great grebe, one kelp gull, one South American tern) were tested and found to be negative for DA. No samples were tested for PSP toxins.

Data from Magellanic penguins at Punta Tombo suggested that breeding success in 2000/2001 was exceptionally low (5%) and that foraging trips were unusually long and extended further than usual (up to 600 km) during the same period, suggesting a local shortage of prey (D. Boersma, pers. comm.). No mortality or abnormalities were noted during field visits to other sites further south such as the breeding colonies of imperial and rock shags at Islas Vernacci on 27 November to 2 December 2000, southern giant petrels and imperial shags at Islote Gran Robredo, and of imperial and rock shags at Islas Vernacci on 11 to 15 January 2001 (see Fig. 1A).

Event 3 – Falkland/Malvinas Islands (December 2002–January 2003)

Starting early December 2002, residents at various sites along the Falkland/Malvinas Islands reported sick or deceased seabirds. Based on information gathered through field visits and telephone interviews, a minimum of 3,500 seabirds were reported deceased (Table 2). The outer southwestern, northwestern and northeastern parts of the archipelago appear to have been most affected, although this could be influenced by sampling bias due to lower human population density in other regions (e.g. southeast). Gentoo penguins (*Pygoscelis papua*) were the most affected species observed. Additionally, imperial shags, Magellanic penguins, prions, black-browed albatrosses (*Thalassarche melanophris*), southern rockhopper penguins (*Eudyptes chrysocome*), kelp gulls, diving petrels (*Pelecanoides* sp.) and steamer ducks (*Tachyeres* sp.) were also affected. Affected gentoo penguins displayed clinical signs such as disorientation, weakness, inability to stand and walk, lack of coordination and some showed leg paralysis, resorting to belly crawling for movement (Fig. 2; video footage is provided in Supplementary File S2). In one instance, a striated caracara (*Phalcoboenus australis*) was witnessed attacking an affected gentoo penguin.

Necropsies were conducted on 11 birds: five gentoo penguins that were found ill and euthanized (three from Saunders Island, one from Steeple Jason Island, one from an unrecorded location), four gentoo penguins found deceased (three from Sea Lion Island, one from Fox Bay) and two Magellanic penguins found deceased (from Volunteer Point). The distribution by body condition was 55% good and 45% poor, and the sex distribution was 55% female and 45% male. The stomach of examined birds did not contain parasites and were either empty or contained small amounts of lobster krill (*Grimothea gregaria*; recorded in three gentoo penguins). One gentoo penguin had seaweed-like green material in its stomach. No necropsy findings were consistently observed. One gentoo penguin had multifocal hepatic cysts (3 to 6 mL, filled with pale brown exudate), and another had petechial haemorrhages on the spleen surface. The remaining penguins did not exhibit significant necropsy lesions.

Table 2 Field observations and resident reports of mortality of seabirds in the Falkland/Malvinas Islands during the summer of 2002/2003 (Event 3)

Location	Period reported	Species affected (number of individuals)	Other remarks
Albemarle	December 2002	Gentoo penguins	
Beaver Island	21–29 December 2002	Prions (40), Magellanic penguins (7), southern rockhopper penguin (6), gentoo penguins (5), black-browed albatross (4), steamer duck (1)	By 29 December 2002, all nests failed at the gentoo penguin colony of 3,000 pairs
Carcass Island	11 December 2002–early January 2003	Gentoo penguins (370 deceased, 350 apparently ill), Magellanic penguins ("many"), black-browed albatrosses, prions	Gentoo and Magellanic penguin colonies were reportedly normal in September 2002, but were "greatly reduced" by December 2002
Falklands Sound	28 December 2002	Gentoo penguins ("few")	Most gentoo penguins appeared healthy, however "a few" moribund individuals were seen at beaches and "a few" carcasses were seen afloat
Fox Bay	30 November–mid December 2002	Gentoo penguins (*c.* 500), imperial shags (*c.* 500), kelp gulls	By 17 December 2002, only 50 nests remained occupied at the local gentoo penguin colony of 2,600 pairs
New Island	Late November–late December 2002	Gentoo penguins ("thousands"), Magellanic penguins ("occasional"), kelp gulls, prions, diving petrels, black-browed albatrosses	By 28 December 2002, only one nest remained occupied at the gentoo penguin colony of 5,000 pairs
Pebble Island	December 2002	Gentoo penguins (< 50), Magellanic penguins (< 50)	There was no evidence of large-scale mortality of gentoo, Magellanic and southern rockhopper penguins
Port Edgar	December 2002	Gentoo penguins (150–200)	
Port Stephens	17–31 December 2002	Gentoo penguins (*c.* 50), prions (50)	Gentoo penguin colonies were "much reduced", with many birds only on one egg or not incubating, but standing around the colonies
Saunders Island	September–December 2002	Gentoo penguins ("most affected")	Moribund or deceased seabirds were seen in a constant flow starting as early as September 2002
Sea Lion Island	7–19 December 2002	Gentoo penguins (20), Magellanic penguin (1), steamer duck (1)	
Seal Bay	December 2002	Magellanic penguins ("few")	Southern rockhopper penguins apparently were not affected
South Harbour	December 2002	Magellanic penguins ("most of 73 penguins"), gentoo penguins ("some")	
Staats Island	19 December 2002	Gentoo penguins ("lots"), prions ("lots")	
Steeple Jason Island	January 2003	Black-browed albatrosses (44), gentoo penguins (1)	By mid-April 2003, only 268 nests still had chicks at the black-browed albatross colony of 1,056 pairs. Also, all nests at the gentoo penguin colony reportedly failed during the 2002/2003 breeding season
Volunteer Point	November–late December 2002	Magellanic penguins (64), gentoo penguins (1)	
West Heads	16 December 2002	Gentoo penguins (> 70)	By 19 December 2002, only 15 nests remained occupied at the gentoo penguin colony of 4,000 pairs. It was noted that predators and scavengers did not feed on penguin eggs and carcasses

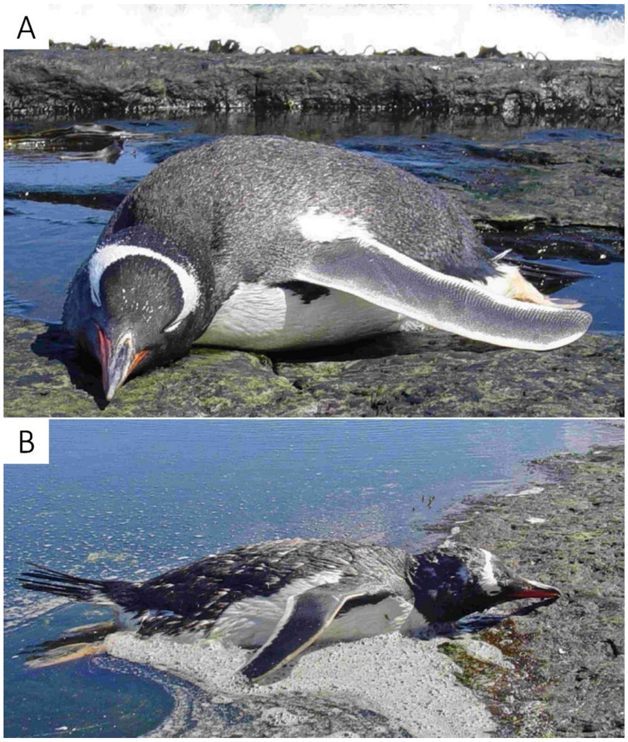

Fig. 2 Gentoo penguins (*Pygoscelis papua*) showing neurological signs (lethargy, disorientation, difficulty to stand and walk, and lack of coordination) during the unusual mortality event at the Falkland/Malvinas Islands (Event 3). Photo credits: Falklands Conservation/Wildlife Conservation Society

Histopathology of birds found ill (four gentoo penguins) or deceased (five gentoo penguins, one Magellanic penguin) did not reveal microscopic changes that could be considered unequivocally indicative of acute intoxication. Most birds exhibited older inflammatory reactions in the liver, such as periportal infiltrates of eosinophils, heterophils and other leukocytes. Areas of hepatic fibrosis were observed in one bird. Hemosiderosis was present in the liver of seven birds. Liver parenchyma appeared normal without signs of necrosis, reactive changes or inclusion bodies. In the intestines, older inflammatory reactions were noted, with degeneration of crypts and epithelium, along with leukocyte infiltrations. Lungs exhibited varying levels of congestion. Spleens were active, some with hyperplasia, but no necrosis was observed. No histological lesions were detected in the brains, meninges, hearts, or kidneys.

PSP toxins were detected in tissue samples from 80% of gentoo penguins found deceased (4/5), from 75% of gentoo penguins found ill and euthanized (3/4), but not from two Magellanic penguins found deceased. All but one of the toxin-positive individuals had high levels of PSP toxins (levels above those considered unsafe for humans: 80 µg STX equivalent per 100 g) in at least one of the tissue samples tested, with toxins levels ranging from 20 to 262 µg STX equivalent per 100 g depending on the organ analysed (File S1). NeoSTX (range = 47 to 262 µg STX equivalent per 100 g) and GTX4 (20 to 27 µg STX equivalent per 100 g) were detected at the highest concentrations, but low or trace levels of GTX1, GTX2, GTX3 and STX were also detected. The tissues from which high toxin levels (≥ 80 µg STX equivalent per 100 g) were recovered were intestinal contents or wall (80% of tested samples), followed by liver (45%) and stomach content or stomach wall (33%). Assuming that all birds had ingested similar levels of toxins, samples collected from euthanized or dying penguins proved to be better for toxin detection (i.e. greater proportion of positive tissues, higher toxin concentrations) than from those found deceased, even if the latter appeared freshly deceased.

Coinciding with the mortality event, bright red water discoloration was observed during flights over Queen Charlotte Bay on 21 December 2002 (T. Charter, pers. comm.). From November onwards, local authorities deemed that mussels from aquaculture farms at Darwin Harbour were unsafe for consumption due to the presence of PSP toxins.

Event 4 – Punta León and Punta Loma, Argentina (November 2006)

Field biologists working at the Punta Loma and Punta León seabird colonies reported an unusual number of sick and deceased seabirds in November 2006. Weather conditions at the time were relatively cold, dry and without strong winds (mean temperature 16.9 ± 2.6 °C, daily precipitation 0.3 ± 0.8 mm, mean wind speed 6.0 ± 1.8 m/s). Field visits to both sites confirmed that at least seven kelp gulls (four moribund, three deceased) were affected at Punta Loma, and 49 kelp gulls (six moribund, 43 deceased) and one royal tern (*Thalasseus maximus*; deceased) were affected at Punta León. Affected kelp gulls were found on the ground of the gull colony, lying on their back or sitting as if incubating (but not at a nest) with the wings slightly open to the sides. They were unable to move when approached, as if paralysed, and did not flap their wings or stand. Their pericloacal feathers were stained with greenish faecal material, suggesting recent diarrhoea.

Necropsies were conducted on six kelp gulls (two females from Punta Loma, three males and one female from Punta León) that were found agonal in the field and euthanized, along with the royal tern (female) found deceased at Punta León. All necropsied individuals had empty stomachs but varied in body condition (four kelp gulls in poor body condition, the royal tern and two kelp gulls in good body condition). Their intestines were also predominantly empty, containing parasites and mucus, with reddening of the intestinal walls. Two kelp gulls from Punta León also showed spleen enlargement and heart dilation. One kelp gull from Punta

Loma had subcutaneous oedema over the skull, suggesting aggression by other kelp gulls.

Histopathology was conducted on all birds that underwent necropsy. Among the kelp gulls, consistent histopathological findings included lung congestion (5/5 individuals for which lung samples were examined), mixed to lymphoplasmacytic multifocal hepatitis (4/5), and systemic trematode infection (3/5). Other notable findings comprised multiorgan amyloid deposition (2/5), anthracosis (2/5), multifocal granulomatous or diffuse histiocytic steatitis (2/5) and multifocal hepatocellular degeneration with eosinophilic inclusions combined with multifocal granulomatous coelomitis and serositis (1/5). Only one kelp gull showed lesions in the central nervous system, presenting with minimal focal lymphocytic perivascular cuffing associated with a trematode cysts (in association with a systemic trematode infection). The royal tern exhibited a few significant findings: moderate multifocal to coalescing lymphohistiocytic steatitis, intratubular trematodes and eggs in the peripelvic region of the kidneys and a local fibrin thrombus within a venule in the pelvic region.

GTX4 was detected in stomach, intestine, liver and kidney samples from four individuals (two kelp gulls from Punta Loma, one kelp gull and one royal tern from Punta León) with levels ranging from 4 to 25 µg STX equivalent per 100 g. Additionally, trace levels of STX were also detected in the liver and kidney samples from the royal tern. Stomach, intestine, liver, kidney and brain samples from one kelp gull from Punta León were tested and found to be negative for DA.

During the same period, routine monitoring by the Fisheries Secretariat of Chubut province reported above-threshold levels of saxitoxin-group compounds (> 80 µg STX equivalent per 100 g) in bivalves at Golfo San José, Golfo Nuevo and Golfo San Matías. As a result, shellfish fisheries were temporarily closed and a ban on consumption was implemented.

Discussion

We documented four seabird UMEs in the Patagonian Sea in the early 2000s, with a minimum of 8,107 birds found dead in association with these events. However, it is likely that the death toll of these events was substantially greater, as it is known that the number of carcasses found ashore represents only a small fraction—often less than 10%—of the actual death toll due to mortality occurring at sea and/or carcasses being removed by scavengers (Van Pelt and Piatt 1995; Byrd et al. 2009; Williams et al. 2011; Zimmerman et al. 2019). Furthermore, the events we report here likely represent only a fraction of the UMEs occurring in the Patagonian Sea during the study period, as other events may have gone unnoticed due to sparse human habitation, few existing or sufficiently staffed protected areas, or residents failing to communicate UMEs they witnessed to researchers or local authorities. It is therefore possible that the frequency and impacts of UMEs on the Patagonian seabird community in the early 2000s are greater than currently appreciated in the literature.

Beyond detection bias, incomplete documentation and variability in investigative and diagnostic efforts can hinder robust conclusions about the causes of UMEs, as was the case for Events 1 and 2 in this study. Most birds affected in Event 1 were in very poor body condition, with high gastric nematode prevalence and dark mucus in their stomach (a finding typically associated with severe chronic malnutrition; Hocken 2002), suggesting that malnutrition/starvation played a role in this event. However, the fact that the species affected in Event 1 represented a broad variety of foraging guilds makes it unlikely that a shortage of prey was the sole factor driving mortality. Many individuals in that event had pulmonary lesions consistent with drowning, which could be related to agonal drowning (i.e. birds becoming unable to swim or keep their head above the water as they become weaker or are affected by neurological signs) but may also be an indication of interaction with fisheries (Vanstreels et al. 2016; Ewbank et al. 2020). Although tissue samples from seabirds collected in Event 1 were submitted for biotoxin testing, it was later found that the freezer where samples were stored malfunctioned, with samples probably undergoing an unknown number of thawing-refreezing cycles. This was in addition to beach-cast carcasses being quite decomposed upon collection and thus suboptimal for toxin detection from the onset (Indrasena and Gill 2000). Thus, we cannot confidently rule out the possibility of DA or PSP having been involved in Event 1 despite negative toxicological results. On the other hand, many birds in Event 2 were in relatively good body condition and had an empty stomach (at times with inflammation of the upper digestive tract, suggestive of regurgitation), which leads us to suspect that this event had an acute infectious or toxic aetiology. Tissue samples collected from seabirds in Event 2 were negative for DA, but no testing was done for PSP toxins. However, mussels collected at Bahía Engaño (see Fig. 1C) in November 2000 exceeded the regulatory limit for PSP toxins for human consumption, with a maximum toxicity value reaching 2342 µg STX equivalent per 100 g (Villalobos et al. 2019), hence we consider it plausible that PSP played a role in Event 2.

Interaction with fisheries is a known cause of seabird mortality worldwide, including in the Patagonian Sea (González-Zevallos et al. 2007; Favero et al. 2011; Marinao et al. 2014; Fogliarini et al. 2019), and globally there have been several instances where penguin UMEs were attributed to bycatch in fisheries after pathological investigation (Simeone et al. 1999; Schlatter et al. 2009; Crawford et al. 2017; Ewbank et al. 2020). The central coast of Chubut, including the area from Bahía Engaño to Punta Tombo, is subject to intense activity by coastal trawlers, with Magellanic penguins being frequently bycaught and drowned (Marinao et al. 2014). On the other hand, fishery activity was scarce in Golfo Nuevo during the study period, with the exception of a brief experiment with artisanal longlining in 2000 and 2001 where no interactions with seabirds were reported (Elías and Pereiro 2003; Elías et al. 2011). Hence, we consider it unlikely for interactions with fisheries to have played a significant role in Event 1, but would consider it a plausible contributing factor to Event 2.

Events 3 and 4 were likely caused by paralytic shellfish poisoning, as PSP toxins were detected in seabird tissues and pathological findings were generally consistent with this syndrome. PSP toxins are produced by some dinoflagellates (especially *Alexandrium* spp.) and cyanobacteria (Hallegraeff 1993; Martínez et al. 2015), and in seabirds, the exposure route is usually through the ingestion of contaminated prey, such as shellfish, small crustaceans and planktivorous fish (Shumway et al. 2003). Blooms of PSP toxin-producing species have been recorded throughout the coast of Argentina (Carreto et al. 1981; Krock et al. 2018; Montoya 2019; Villalobos et al. 2019; Cadaillon et al. 2022) and southern Chile (Vinuesa 1993; García et al. 2004; Álvarez et al. 2019). In spite of these occurrences, there are only a handful of seabird UMEs attributed to PSP in the region, notably (a) a bloom of *Alexandrium catenella* in 1980 near Península Valdés (including Golfo San Matías and Golfo San José, but not Golfo Nuevo), which coincided with a die-off of Magellanic penguins, cetaceans and fishes (Carreto et al. 1981); (b) a large-scale bloom of *A. catenella* in 1992–1993 in the Beagle Channel, which was associated with "high mortality" of Magellanic penguins and other seabirds (Carreto and Benavides 1993; Vinuesa 1993); and (c) a highly toxic bloom of *A. catenella* in the Beagle Channel in 2022 which caused mortality of kelp gulls, imperial shags, Magellanic and gentoo penguins (Cadaillon et al. 2024).

PSP toxins lead to progressive paralysis and death due to respiratory arrest (Montoya et al. 2010). The clinical signs of disorientation, lack of coordination, inability or refusal to stand up or walk we observed in gentoo penguins (Event 3) and kelp gulls (Event 4) are consistent with those previously reported in cases of PSP in seabirds and humans (Hallegraeff 1993; Shumway et al. 2003). The necropsy findings in this study lacked any obvious lesions that could be considered unequivocally indicative of biotoxin exposure. Interestingly, although many carcasses in these PSP events were in relatively good nutritional condition, their stomachs were empty or only contained small quantities of food or non-food items (e.g. seaweed). This is consistent with previous reports of PSP in seabirds (Shearn-Bochsler et al. 2014) and could be due to toxin-induced regurgitation (Hallegraeff 1993). There were also no histopathological findings that could be considered reliably indicative of intoxication. In the kelp gulls necropsied from Event 4, all individuals had marked lung congestion, which could be related to asphyxia due to respiratory paralysis (Evans 1965). However, lung congestion is a relatively common and non-specific finding that may also be present in respiratory infections (Schmidt et al. 2015) as well as in seabirds that drowned due to bycatch (Vanstreels et al. 2016). In the absence of unequivocal necropsy or microscopic lesions, toxicological testing becomes essential to confirm the diagnosis of PSP in seabirds. We were able to detect PSP toxins (saxitoxin, neosaxitoxin and gonyautoxins 1–4) in samples from various tissues, with intestinal contents/wall and liver yielding the highest concentrations. Moving forward, new methods for biotoxin detection relying on biosensors may increase sensitivity even in degraded or complex matrices such as tissues from birds and mammals (Zhu et al. 2024), and acidic buffering of samples can also be used to reduce degradation of PSP toxins and improving performance of toxicological assays (Indrasena and Gill 2000).

Event 3 stands out as the most severe UME in this study with regard to the death toll. Our data indicate that a minimum of 3,500 seabirds died during this event, but considering how limited the observation effort was in relation to the extensive area in which carcasses were found, we roughly estimate that as many as 10,000 seabirds may have died in association with this event. However, long-term population monitoring data suggest that the death toll could have been substantially greater, since an archipelago-wide census in 2000 and 2005 indicated population decreases of 88,000 pairs of southern rockhopper penguins, 48,000 pairs of gentoo penguins and "tens of thousands" of pairs of Magellanic penguins in the Falkland/Malvinas Islands (Huin 2003; Pistorius et al. 2010; Baylis et al. 2013). Unfortunately, it is impossible to produce a precise mortality estimate for Event 3 because (a) many interviewees used imprecise terms such as "lots" or "thousands", (b) data could only be obtained from select inhabited locations, whereas the event seemed to be much more widespread across the archipelago and (c) another UME occurred earlier in the same year, making it difficult to differentiate the contribution of these events to the demographic change over the period. In April and June 2002 (i.e. the winter preceding Event 3), another UME was documented in the Falkland/Malvinas Islands, with reports of 2067 southern rockhopper penguins and 509 gentoo penguins found deceased at Saunders Island (Wilson 2002; Royal Society for the Protection of Birds 2003; Bingham 2005). The cause of that winter UME is not known, but it is speculated to have been starvation based on the poor body condition of the birds and the fact that many had an empty stomach (Bingham 2005). Decreases in breeding pairs at monitored sites in November 2002 (i.e. before the onset of Event 3) would support a large-scale mortality of gentoo, southern rockhopper and Magellanic penguins and black-browed albatrosses in the preceding winter (Huin 2003), and it is plausible that large-scale at-sea mortality could have gone unnoticed because seabirds tend to forage further away from the coast during winter (Boersma et al. 2002; White 2002; Baylis et al. 2021). In the case of the gentoo penguins, which apparently was the species most affected by Event 3, demographic data suggest a population decrease of 20,000 pairs during the winter of 2002 and a further decrease of 30,000–40,000 pairs during the summer of 2002/2003 (i.e. Event 3) (Huin 2003, 2007). Without further data, it is difficult to differentiate the relative contribution of these two UMEs (winter of 2002 and summer of 2002/2003) to the large-scale seabird population decreases in the Falkland/Malvinas Islands in 2000–2005. It is also unknown the extent to which these UMEs may have synergized (e.g. food shortages precipitating dietary shifts that in turn led to the exposure to biotoxins).

Our findings contribute information on previously unreported UMEs in seabirds from the Patagonian Sea in the early 2000s. Moreover, they confirm that paralytic shellfish poisoning can be associated to seabird mass mortalities in this area. However, they also show that other factors may be contributing to deaths and that thorough investigations are needed to tease them apart. Identifying the cause of death in wildlife is not always straight-forward, particularly since there is a need for fresh tissues for histology to enable linkage between pathogen or toxin detection and pathological lesions (Ryser-Degiorgis 2013; Zhu et al. 2021). But UMEs are typically unexpected, often being first witnessed by local residents, park rangers or field biologists without the resources (equipment, training, etc.) necessary to collect data and samples to document these events. In scarcely inhabited regions such as remote Patagonian coastal areas, proper documentation and investigation of these events will largely rely on the local population noticing these events and bringing them to the attention of conservation managers and researchers in a timely manner. This highlights the value of researchers developing relationships with local communities, especially with those sharing the environment with the wildlife being studied (farmers, fishermen, ecotourism guides, park rangers, etc.), to raise awareness about the importance of promptly communicating UMEs. Technological advances since the time of this study, such as smartphones and internet connectivity, open many opportunities for increased reporting and documentation. Importantly, reports can now also capture details such as video recording of clinically ill animals and photographs of carcasses that may be washed away from shore before investigators arrive. There are multiple innovations in wildlife surveillance stemming from citizen science and park ranger monitoring that could be applied to the coast of the Patagonian Sea with relative ease (Lawson et al. 2015; Montecino-Latorre et al. 2024).

Moving forward, with governments being responsible for reporting new and increasing cases of notifiable diseases in wildlife (e.g. high pathogenicity avian influenza), there might also be opportunities for targeted efforts (rather than fortuitous encounters) where citizen science projects contribute to the detection and documentation of UMEs. Examples are volunteer beach survey programmes (e.g. Powlesland 1984; Avery 1989), standardized reporting by tourism operators (e.g. International Association of Antarctic Tour Operators 2024) and mobile phone applications (e.g. Olson et al. 2014). Furthermore, UME preparedness plans can be instrumental in defining the procedures and protocols for reporting these events and collecting data and samples (e.g. Wilkinson 1996; Kerry and Riddle 2009). Such plans can also encompass the training of field personnel already working in the region (e.g. field biologists, park rangers, domestic animal veterinarians) and the acquisition and deployment of field kits to remote locations (necropsy and sample collection manuals, personal protective equipment, sample collection materials, etc.). Moreover, in the absence of diagnostic laboratories with broad analytical capacities locally available, access to point-of-care, field-based diagnostic kits would substantially enhance UME investigations (Hobbs et al 2021). With an apparent rise in the frequency of harmful algal blooms and recent outbreaks caused by high pathogenicity avian influenza virus in the coastal waters of the Patagonian Sea (Villalobos et al. 2019; Ramírez et al. 2022; Díaz and Figueroa 2023; Rimondi et al. 2024; Uhart et al. 2024), there is an evident need for further efforts to detect and investigate UMEs and their impacts on the conservation of marine species in this region.

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Declarations

Competing interests The authors declare no competing interests.

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