Continuing southern right whale mortality events at Península Valdés, Argentina

Marcela M. Uhart[1, 2], Victoria Rowntree[1,3], Mariano Sironi[1,6], Andrea Chirife[1], Nadia Mohamed[1], Luciana M. Pozzi[1,4], Luciana Musmeci[1,4], Marcelo Franco[5], Denise McAloose[2], G. Doucette[7], and Viviana Sastre[8], T. Rowles[9]

[1] Southern Right Whale Health Monitoring Program, Argentina
[2] Global Health Program, Wildlife Conservation Society, Bronx, NY USA
[3] Whale Conservation Institute, University of Utah, Salt Lake City, UT USA
[4] CONICET, Chubut, Argentina
[5] Cuerpo de Guardafaunas, Subsecretaria de Turismo, Chubut, Argentina
[6] Instituto de Conservación de Ballenas, Buenos Aires, Argentina
[7] Marine Biotoxins Program, NOAA National Oceans Service, Charleston, SC USA
[8] Programa de Monitoreo de Floraciones Algales Nocivas en Aguas Costeras, Secretaría de Pesca, Provincia de Chubut
[9] NMFS, Office of Protected Resources, 1315 East West Highway, Silver Springs, MD 20910 USA

ABSTRACT

Península Valdés (PV) in Argentina is the major nursery ground for the southwest Atlantic Southern Right Whale (SRW, *Eubalaena australis*) population. Probably due to the topography and currents of the Península's large bays, most of the whales that die become stranded on the beaches, allowing for reasonably accurate mortality estimates. Systematic efforts to evaluate SRW health through post-mortem examinations began in 2003. Since then, 291 SRW deaths have been recorded, with peaks in 2005, 2007 and 2008. Ninety percent of beached whales were calves, and most were female. In 2007 and 2008, 83 and 96 whales died and stranded at PV in what are considered the most extreme mortality events ever observed in any baleen whale. We discuss environmental conditions prior to and during the events and report results from analyses of whale tissues and water samples collected in the gulfs where the whales died. Necropsies provided no evidence for cause of death. Most carcasses were in advanced states of decomposition when they were examined. Investigation of marine mammal unusual mortality events (UME) is challenging and complex, and critical information is often missed as the onset of the UME is not initially recognized. The immediate cause of death, predisposing factors, and population effects of UME have been identified for only a small percentage of investigated cases. With an annual population growth rate of 6.9% for the period 1971-2000, the PV SRW may have the capacity to overcome years of such high calf mortality. However, events of this magnitude could drive their sister species in the northern hemisphere towards extinction.

KEYWORDS: STRANDINGS, MORTALITY RATE, HABITAT, STRESS, TRENDS

INTRODUCTION

Unusual mortality events (UME) are situations in which marine mammals die either in unusual numbers, unusual circumstances or over extended geographic and/or temporal scales (Geraci and Lounsbury 2005, Dierauf & Gulland 2001). Reporting of such events has steadily increased during the past two decades. As an example, between 1991 and 2008, 46 UME were recorded in North America, involving 15 different species (NOAA 2009). UME have been recorded in all marine mammal families with the exception of polar bears (Geraci *et al.* 1999, Dierauf & Gulland 2001, NOAA 2009). While pinnipeds and small cetaceans seem to be the groups most often affected, baleen whales have been implicated in at least seven UME since 1987 (Geraci and Lounsbury 2005, NOAA 2009).

Investigation of UME is challenging and complex. Critical information is often lost, when the onset of a UME is not initially recognized. The immediate cause of death, predisposing factors, and population effects of UME have been identified for only a small fraction of cases (Geraci and Lounsbury 2005, Dierauf & Gulland 2001). Causes most commonly reported are infectious disease, biotoxins, human interactions, ecological factors and malnutrition.

Baleen whale die-offs have mostly gone undiagnosed. Known triggers of mortality have included saxitoxin poisoning and human interaction, while malnutrition has been suspected for Gray whales in Western North America between 1999 and 2001 (Dierauf & Gulland 2001, NOAA 2009). Geographically, baleen whale mortality has been reported only in Eastern and Western North America. However, this may reflect differential stranding surveillance and publishing efforts. Therefore, it is likely that a number of events around the world go undetected or unreported.

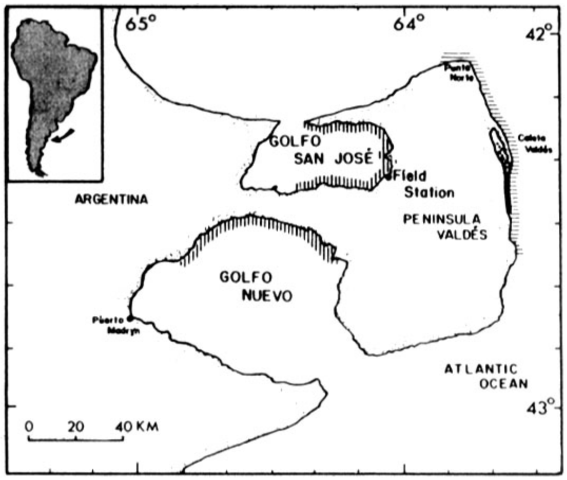

Figure 1. The right whale nursery ground at Península Valdés, Argentina. Cross-hatched areas indicate regions where the whales concentrate.

Southern right whales (SRW-*Eubalaena australis*) are recovering from whaling with most populations growing at 7-8% per year while their sister species in the northern hemisphere could be facing extinction (IWC report, 2001). Península Valdés, Argentina is the major nursery ground for the western South Atlantic population. Calves born in the area spend their first three months of life in shallow waters near the shores of the Península's two large sheltered bays, Golfo Nuevo (GN) and Golfo San José (GSJ) (Payne, 1986; Taber and Thomas, 1982; Thomas and Taber, 1984) (Fig. 1 MAP). The population has been studied continuously since 1970 through annual aerial surveys and boat and cliff-top observations (Payne, 1986; Rowntree *et al*. 2001). Whales begin arriving at the Península in April, reach maximum numbers in September and most have left for their feeding grounds by the end of December (Payne 1986). Most calves are born in August (Whitehead and Payne 1981). The whales are primarily fasting while on the nursery ground but begin to feed sporadically in late September, when plankton begins to bloom in the early spring. The population was estimated at 2,577 whales in 1997 (IWC report, 2001), with an annual growth rate of 6.9% per year (Cooke *et al.*, 2001).

Probably due to the topography and currents of the Península's large bays, a significant number of whales that die become stranded on beaches, allowing for reasonably accurate mortality estimates. Research effort devoted to right whale mortality at Península Valdés was variable and somewhat opportunistic between 1971 and 2002. Systematic efforts began in 2003, with the establishment of the Southern Right Whale Health Monitoring Program (SRWHMP) operated by a group of NGOs. Since then, 291 SRW deaths have been recorded and examined at PV, with unusual peaks in 2005, 2007 and 2008 (Table 1). The majority of strandings were calves (90%) less than four months old.

Table 1. Right whale mortalities at Península Valdés, Argentina from 2003-2008. (*one stranding in 2008 of unknown age)

Year	2003	2004	2005	2006	2007	2008	Total
Calves	29	13	36	16	77	90	261
Juveniles	1	0	4	1	1	2	9
Adults	1	0	7	1	5	7	21
Total	31	13	47	18	83	100*	291

Here we describe three distinct UME that occurred at the SRW PV nursery ground between 2003 and 2008. In 2005, three adult females were found dead on the same day on adjacent beaches in GSJ. Within a week another cow died nearby, followed by two more in the next six weeks. In 2007, 61 whales died over 72 days (60 were calves), with only three carcasses found in GSJ, and 58 in GN. Finally, in 2008, 81 dead whales were beached over 10 weeks. Fifty-seven (3 adults, 2 juveniles, and 52 calves) washed onto the shores of GN, while 24 dead calves were found in GSJ.

METHODS

Locating stranded whales. The SRWHMP field team is active during the six months that right whales are present in numbers at Península Valdés (mid-June to mid-December). The team locates strandings through bi-monthly surveys of the beaches where the whales concentrate, aerial surveys of the coast and through reports from members of a local Stranding Network. Land-based survey effort has varied with vehicle availability and the number of strandings needing to be examined. When the team is busy visiting multiple strandings in a given week, the survey for that week is cancelled or postponed. Aerial survey effort also varies. Strandings are recorded during at least one aerial survey a year of the entire perimeter of the Península at the time of peak whale abundance. This survey is dedicated to photo-identification of individual whales. During the 2007 UME, additional surveys of the two gulfs were provided by the Administración del Área Natural Protegida Península Valdés and again in October-December 2008. The Stranding Network consistently reports most of the strandings (60-80%) recorded in a year, demonstrating the importance of developing such networks. The Network's 70+ members live and work along the coast of the Península and include wildlife officers, fishermen, local inhabitants, whale-watch operators, dive-boat operators, tour guides, boat captains, airplane pilots, scallop fishermen, researchers, non-governmental organizations and local authorities such as the Coast Guard.

Necropsy protocol. Each stranded animal is investigated according to a right whale necropsy protocol developed for the program by M. Uhart, L. La Sala and L. Pozzi. The protocol is based on protocols developed by McLellan *et al.* (2004), F. Gulland (pers. comm), A. Carribero (pers. comm.) and Geraci *et al*. (1993). The animal is first photographed and examined for cuts, wounds or other external evidence of human activities (entanglement in ropes, propeller scars). Then body measurements are taken. As body condition allows, a complete or partial necropsy is conducted to examine and collect tissue samples from internal organs that are analyzed for injury or disease. Each stranding is identified by attaching a plastic numbered tag to its fluke to indicate that the animal has already been investigated.

The UME do not appear to be artifacts of variation in survey effort. Consistently since 2003, The field team has been notified of strandings by different members of the Stranding Network, or has found dead animals opportunistically when visiting a reported stranding or as well as during periodical biweekly surveys.

In 2005 five adult females died in GSJ within a period of 2 weeks. Unfortunately these animals decomposed extremely quickly which greatly limited the collection of quality samples and the value of the few tissues collected (i.e. baleen, blubber, skin, measurements). Excessive bloating of carcasses prevented full dissections of adult whale carcasses. Personnel safety became particularly important after one dead adult female exploded during sample collection, and her 5meter calf landed a few feet away from the working field team.

In 2007 the US National Marine Fisheries service sent a stranding response team (W. McLellan, M. Moore and K. Touhey) to Argentina to assist with necropsies. Fifteen right whales were examined during their visit, which extended from 31 October to 9 November 2007. The state of decomposition limited sampling in most cases, with only a few carcasses found in condition code 3 (organs intact but not of histological quality) and most in codes 4 or 5 (most organs liquefied). As is often the case at the Península, calves mostly died offshore and were later moved to shore by the wind, currents and tides. Furthermore, throughout the die-off, the high number of stranding reports received per day greatly challenged the teams' capacity to respond in a timely manner. Given these constraints, the detail and extent of the necropsies (a total of 9 were performed) varied from minimal (dissection for colon contents only) to thorough necropsies (examination for any/all identifiable organs). Fecal samples were collected from all nine whales, and organ tissues from six. The local team did, however, collect a minimum set of samples from 33 whales during the peak mortality period (skin and baleen) and measurements were recorded for 54 whales.

In 2008, samples from animals in good enough condition for diagnostics and/or biological studies (i.e., mild decomposition) were only obtained from a very small number (22) of the total whales examined (75). Unexamined animals include those from which no tissues could be recovered due to their decomposed status (i.e., only skeletal remains) or those that were located in completely inaccessible locations. Nonetheless, in a special effort to discover the causes of this UME, samples for biotoxin analysis were collected from digestive tracts and other organs even when carcass condition was way below optimum standards. Evidence of this is that samples for biotoxin analysis represented 39% of samples collected, while tissue for histopathology were only 7.5%. Furthermore, 5% of dead animals were found in condition 2 and 17% in condition 3, while 56% were in conditions 4 and 5.

Water sample collection and analysis. The waters surrounding the area are monitored for toxic algae and biotoxin levels on a regular basis to prevent human shell-fish poisoning. Oceanographer Viviana Sastre of the Programa de Monitoreo de Floraciones Algales Nocivas en Aguas Costeras de Chubut, Argentina provided measurements of the densities of potentially harmful algal blooms during the periods when right whales are abundant at Península Valdés (2000-2008). In addition, samples were collected during the 2007 UME from each gulf of the Península and at sites with multiple strandings and analyzed by Drs David Kulis and Luciano Fernandes in Dr. Donald Anderson's laboratory at Woods Hole Oceanographic Institute (WHOI) for evidence of HABs. Collection dates ranged from 31 October to 6 November, 2007. The entire volume of each sample was settled in Utermohls chambers for at least 18 hours. The settled material was then examined under an inverted microscope at 100x total magnification. Samples containing dinoflagellate species of concern were examined in finer detail to determine species and densities.

Histopathology and toxin analyses. Histopathology analyses of samples collected from UME animals were conducted by pathologists Denise McAloose (Global Health Program, Wildlife Conservation Society, Bronx, NY) and David Rotstein (NOAA Center for Marine Animal Health, College of Veterinary Medicine, University of Tennessee). Toxin analyses were conducted by Greg Doucette (The National Ocean Service, Marine Biotoxins).

Chlorophyll a maps. Composite eight-day satellite images (MODIS-Aqua, Bloomwatch 180, coastwatch.pfel.noaa.gov) were examined for evidence of plankton blooms by comparing chlorophyll a concentrations before, during and after the peaks in whale strandings in 2005, 2007 and 2008. Eight day composite maps were used because maps made from combinations of fewer days were often blank probably due to cloud cover. Given the 8-day composites of Chl *a* data we also grouped the stranding data into into 7-day bins that were then plotted by Julian day from July 9th through December 23rd. Because strandings are not usually found and reported on the day a whale died, and Chl *a* concentrations are likely to change through the days of a week, binning both data sets provides an average date for the timing of peaks seen in the data.

RESULTS AND DISCUSSION

The temporal distribution of right whale strandings at Península Valdés from 2003 through 2008 is shown in Figure 2. The time when strandings peak as well as the total number of dead animals has changed from year to year. The UME in 2005 and 2007occurred late in the season (October-November) but the one in 2008 occurred in August at the beginning of the season and had a much longer duration (Figure 2). The following sections give brief summaries of each UME with descriptions of distinct characteristics of the stranding patterns, a comparison of oceanographic conditions surrounding the events and results of water and histopathological analyses.

The 2005 UME. Forty-seven whales stranded at Penìnsula Valdès in 2005 with almost half of the deaths (22) occurring over a 26-day period from October 19 through November 14. Prior to 2003 the largest number of strandings recorded in a year was 17 whales in 2000. The 2005 mortality event began on October 19 when three adult females washed onto adjacent beaches in GSJ on the same day followed by two more adult females in GSJ within the next two weeks. One was a female that had been seen a few weeks earlier swimming with a large and healthy calf. An unusual characteristic of the 2005 UME was the high proportion of adults and juveniles among the whales that died in the event in GSJ (6 adults, 4 juveniles and 2 calves). Fourteen calves died during the same period in GN. A total of seven adults died at PV in 2005, more than had ever been recorded in a year.

The 2007 UME. Sixty-one whales died between October 4 and December 16, 2007, with three whales stranding in GSJ and 58 in GN. One was an adult and 60 were calves. The strandings appeared in bursts, one in the first two weeks of October, another at the end of October and a smaller spike in the first two weeks of December (Figure 2).

The 2008 UME. Ninety-nine dead right whales were beached off the Patagonian coast in 2008. Ninety-six died at PV while 3 adults and one whale of unknown age stranded in Golfo San Matias and Monte Hermoso, respectively, to the north of PV. Again most of the strandings (67) at PV were in GN. An unusual characteristic of the 2008 UME was that one-third of the whales died in August, at the beginning of the nursery season and deaths continued at a steady rate with 3-12 deaths per week until October 22rd, when mortality totaled 82 whales over an 82-day period, including 76 calves. As in 2007, the stranding had two spikes, one in the week of August 20th and another in the week of October 1st (Figure 2).

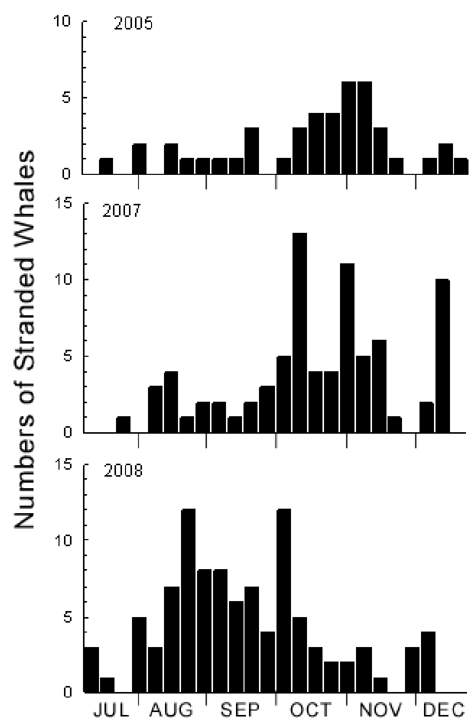

Figure 2. Temporal distribution of right whale strandings at Península Valdés Peninsula in years with high mortality events.

Conditions prior to and during the mortality events. High concentrations of chlorophyll *a* in the ocean indicate plankton blooms that could include toxic species. We examined composite eight-day satellite images (MODIS-Aqua, oceancolor.gsfc.nasa.gov) of PV to look for evidence of plankton blooms before and during the UME events. Chl *a* concentrations were low (less than 4 mg/m^3) throughout the 2005 nursery season. However, chlorophyll *a* levels were extremely high (180-100 mg/m^3) throughout GN on the 8-day averaged satellite maps centered on October 1st in 2007 and October 29th in 2008 (Figure 3). In 2007, three whales died at the end of September when Chl *a* concentrations were again high (180 mg/m^3) throughout GN. Right whale deaths peaked (13 whales) in the following week (October 8-14)(Figure 2). High concentrations of Chl *a* continued at a level of 90 /m^3 but with a patchy distribution until around October 20. A second peak of strandings (12 whales) occurred in the last week of October 2007 (Figure 2), about a week after the patchy high concentrations of Chl *a* had disappeared. . In addition to Chl *a* analyses, researchers conducting the right whale photo-id survey oin October 5, 2007 photographed an unusual green coloring in the water along the eastern shore of GN. During a later on October 23, 2008 to count and document the distribution of strandings, researchers photographed an intense red coloration of the water along the shores of GN.

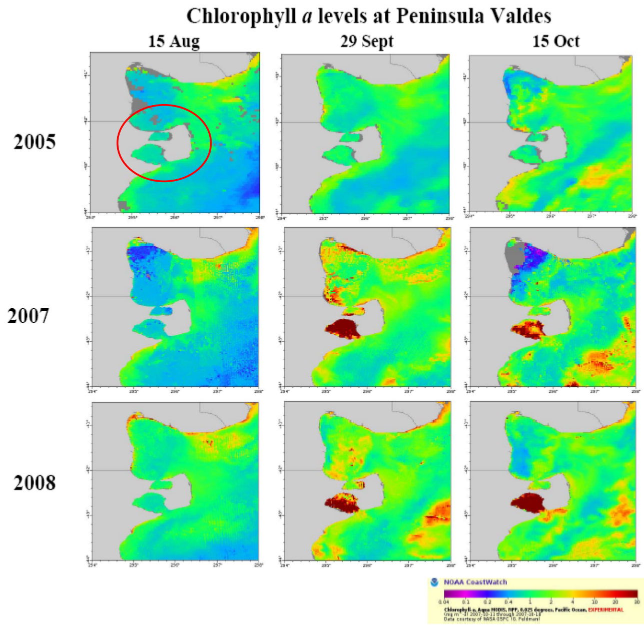

Figure 3. Satellite maps showing changes in chlorophyll *a* levels in the waters surrounding Península Valdés as the seasons change from winter to spring. The land is grey and the Península and its northern (GN) and southern (GSJ) bays are indicated by an oval in the top left map. The dark coloring filling GN in the bottom right map indicates extremely high levels of chlorophyll *a*. (MODIS-Aqua, Bloomwatch 180, coastwatch.pfel.noaa.gov)

Chl *a* concentration in GN was low in August in all years with UME (around 0.65 mg/m^3, Figure 3). In 2008, whales began to strand on August 1 and died at a steady rate through October 22 with peaks (12 whales each) in the weeks of August 20-29 and October 1-8 (Figure 4). Chl *a* concentrations were low (less than 1 mg/m3) throughout August 2008. They rose to 2.7 mg/m^3 in September 2008 and then spiked to about 50 mg/m^3 over half of GN from Sept 27-October 4. Chl *a* spiked again to 100 mg/m^3 in the week of October 23 to 30 throughout GN. The peak in strandings at the beginning of October coincided with the initial spike of Chl *a* to 50 mg/m^3. Later, strandings declined and there were no peaks associated with the increase in Chl *a* concentration and its distribution throughout GN at the end of October 2008.

In summary, five peaks in strandings occurred during the UME recorded in 2005, 2007 and 2008. Three of the peaks occurred within a week of extremely high concentrations of Chl *a* (50-180 mg/m^3) indicating the deaths could have resulted from harmful algal blooms. The high chlorophyll levels in GN at the beginning of October 2007 coincided with the closure of the three gulfs surrounding Península Valdés (Golfo San Matias, GSJ and GN) to scallop fishing due to high levels of paralyzing toxins in the water.

Water Samples. *Alexandrium tamarense.* Water samples collected in September 2007 off the southwestern shore of GN by the Programa de Monitoreo de Floraciones Algales Nocivas en Aguas Costeras de Chubut, Argentina showed high densities of the toxic dinoflagellate *Alexandrium tamarense* (18,125 cells/liter) (Figure 4). Paralyzing toxin concentrations in mussels were 3,612 UR. Densities of 18,480 occurred in the same location on September 26, 2008. In GSJ, A. tamarense densities of 21,840cells/liter we collected in GSJ on 6 September (Figure 4.). Although this toxin concentration is above the limit for human consumption we do not know if it could be harmful to whales.

Lepidodinium chlorophorum . The 2007 samples also had high densities of a non-toxic green dinoflagellate tentatively identified as *Lepidodinium chlorophorum (= Gymnodinium chlorophorum)* (61,488 cells/liter). The significance of this finding for the whales is unknown, as there were no mass whale mortalities observed in GN in November 2004 when densities of *L. chlorophorum* were several times higher, reaching 310,848 cells/liter.

Pseudonitzschiasp. is a diatom that can produce domoic acid which has been linked to the deaths of over 400 sea lions off the coast of California in 1998 (Scholin *et al.* 2000). . Water samples from GSJ collected by the Programa de Monitoreo de Floraciones Algales Nocivas en Aguas Costeras de Chubut, Argentina (Sastre pers. comm.) showed *Pseudonitzschia sp.* densities of 1.3 millions cells/liter in December 2007 and 2 - 3.8 million cells/liters on 6 and 22 November 2008 respectively (see Figure 4). Additional samples collected in GN at the end of December 2008 had *Pseudonitzschia sp.* densities of 4.7 million cells per liter. Sastre's data from 2000-2008 (Figure 4) did not begin to show high densities of *Pseudonitzschia* until November of 2007. Water samples collected by Michael Moore in early November 2007 were analyzed at WHOI and showed high concentrations of *Pseudonitzschia* (1-2 million cells/liter), tentatively identified as *Pseudonitzschia australis*. Many of the cells in the water samples collected in GSJ lacked chloroplasts suggesting they were remnants of an earlier bloom.

Sastre's data shows that since the year 2000, large blooms of potentially toxic algal species at PenÍnsula Valdés are a relatively new phenomenon as are the sudden deaths of large numbers of right whales. The episodes with high densities of *Pseudonitzschia* however occurred *after* the peaks in whale mortalities. Collection of water samples at regular intervals throughout the nursery season will help in seeing if there is a correlation between these two events. *A. tamarensis,* on the other hand, had high density blooms in September in 2007 and 2008 before and between the highest peaks in strandings in those years. The best way to prove a relationship between whale deaths and HABS is to find toxins in the bodies of dead whales but this requires collecting tissue samples within hours, not days, of the whale's death. Right whales are so well insulated by their thick coats of blubber that the toxins in HABS or disease causing bacteria decompose rapidly along with the whale's tissues, therefore presenting a real diagnostic challenge.

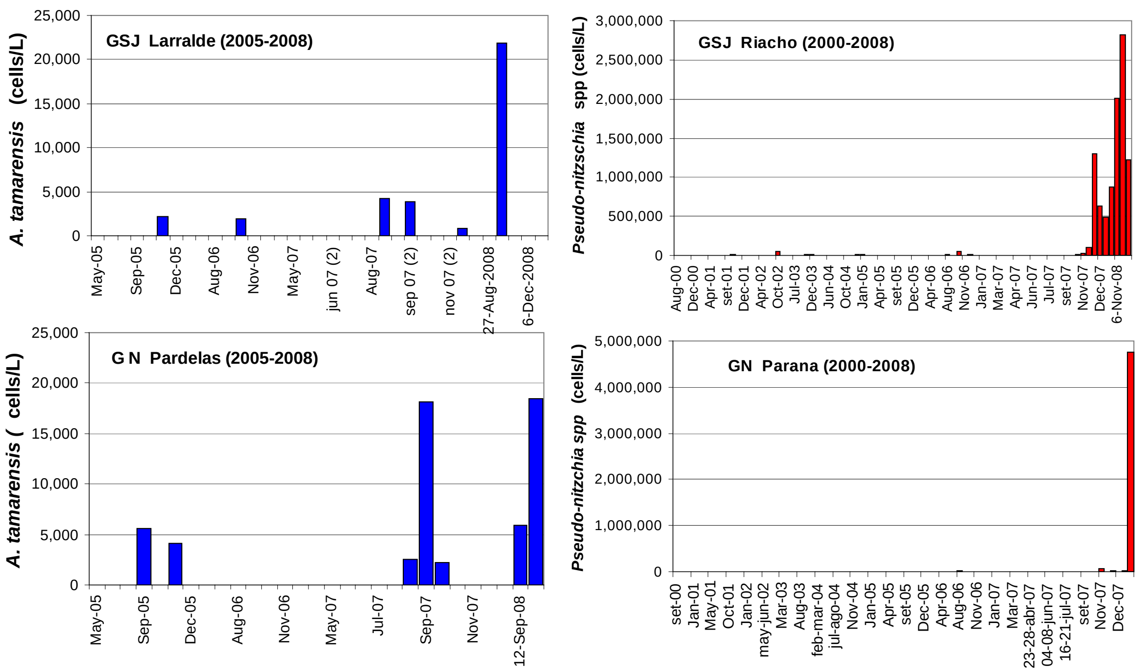

Figure 4. Dates of plankton blooms of potentially toxic species at Península Valdés, Argentina. Left, the dinoflagellate *Alexandrium tamarensis*, from May 05 – December 08. Right, the diatom *Pseudonitzschia spp.*fromSeptember 00 to December 08. Golfo San Jose (top), Golfo Nuevo

Biotoxins. Of the ten samples collected from dead whales in 2005, only two were positive for domoic acid (G. Doucette, pers. comm.) These belonged to an adult female which died in GSJ and one male calf found dead in GN. Samples analyzed included urine, feces and blood. Domoic acid levels found were low when compared to those reported for marine mammals with domoic acid toxicity symptoms. Therefore, while these results provide evidence of exposure of the dead whales to domoic acid, it is unsure whether it might have contributed to their deaths.

Results of histopathology analyses. No evidence was found of saxitoxin, domoic acid or other consistent indicators of significant disease in any of the whale tissues analyzed with the exception of gull attack lesions. Poor tissue quality due to autolysis compromised determining the cause of death in all of the whales examined.

Unequal distribution of strandings between the two gulfs. 2005 was unusual with more mother/calf pairs (154) counted during the annual aerial survey than in any previous year and more mother/calf pairs counted in GSJ than in GN (113 versus 68) in 2005 (Table 2). Over all years (2003-2008), 52% percent of calves counted during the aerial photo-identification surveys were in GN, almost an equal distribution between bays. However, more calves stranded in GN than GSJ (68%, $X^2 = 40.5$, $p<10^{-9}$). This could indicate that whatever is causing the high mortalities could be more intense in GN. An alternate hypothesis could be that mother/calf pairs from GSJ migrate into GN at the end of the nursery season, as was observed with repeated sightings of the same individuals in the early 1970s when the whales were surveyed multiple times in the same year.

Table 2. A comparison of the number of living and dead calves counted in Golfo San Jose and Golfo Nuevo during aerial surveys at the time of peak whale abundance and stranding counts from 2003-2008. Note that number of living whales is an underestimate because whales in the middle of the gulfs (including calves) are not counted due to safety restrictions that prohibit flying far from shore.

Year	Live calves		Total live	% GN	Dead calves		Total dead	% GN	% Dead/Live
	GSJ	GN			GSJ	GN			
2003	72	79	154	51	13	16	29	55	19%
2004	40	49	89	55	5	8	13	62	15%
2005	113	68	182	37	6	30	36	83	18%
2006	70	92	162	57	9	7	16	43	9%
2007	103	136	241	56	6	70	76	92	32%
2008	90	115	207	56	28	63	90	70	43%
Total/mean	488	539	1027	0.52	67	194	261	0.68	23%

From 2003-2008 the observed rate of increase in living calves from counts was 0.124 per year, whereas the number of stranded calves increased at 0.282 per year, indicating that the number of strandings is increasing at more than twice the rate of number of living calves counted per year. The higher number of living calves counted could result from females who lost their calves returning in the following year or two with new calves instead of at the usual 3-year calving interval.

CONCLUSIONS

Although the evidence seems to suggest that the mortality cluster of 2005, 2007 and 2008 may be related to harmful algal blooms, other causes cannot be ruled out.

Possible causes of death and/or strandings, not necessarily related to disease have been reported in baleen whales. Among these are an abrupt decline in food availability (Reddy et al. 2001), red tide intoxication, unusual weather conditions, acoustic disruption due to boat and submarine navigation and human-related injuries (Geraci and Lounsbury 1993). However, the fact that the October 2005 deaths of adults occurred in GSJ, the bay at the Península with less pollution, fewer human establishments and less ship activity, suggests that these cases may not be related to pollution, harassment from whale-watching boats or acoustic disruption.

It is possible that we are witnessing increased "natural" calf mortality as the number of adult whales coming to Valdés increases but the slower rate of increase in number of calves counted compared to the number of calves stranding indicates this is not the case. Higher calf mortality could, however, be a result of breeding females in poor body condition, which would produce weak, unviable calves. Even though these suggestions are somewhat speculative at this point, it has been shown that whales breeding at Valdés experience reproductive failures in El Niño years, when ocean temperatures rise, and krill abundance (an important prey species) declines on the whales' suspected feeding ground off South Georgia (Leaper *et al.* 2006). Analysis of collected blubber and tissue samples is currently ongoing to evaluate these possibilities.

HABs have expanded both their geographic range and frequency in South America in recent years (Van Dolah 2000). The causes however, are not well defined. The lack of long-term phytoplankton data hinders the ability to determine if novel outbreaks respond to recent introduction of organisms, changes in local nutrient conditions, or large-scale climatic changes (Van Dolah 2000). An important factor is determining to what extent human impacts on the environment (locally, regionally or globally) are responsible for these increases, so urgent mitigation measures can be implemented.

Southern right whale populations at Península Valdés and elsewhere might continue to grow even if high-mortality events like the ones reported here recur. However, the remaining northern right whale populations might be devastated by even a few such events, though this might not be the single most critical threat for their populations. Because of the significance of losing adult reproductive females and the unknown long-term population effects that these types of events might have, we think it is urgently important to understand the causes of mortality clusters such as those described here. Regular water sampling and prompt analysis might provide some warning of conditions likely to trigger increased mortality, as well as provide critical baselines, particularly for HAB events. Thorough investigation of ongoing mortality events and retrospective analysis of conditions associated with mortality clusters after they have occurred is essential, and requires significant collaborative efforts. With better logistical preparation and improved abilities to recognize mortality clusters in progress, researchers would be able to find more of the affected animals in fresh condition, and thus to gather evidence critical to determining the causes of death.

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