REVIEW

Overview of sperm whale *Physeter macrocephalus* mortality events in the Adriatic Sea, 1555–2009

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ABSTRACT

1. In the Mediterranean Sea, the sperm whale *Physeter macrocephalus* is one of eight regular cetacean species. Poor knowledge of its ecology and status, together with suspected decline in numbers, make studies of historical and present occurrence especially relevant. Long-term time series of stranding events are the most reliable data to provide a scientific framework for testing hypotheses that seek to explain the mechanisms responsible for cetacean strandings.

2. We present a comprehensive overview of cases of sperm whale mortality and human response to such events encompassing five centuries (1555–2009) within a portion of the Mediterranean Sea that offers a wealth of historical information – the Adriatic Sea.

3. A total of 36 mortality events were validated, involving 68 animals. Two findings of skeletal materials are also reported. The geographic distribution of strandings within the basin clearly was uneven: 44% of records (n = 16) were clustered along a 280km portion of the western Adriatic coast. A relatively high number of mortality events occurred along gently sloping sandy beaches away from suitable sperm whale habitat.

4. Until the first half of the 20th century, live-stranded animals were routinely killed: all but one cases with known human response elicited killing attempts. Starting from the 1980s, killing was replaced by efforts to rescue the animals.

5. Mass strandings of sperm whales have occurred since historical times in the Adriatic Sea. Mortality events involving multiple individuals accounted for at least 17% of the total sample (6 of 36 mortality events). At least 29% of live strandings (6 of 21) involved more than one individual.

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6. This study contributes a long-term dataset based on careful validation of historical information, suitable for hypothesis testing aimed at investigating spatial and temporal correlates of sperm whale strandings – particularly live strandings – as a clue to their causes.

Keywords: beaching, human–cetacean interactions, mass mortality, Mediterranean Sea, stranding

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INTRODUCTION

The sperm whale *Physeter macrocephalus* is one of eight cetacean species considered to be regular inhabitants of the Mediterranean Sea (Notarbartolo di Sciara 2002). While there are no estimates of overall abundance in the region, numbers seem to be low (in the hundreds rather than the thousands), and the Mediterranean population, thought to have considerably declined, qualifies as Endangered in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Notarbartolo di Sciara et al. 2006). Threats include incidental mortality in fishing gear (particularly pelagic gillnets still extensively used in the region, mostly illegally; Pace et al. 2008, Cornax & Pardo 2009) and ship strikes (Pesante et al. 2001). In addition, the population may be negatively affected by disturbance and noise generated by the intense maritime traffic (Dobler 2002, Notarbartolo di Sciara et al. 2006).

Preferred sperm whale habitat in the Mediterranean Sea consists mostly of deep continental slope waters where mesopelagic cephalopods – the species' preferred prey – are most abundant (Azzellino et al. 2008, Praca & Gannier 2008). Sperm whales, however, can also be found in deep offshore waters (Praca & Gannier 2008, Praca et al. 2009). The shallow waters of the northern and central Adriatic Sea do not represent a suitable habitat for this deep-diving species (Bearzi et al. 2004). Neither visual ship-based surveys and opportunistic sightings in the northern Adriatic between 1988 and 2007 (Bearzi et al. 2009), nor extensive survey effort in continental shelf waters off Italy, Slovenia and Croatia (e.g. Bearzi et al. 2004, Fortuna 2006, Genov et al. 2008), have yielded sightings of sperm whales. Conversely, the southern part of the Adriatic – with waters up to 1222m deep – includes continental slope and steep bottom relief where the species may be present. Unfortunately, there has been limited survey effort in deep Adriatic waters. Ship surveys in the western sector of the whole Adriatic Sea between 1988 and 2000, including deep waters, resulted in four sperm whale sightings totalling 16 individuals, but sighting locations were not reported (Manoukian et al. 2004). A subsequent visual and acoustic survey yielded no encounters (Boisseau et al. 2008). Sperm whales are known to occur in the Ionian Sea, especially in the north-western part of the Hellenic Trench (Gannier et al. 2002, Frantzis et al. 2003, Lewis et al. 2007).

Poor knowledge on the ecology and status of Mediterranean sperm whales, together with the suspected decline in numbers, make studies of historical and present occurrence particularly relevant. Studies of this kind are often challenging because early historical accounts are difficult to access and scarce. However, the Adriatic Sea can bring valuable insight, as a wealth of historical information is available from this portion of the Mediterranean. Relevant accounts of sperm whale mortality in the Adriatic Sea date back to the 19th century, when partial

reviews – often including (and sometimes limited to) lists of dates and locations reported by previous authors – were published by Nardo (1854), Cornalia (1872), De Sanctis (1879), De Marchesetti (1882), Trois (1894), Parona (1896, 1909) and especially by Brusina (1889), who reported several strandings, sightings and captures between 1713 and 1885. More recently, information was partially reviewed by Kryštufek and Lipej (1985, 1993), who listed three mortality events in the northern Adriatic and validated a case in 1555 (first reported in the post-1555 addenda to Gesner 1553), i.e. at present, the oldest known Adriatic record. Additional recent attempts to review sperm whale strandings in the Adriatic Sea have been published, but not subject to peer review (e.g. Notarbartolo di Sciara & Bearzi 1992, Affronte et al. 1999, De Nicolò 1999).

To advance understanding of the reasons behind sperm whale mortality and shed light onto the historical occurrence of strandings as well as human responses to such events in the Adriatic Sea, we reviewed the literature and other accounts of sperm whale mortality encompassing five centuries. We then matched and merged the available information, resulting in a validated list that represents a valuable data set that can be used to investigate trends in geographical distribution, sperm whale occurrence over time, type and relative frequency of mortality events (i.e. live, dead, single or multiple strandings) and human responses to such events.

METHODS

Study area

The Adriatic Sea (Fig. 1) extends north-west from 39°44′ to 45°45′ N, with a maximum length of about 830km. It has a mean breadth of about 150km, with a minimum of 75km in the Strait of Otranto, through which it connects at the south with the Ionian Sea. Its total surface area is about 150000km^2. For the purposes of this study, the Adriatic Sea was defined according to the International Hydrographic Organization as delimited by a line running from Butrint, Albania (39°44′ N) to Cape Karagol in Corfu, Greece, through this island to Cape Kephali, Greece and on to Cape Santa Maria di Leuca, Italy (Cape Meliso, 18°22′ E). The basin's maximum depth of 1222m occurs south of the central area.

Classification of information

We conducted a content analysis of the scientific and other literature – as well as of engravings, prints, press clippings, video clips and photos – starting from the 16th century. We also looked for emerging themes and classified public responses (or lack thereof) according to occurrence of killing, killing circumstances, use of sperm whales as resources or for display, preservation of biological materials and rescue attempts. Date, location, number of animals involved, size and sex, whether they stranded dead or alive and any other relevant information, were noted. All the reported mortality events were catalogued together with the available facts, and information was subsequently matched. Information reported in sources that were non-scientific in nature was considered only when complemented by convincing evidence (e.g. photos, videos, press coverage or detailed descriptions). All the available information on stranding circumstances was taken into account and checked for consistency to discriminate between accurate and inaccurate records. Geographic positions were attributed to the available records with the best possible approximation of reported location. For instance, when stranding locations referred to cities or

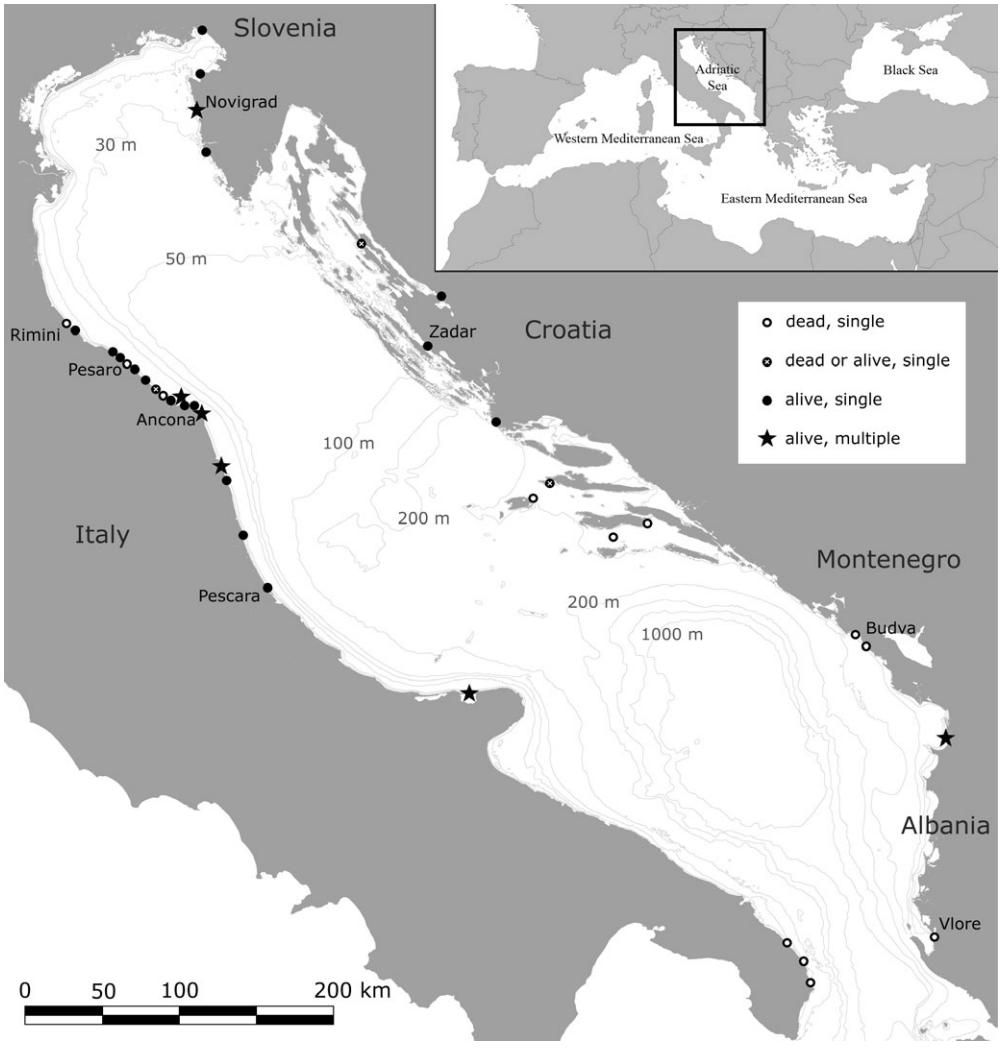


Fig. 1. Geographic distribution of single (dots) and multiple mortality events (stars) involving sperm whales in the Adriatic Sea, with bathymetric lines and some of the locations cited in the text.

other locations inland, we considered the position of the nearest coastline. Findings of skeletal parts along the Adriatic coast were included, but not mapped or considered as true mortality events in the analyses.

RESULTS

Table 1 shows sperm whale mortality events reported to have occurred along the Adriatic shores from 1555 (Fig. 2) to 2009. A total of 36 validated mortality events are listed, involving 68 animals. Two findings of skeletal parts are included in Table 1, but were not used in the analyses or plotted. The geographical distribution of mortality events is shown in Fig. 1, while Figs 3 and 4 show the number and breakdown of events and animals over time.

Table 1. Mortality events ($n = 36$) involving sperm whales in the Adriatic Sea between 1555 and 2009

Date	Latitude	Longitude	Location	Event	Human response if alive	Use as resource	*n* of animals	Length (m)	Sex	Source
1 June 1555	45°31.644′	13°34.006′	Piran, Slovenia	Stranded (A)	Killed	Spermaceti sold	1	12.4	M	Gesner 1553, 1560, 1575, Kryštufek 1991, Kryštufek & Lipej 1985, 1993, Faust et al. 1999, in press
29 July 1584	43°37.355′	13°31.283′	Ancona, Italy	Stranded (A)	Killed	U	7 or 8 (arbitrarily considered as 7 in the analyses)	About 8	U	Anonymous manuscript of 16th century, Archivio di Stato of Ancona; hand-made watercolours (two tables) by Ulisse Aldrovandi (1522–1605), Biblioteca Universitaria of Bologna 'Fondo Ulisse Aldrovandi' 001-2, Animali (pp. 149–150, http://tinyurl.com/yconnc2)
3 February 1601	43°41.185′	13°16.298′	Between Senigallia and Ancona, Italy	Stranded (U)	U	Oil extracted	1	About 16	U	Manuscript in Biblioteca Oliveriana of Pesaro (mentioning another animal was 'caught' on a later date, possibly the one of 25 February 1601); De Nicolò 1999
25 February 1601	43°37.355′	13°31.283′	Ancona, Italy	Stranded (A)	U	Oil extracted	1	About 14	U	Engraving (reported date: 25 February 1601, portrayed as male); engraving in Barthelmess Whaling Collection #846 (reported date: 25 February 1602, but see record above and Faust et al. 1999, in press); Parona 1909 (reported as female, with a supposed male 'lowing' in the vicinities); Faust et al. 1999, in press
19 December 1611	43°40.604′	13°17.493′	Marzocca, Senigallia, Italy	Stranded (D)	n.a.	U	1	About 8	U	Diary of Francesco Maria II della Rovere (Sangiorgi 1989); De Nicolò 1999
10 or 18 April 1713	43°54.774′	12°55.257′	Pesaro, Italy	Stranded (A)	Killed	U	1	About 18	M	Procaccini Ricci 1825, Nardo 1854, Cornalia 1872 (reported date: 19 April 1713), De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896, 1909, Faust et al. 1999, in press
18 April 1715	43°54.774′	12°55.257′	Pesaro, Italy	Stranded (A)	Killed	Oil extracted	1	About 18	M	Engraving by Domenico Franceschini; engraving by Bartolomeo Griffo; Ranzani 1821, Nardo 1854, Ronconi 1857, Cornalia 1872 (reported location: Gulf of Venice), De Sanctis 1879 (two different strandings, reported locations: Pesaro and Gulf of Venice), De Marchesetti 1882 (reported location: Gulf of Venice), Brusina 1889, Trois 1894 (reported location: Gulf of Venice), Parona 1896, 1909, De Nicolò 1999, Faust et al. 1999, in press

Table 1. (*Continued*)

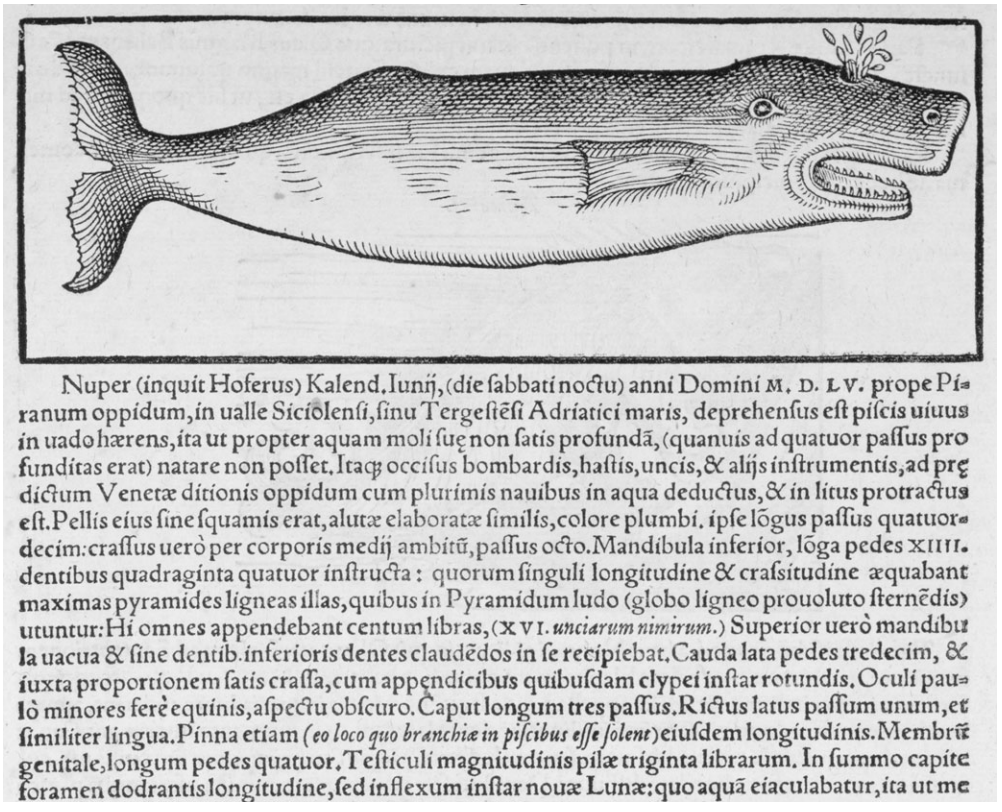
Date	Latitude	Longitude	Location	Event	Human response if alive	Use as resource	*n* of animals	Length (m)	Sex	Source
Circa 1715	42°51.473′	13°55.632′	Ascoli Piceno, Italy	Stranded (A)	Killed	U	1	U	U	Ranzani 1821, Brusina 1889, Parona 1896
Circa 1750	43°31.203′	15°58.203′	Peleš, Rogoznica, Sibenik, Croatia	Stranded (A)	Killed	Oil extracted	1	U	U	Nardo 1854, Cornalia 1872, De Sanctis 1879, De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896, 1909
27 November 1764	45°04.792′	13°38.243′	Salina, Rovinj, Croatia	Stranded (A)	Killed	Oil extracted	1	About 12	M	Griselini 1765, Cornalia 1872, De Sanctis 1879, De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896, 1909, Kryštufek & Lipej 1993, De Nicolò 1999
31 January 1767	43°58.018′	15°24.454′	Turanj, Zadar, Croatia	Stranded (A)	Killed	U	1	Between 11 and 14	M	Nardo 1854, Ronconi 1857, Cornalia 1872, Kolombatović 1882, 1885 (reported yr: 1867), 1894, Brusina 1889, Trois 1894, Parona 1896, 1909, Langhoffer 1917
8 June 1767 (reported by most authors as 1768)	43°50.959′	13°01.437′	Osteria Nova or Torrette, Fano, Italy	Stranded (A)	Killed	Oil extracted	1	About 10	M	Engraving and report by Giuseppe Benedetto Calvani (Faust et al. 1999, in press); canvas by Sebastiano Ceccarini, Civic Art Gallery of Fano; engraving by Giuseppe Ceccarini, Biblioteca Federiciana of Fano; Nardo 1854, Cornalia 1872, De Sanctis 1879, De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896, 1909, De Nicolò 1999, Faust et al. 1999, in press
Early autumn 1775	43°45.878′	13°08.896′	Marotta, Senigallia, Italy	Stranded (A)	Killed	U	1	U	U	Procaccini Ricci 1825, Nardo 1854, Cornalia 1872, De Sanctis 1879, De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896, 1909, De Nicolò 1999
1791	45°46.315′	13°36.279	Duino, Trieste, Italy	Stranded (A)	Killed	U	1	U	U	Nardo 1854, Parona 1896
1802, 1803 or 1805	43°15.568′	13°45.697′	Porto Sant'Elpidio, Civitanova Marche, Italy	Stranded (A)	Killed	U	3	Between 10.7 and 12.0	One M	Procaccini Ricci 1825, Nardo 1854, Cornalia 1872, De Sanctis 1879, De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896, Franzoi 1898 (reported date: 30 December 1802), Parona 1909, Bolognari 1949, 1950, De Nicolò 1999 (includes copy of engraving reporting 30 December 1802)
1810	45°12.936′	12°17.905′	Chioggia, Italy	Finding of lower jaw	n.a.	n.a.	1	U	U	Nardo 1854, Cornalia 1872, De Sanctis 1879, Brusina 1889, Trois 1894, Parona 1896, 1909
October 1833	40°23.485′	18°18.343′	San Cataldo, Lecce, Italy	Stranded (D)	n.a.	U	1	U	U	Costa 1847, Parona 1896, 1909

4 May 1837	42°12.674′	18°50.182′	Budva, Montenegro	Stranded (D)	n.a.	Oil extracted	1	U	U	Nardo 1854, Cornalia 1872, De Sanctis 1879, Trois 1894, Parona 1896, 1909, De Nicolò 1999 (all reporting 4 March 1837). Brusina (1889) checked original source and corrected the date
1845 or 1846	42°12.327′	18°56.449′	Petrovac, Budva, Montenegro	Floating (D)	n.a.	U	1	U	U	Brusina 1889, Parona 1896, 1909
15 August 1853	45°18.875′	13°33.715′	Novigrad, Croatia	Stranded (A)	Killed	Oil extracted	6	Up to about 12	U	Heckel 1853, Nardo 1854, Cornalia 1872, De Sanctis 1879, Brusina 1885, 1889, Trois 1894, Parona 1896, 1909, Langhoffer 1917, Kryštufek 1991, Kryštufek & Lipej 1993, De Nicolò 1999
10 March 1874	43°11.033′	13°47.897′	Porto San Giorgio, Italy	Stranded (A)	None	No	1	15	U	De Sanctis 1879, Brusina 1889 (date misreported as 10 September 1879), Trois 1894, Parona 1896, 1909
1875	45°23.729′	12°21.581′	Lido of Venice, Italy	Finding of skull part	n.a.	n.a.	1	U	U	Trois 1894, Parona 1896, 1909
10 May 1885	42°50.327′	16°54.746′	Between islands of Lastovo (Glavat) and Korcula, Croatia	Floating (D)	n.a.	U	1	9.4	U	Brusina 1885, 1889, Kolombatović 1885, 1894, Trois 1894, Parona 1896, 1909, Korljević 1903, Langhoffer 1917, Hirtz 1929
18 January 1902	40°08.888	18°29.229	Otranto, Italy	Stranded (D)	n.a.	U	1	Skeleton of 12.6	F	Parona 1896, 1909, Repetti 1925, Braschi et al. 2007
1908	44°33.402′	14°52.933′	Island of Pag (arbitrarily located in Novalja), Croatia	Stranded (U)	U	U	1	U	U	Renić 1983a
May or June 1917	43°04.376′	16°15.303′	Stončica lighthouse, Island of Vis, Croatia	Stranded (D), possibly killed by mine or shot offshore	n.a.	Oil extracted	1	7	U	Langhoffer 1917
February 1919	44°15.555′	15°32.280′	Bay of Modrić, Jasenice, Croatia	Stranded (A)	Killed	U	1	16.5	U	Hirtz 1921, 1922, 1929
1936	43°50.959′	13°01.437′	Torrette, Fano, Italy	Stranded (D)	n.a.	U	1	U	U	Photo by Foto Eusebi, Fano; http://tinyurl.com/ylmqkss
12 April 1938	43°40.604′	13°17.493′	Marzocca, Senigallia, Italy	Stranded (A)	Some killed	Oil extracted	7	U	U	Corriere Adriatico 13–14 April 1938; Istituto Luce 1938; Luca Celidoni, pers. comm.

Table 1. (*Continued*)

Date	Latitude	Longitude	Location	Event	Human response if alive	Use as resource	*n* of animals	Length (m)	Sex	Source
17 November 1940	42°55.493′	17°10.480′	Uska luka, Lumbarda, island of Korcula, Croatia	Stranded (D); possibly killed by mine or shot offshore	n.a.	Oil extracted	1	12	U	Renić 1983b
1943	43°09.896′	16°23.571′	Pakleni islands, Hvar, Croatia	Stranded (U)	U	Oil extracted	1	U	U	Renić 1983b
4 April 1943	44°04.436′	12°34.753′	San Giuliano a Mare, Rimini, Italy	Stranded (A)	Killed	Soap, cosmetics	1	10	M	Ghirardelli 1944, Bolognari 1949, Matteini 1977
6 December 1948	40°17.047′	18°25.858′	Melendugno, Lecce, Italy	Stranded (D)	n.a.	U	1	About 5.5	U	Bolognari 1950
June 1956	41°38.227′	19°34.279′	Mounth of river Mat, Shengjin, Albania	Stranded (A)	None	U	8	Between 4 and 9.8	5F, 3U	Puzanov & Lamani 1956, Hajderi 1994, Beqiraj et al. 2007
1956 (a few days after the previous event)	40°26.166′	19°29.686′	Gulf of Vlore, Albania	Stranded (D)	n.a.	U	1	'Young'	U	Puzanov & Lamani 1956, Beqiraj et al. 2007
1 May 1984	42°32.872′	14°07.520′	Silvi Marina, Pescara, Italy	Stranded (A)	Rescue attempts	No	1	10.8	M	Il Messaggero d'Abruzzo 3-4-8-20 May 1984; Il Tempo d'Abruzzo 3 May 1984; Giaccio & Cichelli 1984, Cagnolaro et al. 1986. Classified as male at Museum of Marine Wonders of Pescara
29 January 2005	44°05.700′	12°31.740′	Viserbella, Rimini, Italy	Stranded (D)	n.a.	No	1	About 9	M	Affronte et al. 2005, Centro Studi Cetacei Onlus e Museo Civico di Storia Naturale di Milano 2006, Scaravelli et al. 2006
11 December 2009	41°54.999′	15°45.141′	Between Foce Varano and Capoiale, Italy	Stranded (A)	Rescue attempts	No	7	Between 10.5 and 12.2	M	Bearzi et al. 2010; This study

Two findings of skeletal parts in 1810 and 1875 – not considered as mortality events – are included in the Table; these cases were not included in the Figures.
(A), alive; (D), dead; (U), unknown; n.a., not applicable.



Nuper (inquit Hoferus) Kalend. Iunij, (die ſabbati noctu) anni Domini M. D. LV. prope Piranum oppidum, in ualle Siciolenſi, ſinu Tergeſtēſi Adriatici maris, deprehenſus eſt piſcis uiuus in uado hærens, ita ut propter aquam moli ſuę non ſatis profundā, (quanuis ad quatuor paſſus profunditas erat) natare non poſſet. Itaq; occiſus bombardis, haſtis, uncis, & alijs inſtrumentis, ad prędictum Venetæ ditionis oppidum cum plurimis nauibus in aqua deductus, & in litus protractus eſt. Pellis eius ſine ſquamis erat, alutæ elaboratæ ſimilis, colore plumbi. ipſe lōgus paſſus quatuordecim: craſſus uerò per corporis medij ambitū, paſſus octo. Mandibula inferior, lōga pedes XIIII. dentibus quadraginta quatuor inſtructa: quorum ſinguli longitudine & craſsitudine æquabant maximas pyramides ligneas illas, quibus in Pyramidum ludo (globo ligneo prouoluto ſternēdis) utuntur: Hi omnes appendebant centum libras, (XVI. *unciarum nimirum.*) Superior uerò mandibula uacua & ſine dentib. inferioris dentes claudēdos in ſe recipiebat. Cauda lata pedes tredecim, & iuxta proportionem ſatis craſſa, cum appendicibus quibuſdam clypei inſtar rotundis. Oculi paulò minores ferè equinis, aſpectu obſcuro. Caput longum tres paſſus. Rictus latus paſſum unum, et ſimiliter lingua. Pinna etiam *(eo loco quo branchiæ in piſcibus eſſe ſolent)* eiuſdem longitudinis. Membrū genitale, longum pedes quatuor. Teſticuli magnitudinis pilæ trigínta librarum. In ſummo capite foramen dodrantis longitudine, ſed inflexum inſtar nouæ Lunæ: quo aquā eiaculabatur, ita ut me

Fig. 2. A portion of the document reporting the live stranding of a male sperm whale 12.4m long in Piran, Slovenia, on 1 June 1555. As yet, this is the oldest account in the Adriatic Sea. The text, in Latin, includes an accurate description of the animal's external morphology and a mention to killing circumstances and subsequent use (from the post-1555 Addenda to Gesner 1553, p. 367; http://tinyurl.com/yzu8sem and see Kryštufek & Lipej 1985, 1993, Kryštufek 1991).

Various degrees of inconsistency were found, particularly in early reports. Authors often quoted one another or relied on second-hand reports, making assessment difficult. Redundancy was aggravated by occasional inconsistencies including year or location (Table 1; also see the following discussion). Because such inconsistencies could result in overestimation of the actual number of mortality events (e.g. due to the same event being reported more than once with different dates or locations), we preferred to err on the precautionary side by only including the most accurate, authoritative or consistent information whenever there was inconsistent reference to records likely to be single rather than multiple events.

An example of problems found assessing the historical literature, even when information was reported by authoritative naturalists, is provided by live strandings of sperm whales near Pesaro, Italy, in 1713 and 1715. Ranzani (1821), referring to engravings by Domenico Franceschini and Bartolomeo Griffo, reported a sperm whale stranding near Pesaro on 18 April 1715. Procaccini Ricci (1825), however, reported 18 April 1713. Nardo (1854) suggested that the 1715 event was likely a misdating of the former. Cornalia (1872) also referred to the engraving by Domenico Franceschini, but reported 19 April 1713 as date of stranding and elaborated that the

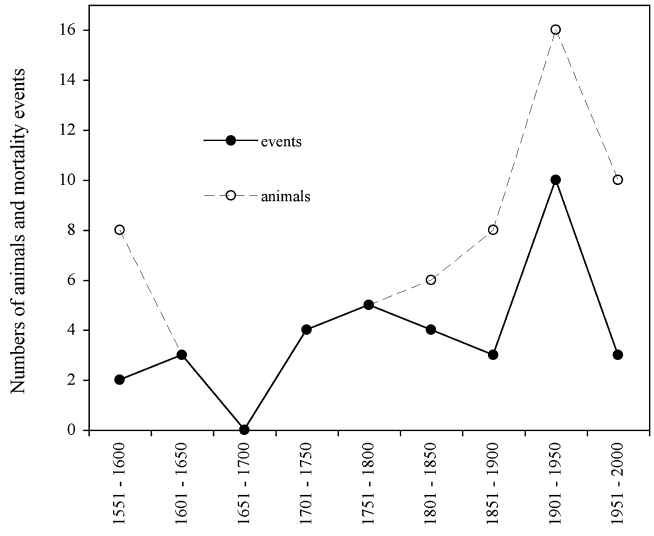


Fig. 3. Mortality events involving sperm whales in the Adriatic Sea ($n = 34$), and numbers of animals involved (total $n = 60$), subdivided into 50-year blocks between 1551 and 2000. Mortality events in 2001–09 are not included.

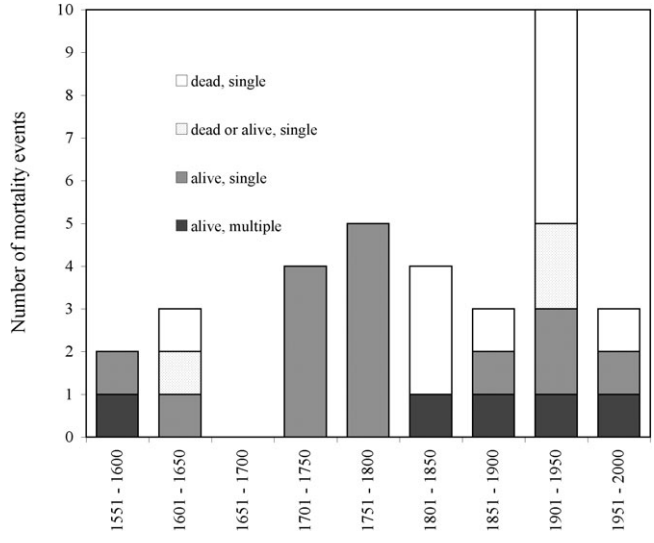


Fig. 4. Relative occurrence of 34 mortality events by type and number of animals involved, subdivided into 50-year blocks between 1551 and 2000. Mortality events in 2001–09 are not included.

correct date was probably 18 April 1713. In addition, Cornalia (1872) mentioned a stranding in the Gulf of Venice in 1715, based on Klein (1741). Brusina (1889) and Parona (1896; again referring to the engraving by Franceschini) reported two events – 10 April 1713 and 18 April 1715 – but reiterated the concern by Nardo that the latter could be a misdating of the former. Parona (1896) also reported a stranding in the Gulf of Venice in 1715. Other reports referred to distinct events that occurred in

Pesaro in 1713 and in the Gulf of Venice in 1715 (De Marchesetti 1882, Trois 1894), while De Sanctis (1879) listed a stranding in Pesaro in 1715 and another in the Gulf of Venice in 1715. It should be noted that in historical times, 'Gulf of Venice' was used to refer to a large portion of the northern Adriatic (which included Pesaro), or even to the whole Adriatic Sea. In this specific case, based on the available information, it was virtually impossible to determine whether the various dates of stranding originated from a mistake, or if there were two separate mortality events. We arbitrarily opted for the latter hypothesis and validated two events (Table 1).

Another complex case concerned the live stranding of three sperm whales near Porto Sant'Elpidio, Italy, on 30 December 1802, reported by Franzoi (1898). This report probably referred to the stranding of three sperm whales in Porto Sant'Elpidio in 1805, described by many authors (Procaccini Ricci 1825, Nardo 1854, Cornalia 1872, De Marchesetti 1882, Brusina 1889, Trois 1894, Parona 1896). Parona (1909) subsequently referred to Franzoi (1898) and only mentioned a stranding in 1802. De Sanctis (1879), however, reported 1803 as the year of stranding, providing no information other than year and location ('S. Elpidio'). Although it is possible that these were distinct events, we felt it was unlikely, and therefore validated only one event (Table 1).

The historical literature often included slight variations or errors, some of which became apparent when the reported information was matched with the original sources. This suggests that some single events may have been inadvertently turned into multiple records over time. Modern accounts sometimes contributed to the confusion rather than to clarification. For instance, Rossi and Graccaceva (2008, p. 21) misreported the caption in a watercolour by Ulisse Aldrovandi and stated that it referred to a sperm whale stranded in 1507, whereas the original drawing indicates 1584. Additional sources clarified that this was a mass stranding of seven or eight animals. In this case, the date handwritten by Aldrovandi was probably misinterpreted – possibly because of Aldrovandi's peculiar way of writing some numbers – and the event was assumed to have been a single stranding, whereas it actually involved several individuals 77 years later.

A few other instances of misdating, confusion and misidentification were found, possibly generated by reliance on someone else's reports combined with insufficient empirical investigation or reporting accuracy. Difficulties in the assessment of controversial or incomplete reports tended to be greater when dealing with events dating back centuries. Recent events were generally better documented and sometimes could be validated through inspection of multiple sources, as well as photos or videos. As expected, the quality of scientific reporting increased over time, with lower chances of error deriving from reiteration of second-hand information.

DISCUSSION

Long-term time series of stranding events are the most reliable data to provide a scientific framework for testing hypotheses that seek to explain the patterns observed and mechanisms responsible for cetacean strandings (Bradshaw et al. 2006). We contribute a long-term data set based on careful validation of historical information, suitable for hypothesis testing aimed at investigating spatial and temporal correlates of sperm whale strandings – particularly live strandings – as a clue to their causes. As yet, the causes of cetacean strandings remain largely unknown (Simmonds 1997, Geraci et al. 1999, Goold et al. 2002, Bradshaw et al. 2006),

although many hypotheses have been advanced. These have included pathology (Jauniaux et al. 1997, Lambertsen 1997); meteorological and oceanographic disturbances such as hurricanes (Mignucci-Giannoni et al. 1999); navigation failure related to use of the Earth's geomagnetic field (Klinowska 1985a, b, Kirschvink et al. 1986, Klinowska 1988, Kirschvink 1990; but see Brabyn & Frew 1994); changing solar activity (which might temporarily influence the geomagnetic field or, over longer periods, the sea surface temperature; Vanselow & Ricklefs 2005, Vanselow et al. 2009); electrical storms (Robson & van Bree 1971); the effects of lunar cycles (Wright 2005); confused navigation arising from bathymetric conditions (Brabyn & McLean 1992, Woodings 1995, Chambers & James 2005); distraction by activities such as foraging (Wood 1979); large-scale climatic events (Evans et al. 2005) or temperature anomalies influencing prey distribution (Pierce et al. 2007); and anthropogenic encroachments such as intensive sound disturbances (Simmonds & Lopez-Jurado 1991, Frantzis 1998, Balcomb & Claridge 2001) and contaminants (Bouquegneau et al. 1997, Joiris et al. 1997, Evans et al. 2004), which may either cause or contribute to strandings (Geraci et al. 1999). While any of these hypotheses may be relevant as causes or concauses, depending on situation, Whitehead (2003) noted that whales stranding *en masse* are not brought to the beach independently because of some common external factor: strandings clearly have a strong social component, which may prompt healthy animals to follow sick or confused ones onto a beach ('doing as the group does'; Whitehead 2003).

Multiple live strandings of sperm whales in the Adriatic Sea have occurred since historical times – the oldest known dating back to 1584. It is reasonable to assume that anthropogenic causes may be ruled out in cases dating back centuries (Pierce et al. 2007). Mortality events involving multiple individuals accounted for at least 17% of the total sample (6 of 36 mortality events), and all of them were live strandings. At least 29% of live strandings (6 of 21) involved more than one individual. In other words, almost one in three live strandings were multiple strandings (Fig. 4). In addition, some reports of single individuals stranded dead or alive included mention of one or more other sperm whales sighted at sea in the immediate vicinities of the stranding location, sometimes for days. Groups of sperm whales stranded in the Adriatic Sea (range three to eight individuals; Table 1) seem small compared to the mean size of groups stranded outside of the Mediterranean Sea (e.g. Rice et al. 1986, Rice 1989, Christensen 1990), where stranding events occasionally involve 100+ animals (Evans et al. 2002).

The relatively common occurrence of mortality events along portions of the Adriatic Sea coast that are not in the proximity of suitable sperm whale habitat, many strandings occurring in coastal areas facing shallow continental shelf waters (Fig. 1), may be consistent with the notion that some parts of the upper Adriatic Sea act as 'sperm whale traps' (see Smeenk 1997, Goold et al. 2002, Pierce et al. 2007), where animals may become cornered for an extended period of time in areas containing little, if any, suitable food. Spiridion Brusina (1845–1908), professor of zoology and director of the Zoological Museum in Zagreb, noted that the majority of sperm whale mortality events occurred along the western Adriatic coast, particularly between Chioggia and Porto S. Giorgio, and noted the absence of strandings (at that time) further south along the Italian coast (Brusina 1889). He suggested that sperm whales entering the Adriatic Sea moved north along the eastern coast, where waters are deeper, following the main northbound circulation. He then speculated that

when sperm whales wanted to exit the cul-de-sac, they followed the southbound stream along the Italian coast, where they often stranded in shallow waters. Brusina concluded that the Adriatic Sea may be a 'hazardous strait' for animals used to open ocean waters. While this interpretation is conjectural, the geographic distribution of sperm whale mortality events in the Adriatic Sea is clearly uneven: the majority of records occur along the Italian coast, particularly between Pescara and Rimini (Fig. 1). This portion of the coastline (approximately 280km long) covers only a small part of the whole Adriatic Sea coast, but it included 44% ($n = 16$) of total mortality events.

Several factors other than those suggested by Brusina may have contributed to this apparently anomalous distribution pattern. Low occurrence of records in some parts of the Adriatic may relate to rocky coasts or uninhabited areas where strandings had lower chances of being reported, or where animals were unlikely to be inspected. Dead animals floating along rocky coasts may be washed away by waves until they get stuck on sand. In addition, animals stranded on a beach may be more easily inspected, and the sandy Adriatic coast of central Italy is (and historically was) more densely inhabited than other coastal portions of the Adriatic. Sperm whale strandings around the world often do not occur at random locations, and stranding frequencies are relatively high on gently sloping sandy beaches with high wave action (Brabyn & McLean 1992), somewhat similar to those in the central part of the western Adriatic Sea. While other conjectures may be added to those of Brusina, the reasons behind the observed geographic distribution of mortality events in the Adriatic Sea remain unknown, and deserve further investigation. Modelling of sperm whale strandings and environmental time series including climate anomalies (e.g. Pierce et al. 2007) goes beyond the scope of this contribution, but future researchers can benefit from the data set presented here. A comprehensive review and careful validation of sperm whale mortality events in other parts of the Mediterranean Sea would bring additional insight, and may clarify whether there is a relationship between stranding hotspots and basin physiography or beach topography.

The temporal trend of sperm whale mortality events, and particularly the peak recorded in the first half of the 20th century (Figs 3 and 4), may be related to improved reporting. An even higher number of strandings should be expected after the 1950s, also considering that in Italy an effective cetacean stranding network has been in place since the mid-1980s, and awareness of environmental issues has generally increased throughout the region, together with scientific interest in cetaceans (Bearzi et al. 2005). The number of mortality events in the second half of the 20th century, however, was particularly low and inconsistent with the expected increase due to reporting effectiveness and geographic coverage (e.g. linked to increases in population size and use of coastal areas). A larger data set covering other portions of the central Mediterranean Sea would be needed to investigate whether stranding trends in the 20th century are linked to factors such as increased anthropogenic pressures resulting in population decline. Alternative hypotheses should be considered, including changes in sperm whale numbers and distribution caused *inter alia* by shifts in prey distribution and availability, as well as temperature anomalies and other factors (Pierce et al. 2007).

Since medieval times, sperm whales and other whales that stranded alive or approached the coast were typically seen as resources and often killed to extract oil (Szabo 2005, Bearzi et al. 2010). Nevertheless, there was never a commercial whaling tradition within the Mediterranean Sea (Notarbartolo di Sciara & Bearzi 2002).

Killing of small cetaceans was common until the 1960s, including in the Adriatic Sea where dolphins were exterminated by the thousands (Bearzi et al. 2004). Cases of sperm whale killings in the Adriatic, however, almost certainly involve animals in difficulty, slaughtered prior to stranding or following a live stranding, rather than being outcomes of improvised or systematic whaling expeditions. Killing of live-stranded animals occurred opportunistically and was frequent until the first half of the 20th century. In two cases of mortality that occurred around the two World Wars, sperm whales were killed by mines or blown up by the military – either by accident, for entertainment or because the whales were used as opportunistic targets. Until 1943, all but one case of live stranding with known human response elicited killing attempts. Starting from the 1980s, however, killings were replaced by efforts to rescue the animals (Table 1; Bearzi et al. 2010).

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