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Cetacean mass strandings in the Hawaiian Archipelago, 1957–1998

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Abstract

Cetacean mass stranding data for the Hawaiian Archipelago, from 1957 through 1998, were analyzed to determine age (estimated from body length), location, frequency, and seasonal distribution of stranding occurrence. Using data collected from the National Marine Fisheries Service Pacific Area Office and published news reports, 9 mass stranding events, involving 4 species comprised of 96 animals, were identified and analyzed. The stranded animals were predominantly adult odontocete whales. Ninety-five percent of the animals that came ashore were alive at the time of stranding. Human intervention occurred in all of the live mass stranding events however, 81% of the animals subsequently died. Short-finned pilot whales (*Globicephala macrorhynchus*) stranded in the largest groups and experienced the greatest number of stranding events (x=14 animals, 5 events); pygmy killer whales (*Feresa attenuata*) stranded in two events, consisting of 2 and 4 animals each; and rough-toothed dolphins (*Steno bredanensis*) stranded in one event in a group of 18 live animals. One pygmy sperm whale (*Kogia breviceps*) event was a female stranding with a calf. The greatest incidence of mass strandings occurred on the Island of Maui during the month of June. Mass strandings occurred on all high Hawaiian Islands, except Hawaii; none were reported on the islands, or atolls north of Kauai. Two-thirds of the events occurred on the leeward sides of the islands with similar bottom topography, coastal configuration, and geomagnetic characteristics in all events.

Introduction

Cetacean strandings have been reported since 335 BC (Aristotle, 1964). During the last several decades of systematic record keeping we have learned that there are several types of strandings; including those strandings that involve only one animal and those that involve more than one animal. There are also distinctions between strandings of carcasses and those of live animals. Some strandings are simply explained because animals die at sea and were washed ashore by the wind, tides, and currents. However, the causes of those animals stranding alive are not fully understood, nor has it been determined whether they come ashore deliberately or accidentally.

While single strandings are usually explained as natural mortality, due to a variety of disease factors (Brabyn & McLean, 1992), injury, weather, food supply, toxic pollutants, and other human activity (Geraci & St. Aubin, 1979), mass strandings are not as easily understood. New hypotheses suggest mass strandings are a result of different circumstances than single strandings (Sergeant, 1982; Leatherwood *et al.*, 1988), and appear to be unique to toothed cetaceans (Geraci, 1978). Some suggested theories of mass strandings include sick leaders, mass suicide, entrapment due to falling tides, confused echolocation, following ancient migratory routes that no longer exist, ritual burial, a response to over-population (Leatherwood *et al.*, 1988; Martin *et al.*, 1990), phases of the moon (Robson, 1984), conditions of oceanography and coastal topography (McCann, 1964; Stephenson, 1975; Sergeant, 1982; Nicol, 1985; Barbyn & McLean, 1992; Barbyn & Frew, 1994), and geomagnetic factors (Klinowska, 1985, 1986a, 1986b, 1988; Kirschvink *et al.*, 1986; Kirschvink, 1990; Walker *et al.*, 1992).

Mass strandings appear to have more complex causes and involve from several to hundreds of individuals (Leatherwood *et al.*, 1988). Much of the complexity in determining causes for mass strandings is that stranded herds often consist of live, apparently healthy animals, while others are not healthy (Odell *et al.*, 1989). Similarity in the species, group dynamics (Porter, 1977), site conditions (McCann, 1964; Stephenson, 1975; Sergeant, 1982; Nicol, 1985), and the way in which they beach

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themselves has been reported (Dudok van Heel, 1962; Porter, 1977; Odell *et al.*, 1980).

There are at least 19 species of odontocetes that have been known to mass strand (Odell *et al.*, 1989; Martin *et al.*, 1990), with short-finned pilot whales (*Globicephala macrorhynchus*), false killer whales (*Pseudorca crassidens*), and sperm whales (*Physeter macrocephalus*) stranding most often (Odell *et al.*, 1989). To date, the only mysticetes recorded in a mass stranding event were 15 humpback whales (*Megatera novaeangliae*), 4 minke whales (*Balaeanoptera acutorostrata*), and 2 fin whales (*Balaeanoptera physalus*). The humpback whales came ashore in late 1987 and early 1988 on the east coast of the United States near the Cape Cod area. Tests done on the mackerel found in the stomachs of the animals sampled showed the presence of a toxin with effects similar to that of paralytic shellfish poison biotoxins (Geraci *et al.*, 1989). The purpose of the present study was to perform a retrospective survey analyzing data from the mass strandings of cetaceans in the Hawaiian Archipelago.

Methods

The study covers the coastal areas of the Hawaiian Archipelago extending from Kure Atoll (28.00°N, 179.00°W) to the Island of Hawaii (19.30°N, 154.70°W). The 40 year period from 18 June 1957 through 31 December 1998 was analyzed. A mass stranding event was defined as two or more animals of the same species stranding simultaneously at the same location (within an 8 mile radius), or when a part of the same group stranded within one or three days after the first recorded stranding. The latter is indicated in the notes as a mass stranding (i.e. part of group), even though it was reported as separate occurrences (Table 1).

Three stranding occurrences (6/28/76, 6/30/76, and 7/17/88) were combined and considered one stranding event rather than counted as three separate strandings. When two animals stranded (2 of 9 events), the stranding was either a cow/calf association or two adults from a group stranding in the same location within a day of one another.

Stranding data were obtained from the National Marine Fisheries Service (NMFS), Pacific Area Office. This information was confirmed and augmented by comparison with data from stranding response personnel involved with the Marine Mammal Stranding Network of Hawaii and with data published in local newspaper reports. Data of stranding, location, body length, gender (if known), and estimated age were documented. The month of stranding was the NMFS report date and/or the date of news articles. From the body lengths and notes from the stranding reports, we estimated age classes for each species of the stranded cetaceans.

In order to examine the distribution of the strandings, the stranding data were plotted in subsets of the total force magnetic intensity map of the Hawaiian Swell which was contoured at 100 gammas by Malahoff & Woollard (1966). The illustrated maps (Fig. 2) are re-drawn from Figure 1 of Malahoff & Woollard (1966). Since the publication of Malahoff & Woollard (1966), the cgs (cm/gm/sec) system unit of magnetization (gamma) used in the original publication has been changed to SI (Systeme International) units, 1 gamma = 1 nT. Periods of magnetic disturbance around the time of the strandings were also analyzed using the geomagnetic Kp or Planetary 3-hour range index. Eight 3-hour values for the day of the stranding and the 3-hour values for the three days prior to and including the stranding were examined. In addition, the daily sums of the Kp indices for the entire month of each stranding were compared.

Results

There were 9 mass stranding events, with a total of 96 animals (Table 1). Four species of cetaceans were reported. All were the suborder Odontoceti, 3 of the family Delphinidae, short-finned pilot whales (*Globicephala macrorhynchus*), rough-toothed dolphins (*Steno bredanensis*), and pygmy killer whales (*Feresa attenuata*), and 1 from the family Kogiidae, pygmy sperm whale (*Kogia breviceps*).

The number of strandings per year was unevenly distributed from 1957 to 1998, with intervals ranging from 5 months to 17 years between events (Table 1). Nearly half of all mass stranding events (4/9), and more than half of the total number of animals (57/96), occurred during two years, 1958 and 1976 (Table 1). There were no mass stranding events during periods of the El Niño Southern Oscillation.

Mass stranding events tended to occur in the summer, when nearly 2/3 of them were reported (Table 1). The greatest frequency occurred in June, 34%, and strandings were evenly dispersed in July, and October, 22%, and January and May, 11% (Table 1). There were no reported strandings in the remaining 7 months of the year.

The species that mass stranded with the greatest frequency and in the largest numbers was the short-finned pilot whales (*Globicephala macrorhynchus*), occurring in 5 of the 9 stranding events, with 14 animals ± 5.2 (means ± standard error) per stranding event (Fig. 1a,b). Pygmy killer whales (*Feresa attenuata*), stranded twice in the 40 year period followed by rough-toothed dolphins (*Steno bredanensis*) in one event of 18 animals, and pygmy

Table 1. Cetacean mass strandings reported in the Hawaiian Archipelago from 1957 through 1998. Years not listed indicate that no mass strandings were reported

Date	Species	Island	Gender (M.F.)	Body length (cm)	Number of animals	Status	Notes
18 Jun 1957	*G. macrorhynchus*	Oahu	Unknown	396	2	Alive	1 died, 1 was transported to the Waikiki Aquarium and died 6 days later. Both adult.
03 Oct 1958	*G. macrorhynchus*	Lanai	Unknown	213–457	24	Alive	23 died. 1 swam free and was harassed by sharks 200 yds offshore. All adult.
28 Oct 1958	*G. macrorhynchus*	Kauai	Unknown	366–457	12	Alive	8 died when trapped behind reef, 4 swam free. All adult.
10 May 1959	*G. macrorhynchus*	Kauai	Unknown	Unknown	28	Alive	All 28 died when trapped behind reef. Similar incident to that occurring on 28 Oct 1958.
27 Jun 1976	*S. bredanensis*	Maui	3.2	228; 218; 235; 227; 209	18	Alive	18 plus fetus. On the first day: 4 died on the beach, 1 died enroute to Honolulu, 1 taken to Sea Life Park where it lived for 2–3 years in captivity, and 12 assisted off the beach. A total of 9+ fetus died, or re-stranded and died, over the next 4 days. The fate of the remaining 9 animals is unknown.
*28 Jun 1976	*S. bredanensis*	Maui	1.2 (F)	202; 215; 211 (93)	—	Fresh dead	3 plus fetus found on the beach in the a.m. Part of group.
*30 Jun 1976	*S. bredanensis*	Maui	Unknown	Unknown	—	Fresh dead	1 found on beach in the a.m.
29 Jul 1976	*K. breviceps*	Maui	0.1+C	284+C	2	Alive	Mother euthanized/calf swam away.
13 Jun 1981	*F. attenuata*	Maui	1.1	264; 259	4	Alive	1 died—others assisted to sea.
16 Jul 1988	*F. attenuata*	Maui	1.0	230	1	Alive	Euthanized, emaciated, adult.
*17 Jul 1988	*F. attenuata*	Maui	1.0	240	1	Fresh dead	Emaciated, part of group, adult.
28 Jan 1989	*G. macrorhynchus*	Molokai	Unknown	519	4	Decomposed	

*Indicate the stranding events were combined with the prior report.

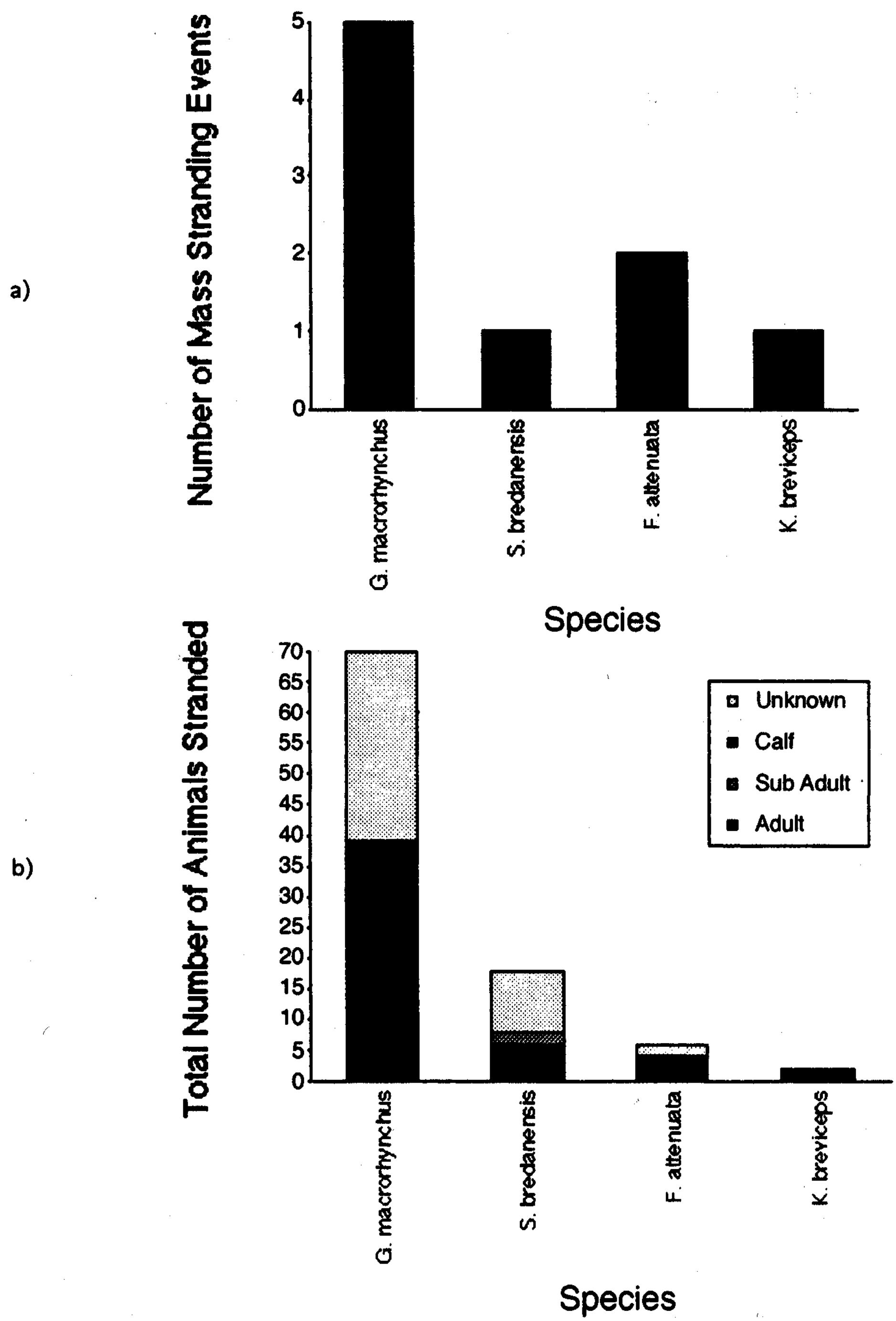

Figure 1. (a) Number of cetacean mass stranding events, and (b) total number of individual cetaceans stranding by species in the Hawaiian Archipelago from 1957 through 1998. The individuals were combined from all of the mass stranding events in each age class. Stranding reports that did not have a length reported, or notes indicating an age class, were classified as unknown.

sperm whales (*Kogia breviceps*) with 2 animals (Fig. 1a,b).

Data on body length and corresponding notes were available for 53 of the 96 animals recorded (Fig. 1b, Table 1). Of the 55% reported, body length indicated that 94% (50/53) were adult, 4% (5/53) sub adult, and 2% (1/53) calf. The remaining animals were of unknown age class and had unreported length. Information on gender was available for only 13 of the 96 animals recorded, 6 were female and 7 were male (Table 1).

Ninety-five percent of the mass strandings were live animals. The remaining 5% died 1–2 days before or, as in one case, was decomposed (Table 1). Although rescue effort occurred in all of the live mass strandings incidents, at least 81% of the animals died (Table 1). The majority, 75%, died within 24 hrs, and the remaining 6.5% died within a week either in captivity or by re-stranding.

Each of the main Hawaiian Islands, except the Island of Hawaii, recorded at least one mass stranding, although the number of strandings per island was variable (Table 1). The greatest incidence of mass strandings occurred near Kihei, Maui, followed by Kauai. There was one stranding each on Oahu, Molokai, and Lanai. There were no mass stranding events reported in the Hawaiian Archipelago north of Kauai or south of Maui. One-third of the mass strandings were reported from the windward coasts and 2/3 from the leeward coasts (Fig. 2b).

The coastal configurations common to all of the mass stranding locations included shallow water bathmetry and fringing reefs. Extensive fringing reefs were found along 4 of the 5 shores (Kauai, Oahu, Molokai, and Lanai) and a gently sloping, sandy bay was present along the remaining shore (Maui). Additional bottom topography common to the sites with fringing reefs were either a bay or inlet, a gradual slope to the beach, and/or a sandy bottom between the reef and shoreline.

The magnetization of these volcanic islands is generally complex with paired highs and lows of the magnetic field (bipole anomalies) and a steep gradient between the bipole. The strandings occurred along coastlines with intermediate magnetization between high and low contours and near steep gradient anomalies (Table 2). Profiles of the magnetic intensity parallel to the coast are shown with arrows marking the stranding sites (Fig. 2b). The stranding on western Molokai is located seaward of a strong bipole anomaly field. The bipolar nature of this field is not well expressed in the offshore, therefore an onshore profile is shown for western Molokai (Fig. 2b). The intensity of the magnetic field along the profiles (Fig. 2a) illustrates that the strandings occurred within a narrow range of intensities, between 36 000 to 36 600 gammas (Table 2). Strandings did not correspond to magnetic variations associated with peaks in sun-spot activity.

Discussion

Similar to the findings in this report, cetaceans that mass stranded elsewhere in the world tended to come ashore alive, mainly during the summer months. The highest number of strandings in Tasmania were recorded in January, an austral summer month, and the winter months of July and August had fewer recorded events (Nicol, 1986). Similarly, in southeastern Australia more strandings were recorded in summer than in winter (Warneke, 1988).

There are several other similarities between mass strandings in Hawaii and in other parts of the world. For example, during the same month in 1958, there was a large herd of sperm whales (*Physeter macrocephalus*) that stranded in New Zealand (Robson, 1984). Similarly, occurring in the same month and a similar latitude in 1976, there were 2 large herds of spinner dolphins (*Stenella longirostris*) and false-killer whales (*Pseudorca crassidens*), that mass stranded near Florida (Odell *et al.*, 1980). While it is possible that the results of the present study share certain similarities with other events, none are as curious as those consistent with the hypotheses that certain coastal configurations and bottom topography, and/or geomagnetic anomalies may play a role in the cause and location of mass strandings.

In New Zealand, Brabyn & McLean (1992) found that coastal morphology was an important factor to be considered in mass strandings of cetaceans rather than the magnetic field of the area. There reports suggested that multiple-herd strandings in New Zealand appeared to have the similar coastal configurations of a protrusion from the coastline and an association with long, gently sloping beaches. Concentrations of mass strandings occurred along protrusions of the coastline associated with a gently sloping bottom in Mexico (Gilmore, 1957), Western Australia (Mell, 1988), Tasmania (Warneke, 1983), Senegal (Sergeant, 1982), and Cape Cod, Massachusetts (Mead, 1979).

All of the mass stranding sites reported in Hawaii were associated with fringing reefs, shallow water bathymetry, sandy bottoms, and/or a gently or gradual slope to the beach (Grace, 1974; Campbell, 1987; Keating, 1994). On Maui, for example, 4 of 4 strandings occurred in the Ma'alaea Bay, which borders the Kihei isthmus, and has a gently sloping bottom. Sea level in the Hawaiian Islands is a function of global sea level and subsidence of the islands related to hot-spot volcanism. At many times in the last few million years, the isthmus

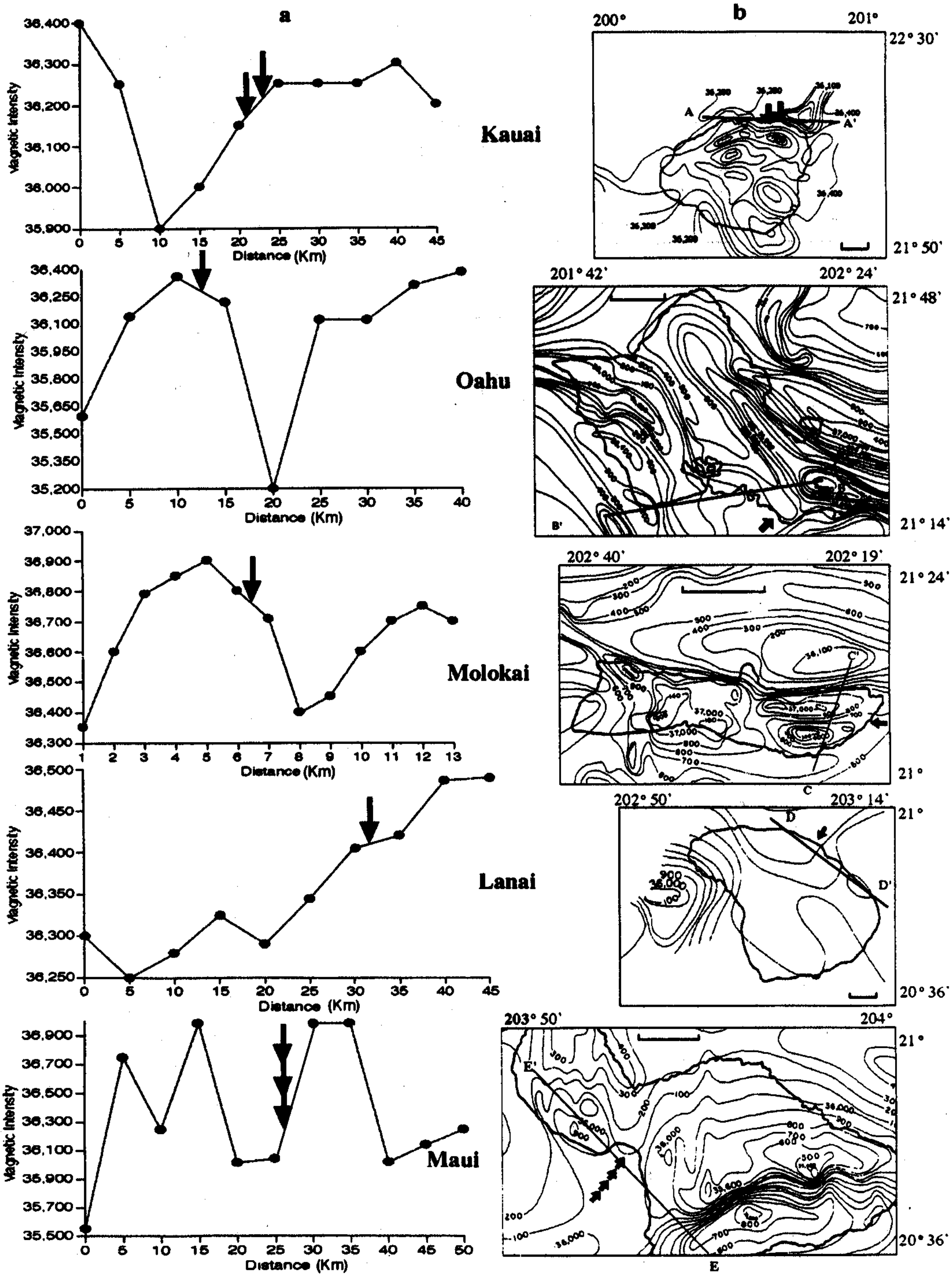

Figure 2. (a) Magnetization profiles for the stranding locations are shown on the magnetic anomaly maps. Discrete points were measured every 5 kms along the profile except on Molokai, where the measurements occur every 1 km. Arrows mark the location of strandings on the profiles. The strandings generally occur within the transition intervals between high and low values of the magnetic field and near high magnetic gradients. (b) Total force magnetic intensity maps (contoured at 100 gammas) of the Hawaiian Swell for the islands of Maui, Molokai, Lanai, Oahu, and Kauai (from Malahoff & Woollard, 1966). Shaded areas show high anomaly lines running parallel to stranding site. Arrows indicate number and location of cetacean mass stranding events. Magnetic field intensity along the profiles illustrates that the cetacean mass stranding events occurred within a narrow range of intensities (between 36 000 to 36 600 gammas).

Table 2. Magnetic field intensity range of Hawaiian Islands where cetacean mass strandings occurred. Intensity is reported in gammas and marked with an asterisk. † marks the point where the stranding(s) occurred. The number of symbols denotes the number of stranding events. Magnetic field intensity along the profiles illustrates that the cetacean mass stranding events occurred within a narrow range of intensities (between 36 000 to 36 600 gammas)

Intensity (in gammas)	Oahu	Maui	Molokai	Lanai	Kauai
37 400	*				
37 300	*				
37 200	*		*		
37 100	*		*		
37 000	*		*		
36 900	*	*	*		
36 800	*	*	*		
36 700	*	*	*		*
36 600	*	*	*		*
36 500	*	*	†	*	*
36 400	*	*	*	†	*
36 300	†	*	*	*	*
36 200	*	*	*	*	††
36 100	*	*	*	*	*
36 000	*	††††	*	*	*
35 900	*	*		*	
35 800	*	*		*	
35 700	*	*			
35 600	*	*			
35 500	*	*			
35 400	*	*			
35 300	*				
35 200	*				
35 100	*				
35 000	*				
34 900	*				
34 800	*				
34 700	*				
34 600	*				

on Maui may have been an open sea passage (MacDonald & Abbott, 1970), implying that the bottom topography of the region may not sufficiently reflect the approaching land mass for stranding cetaceans to properly navigate.

In relation to geomagnetic anomalies, through an analysis of single-animal strandings along the British coast, Klinowska (1985) found that live-strandings occurred excessively within the transition between geomagnetic highs and lows along the coast. Conversely, Walker *et al.* (1992) report on association between the sightings of migrating fin whales over the continental shelf off the north-eastern United States with low geomagnetic intensities. The islands and atolls of the Hawaiian Islands were formed from millions of years of volcanic activity. All of the Hawaiian Islands south of Niihau are high volcanic islands with strong magnetic anomalies. All of these, except the island of Hawaii, recorded mass strandings. The atolls to the northwest of Niihau are low carbonate banks built upon the volcanoes which have subsided below sea level. The carbonate banks have lower magnetization. There were no mass strandings reported north of Kauai even though the United States Department of Defense, Department of Transportation, Fish and Wildlife Service, National Oceanic and Atmospheric Administration, and National Marine Fisheries Service report that there was sufficient human presence to observe mass strandings had they occurred on any of the islands north of Kauai in the Hawaiian Archipelago during the years of this report.

Magnetite is a substance that is based on chains of ferrimagnetic particles (single-magnetic-domain Fe_3O_4), and is found inside of some organisms. An orientation process based on the earth's magnetic field has explained the behaviour of some bacteria and algae (Frankel, 1986). The magnetite crystals provide enough alignment in the Earth's magnetic field against thermal agitation to force the organism to swim along the field lines, thereby remaining in their preferred habitat and avoiding the toxic effects of oxygen (Frankel, 1986). A relationship between geomagnetic cues in the context of travel was found when pigeons were deflected from their normal flight paths in relation to the intensity of the magnetic disturbance (Keeton *et al.*, 1974). More recently, in a variety of shapes and sizes magnetite crystals have been reported in a range of higher organisms, including cetaceans (Bauer *et al.*, 1985; Kirschvink *et al.*, 1986).

In this study, ninety-five percent of the mammals that came ashore were alive at the time of stranding. Yet all the strandings occurred within only a narrow range of 500 gammas. The absence of scatter in the results suggests the impact of dead organisms is insignificant. Since the earth's magnetic field intensity varies from about 29 000 gammas near the equator to 80 000 at the poles, the strandings reported in the present study occurred at a narrow range of less than one percent of the earth's magnetic field strength. If we take a more restricted look at the Hawaiian Islands, the magnetic field ranges from 37 400 to 35 200 gammas (Malahoff & Woollard, 1966), and the Hawaiian mass strandings were restricted to a range of only twenty percent of the regional field intensity.

Kirschvink *et al.* (1986), examining strandings on the east coast of North America, reported *Lagenorhynchus*, *Balaenoptera* and *Globicephala* stranded at magnetic minima, while *Delphinus*, *Grampus*, and *Ziphiidae* stranded at magnetic highs. In the present study, the strandings on Kauai, Oahu, Molokai, and Lanai occur near magnetic highs while repeated strandings on Maui occur at a magnetic low. Only the *Globicephala* in Hawaii stranded near geomagnetic highs on several islands. All other species stranded near geomagnetic minima. While Kirschvink *et al.* (1986) suggest strandings occur at coastal localities with local magnetic minima, our observations around the Hawaiian Islands show the strandings occur between magnetic highs and lows. The suggestion by Kirschvink *et al.* (1986) that the organisms are displaying a behavior of avoidance of high magnetic areas remains a distinct possibility.

While other authors have suggested that strandings occur at protrusions of the coastline, in Hawaii, repeated strandings occurred at a salient in the coastline in Maui. They also occurred on Oahu at a salient. None of the strandings in the Hawaiian Islands were associated with protrusions in the coastline.

Magnetic disturbances associated with sun spot activity are another source of magnetic variation that organisms might detect. To determine if the strandings corresponded with highly disturbed magnetic periods, we examined the geomagnetic Kp or Planetary 3-hour range index on and around the time of strandings. We examined the eight 3-hour values for the day of stranding, the 3-hour values for the three days prior to and including the strandings, and made comparison of the daily sums of the eight Kp indices for the entire month in which the strandings took place. The strandings did not correspond with strong variations in the magnetic field associated with peaks in sun-spot activity.

Often strandings are recovered on windward shores as they are likely blown ashore, while many leeward strandings may never be recovered or reported. The opposite was revealed in the present study, in that more mass strandings were found on the leeward shores of the islands than windward shores. This finding reinforces suggestions that geomagnetic anomalies as well as coastal configuration and bottom topography possibly affect the navigation of the animals.

Consistent with other reports of mass strandings, often the animals come ashore alive (Klinowska, 1985, 1986b). The present study reveals that nearly all of the animals mass stranding in Hawaii came ashore alive. Yet, even with well intentioned and immediate human response and intervention, a majority (81%) of the living animals died. A portion of those animals last seen alive were most likely unable to survive in their habitat after the event, as either the animal was a calf and was subsequently harassed by sharks, or the animals was in poor condition and taken into captivity to be rehabilitated. One rehabilitation attempt was successful, with one of the rough-toothed dolphins maintained in captivity for 2 years. The other rehabilitation attempt resulted in the animal expiring within one week.

In regard to the data used for this report, the cause of death in the stranded animals was never determined with certainty. Many of the animals stranding in large groups appeared to be healthy, but seemed unable to free themselves from the reefs that blocked access to the open ocean. Complete necropsies of future stranded animals will allow a more reliable investigation into cetacean mortality and provide a greater ability to evaluate the potential role of natural phenomena or human activity.

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