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Behavior of melon-headed whales, *Peponocephala electra*, near oceanic islands

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ABSTRACT

Southall *et al*. (2006) concluded that a near mass stranding (MS) of melon-headed whales (MHWs), *Peponocephala electra*, in Hanalei Bay, Kauai, Hawaii, on 3–4 July 2004, was likely related to the operation of mid-frequency sonars (MFS). However, subsequent authors argued that the nearly simultaneous entry of MHWs into Sasanhaya Bay, Rota (~5,740 km away) made this conclusion untenable. They suggested that both sightings, and other MSs of MHWs, could be related to lunar cycles. To resolve this question, we reviewed information on the biology and behavior of MHWs and compared the two sightings to observations of MHWs around Palmyra Atoll and Nuku Hiva, French Polynesia. We also tested for a relationship between observations and MSs of MHWs with lunar cycles. MHWs near many oceanic islands rest nearshore during the day and feed offshore in deeper water at night. The MHWs at Rota exhibited normal diurnal resting behavior as seen at Palmyra and Nuku Hiva, while those at Kauai showed milling behavior typically seen prior to MS events. Thus, these events were not similar. Neither

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observations nor MSs of MHWs were related to lunar cycles. Our review of MHW behavior strengthens the case that MFS use played a major role in the near MS in Hanalei Bay.

Key words: melon-headed whales, *Peponocephala electra*, mass-stranding, mid-frequency sonar, behavior, lunar cycles, Hanalei Bay, Hatihue Bay, Sasanhaya Bay.

The melon-headed whale (MHW), *Peponocephala electra*, is a pelagic dolphin that occurs worldwide in tropical and warm-temperate waters from roughly 20°S to 20°N (Perryman 2002). Although these dolphins are most often seen far from shore over deep water, they sometimes frequent nearshore waters as evidenced by occasional mass strandings (MS) throughout their range (Brownell *et al.* 2006) and observations around various island groups (*e.g.*, Poole 1993, Soury 1996, Gannier 2000, 2002, Huggins *et al.* 2005, Dolar *et al.* 2006, Jefferson *et al.* 2006, Dulau-Drouot *et al.* 2007, Ligon *et al.* 2007). Two nearly simultaneous observations of MHWs entering island bays were made on 3–4 July 2004. The first observation was at Hanalei Bay, Kauai, Hawaii (Southall *et al*. 2006) and the second, approximately 5,740 km away, at Sasanhaya Bay, Rota, Northern Mariana Islands (Jefferson *et al*. 2006). The Hanalei Bay event was reported as a MS, that is, the whales likely would have stranded if it had not been for human intervention (Southall *et al.* 2006). The team investigating this event concluded that mid-frequency sonar (MFS) use by naval ships in the area was a "plausible, if not likely" factor causing the whales to enter and remain in the shallow bay (Southall *et al*. 2006). The Rota observations were published as an "unusual" sighting of MHWs, mixed with rough-toothed dolphins, *Steno brenandensis*, near an oceanic island but these animals never showed prestranding behavior (Jefferson *et al.* 2006). However, Fromm *et al.* (2006) believed that the Rota and Kauai events were "simultaneous and similar" aggregations of MHWs in shallow coastal waters. Because they thought the two events were similar and there was no sonar known to be in use during the Rota event, Fromm *et al.* (2006) questioned the conclusions of Southall *et al*. (2006) that MFS was a plausible factor contributing to the occurrence of the Kauai event. Mobley *et al.* (2007) again interpreted the Kauai and Rota events as similar and "extraordinary" occurrences that "beg explanation" and suggested that both may have been related to the nearly full moon on 3–4 July 2004.

Although the use of MFS has been repeatedly linked to strandings and deaths of beaked whales (Cox *et al*. 2006), the Kauai event is the best-documented case of sonar use plausibly adversely affecting a small cetacean that is not a beaked whale. The team investigating the cause of this event did not consider the Rota event as they were not aware of it (Southall *et al*. 2006) and, if the Rota event were similar to the Kauai event, it would weaken their conclusions regarding sonar use. Therefore, it is important to determine whether the Rota sighting was in fact unusual and similar to the Kauai event.

We examined this question by reviewing the scattered information on MHW strandings, habitat preferences, diet, activity patterns, and behavior, particularly near Pacific oceanic islands, including atolls. This review includes unpublished observations from Palmyra Atoll (by SB) and Moorea (by MMP). Next, we describe three putative unusual events involving MHWs at oceanic islands: the sighting in Sasanhaya Bay, Rota; a previously undescribed event involving both MHWs and killer whales, *Orcinus orca,* in Hatiheu Bay, Nuku Hiva, French Polynesia (reported by local observers to MMP), and the event in Hanalei Bay, Kauai. We reviewed the original reports of the Rota and Kauai events (Jefferson *et al.* 2006, Southall *et al.* 2006) and available unpublished evidence, which consists of videos, photographs, notes, and e-mails from observers present at the events. We also interviewed available observers of these three events.

Here, we summarize information on the biology of MHWs, examine the proposed relationship between MHW stranding events and lunar cycles, and compare the behavior of the MHWs observed during the Rota, Nuku Hiva, and Kauai events with that of MHWs observed at other Pacific Island locations. We then address two questions: (1) are MS events of MHWs and the occurrence of MHWs near oceanic islands correlated with phases of the moon? and (2) were the Rota, Nuku Hiva, and Kauai sightings unusual events? Our answers are, in short: (1) no, and (2) the Rota event was a normal sighting, but the Nuku Hiva and Kauai events were unusual. Herein we explain how we reached these conclusions.

Biology of Melon-Headed Whales

First Record and Type Specimen

The first record of the MHW in the North Pacific Ocean is from an 1841 specimen collected in Hawaii. Based on this specimen, Peale (1848) described a new species of large dolphin as *Phocaena pectoralis*. Today the nominal species is recognized as *Peponocephala electra*. The type location of *P. pectoralis* is Hilo Bay, Hawaii. The holotype is a mandible, U. S. National Museum (Smithsonian Institution) No. 4108, collected by the U.S. Exploring Expedition. According to the report of the U. S. Exploring Expedition (Wilkes 1845), a group of MHWs was driven ashore on 12 February 1841 (not "in the 1870s" as stated in Anonymous 2007). The type specimen must be one of those animals. Peale (1848) reported that: "sixty of these animals were driven ashore by natives at Hilo Bay, island of Hawaii, at one time. They were considered a dainty food and yielded a valuable stock of oil." Wilkes (1845) noted that the school was first seen in the bay during the afternoon and that it was the usual practice of the natives to drive ashore any schools of "porpoises" seen in the bay.

Habitat

MHWs are typically found in deep tropical and temperate waters worldwide (Perryman 2002), primarily inhabiting upwelling-modified and equatorial waters (Au and Perryman 1985). Although mostly pelagic, MHWs have been reported at a number of island groups in the Pacific, including the Hawaiian Islands (Huggins *et al.* 2005, Southall *et al.* 2006, Ligon *et al.* 2007), the Philippines (Dolar *et al.* 2006), the Marquesa Islands (Poole 1993, Gannier 2002), and the Gambier Islands, Tuamotu Islands, and Society Islands of French Polynesia in the central South Pacific Ocean (Poole 1993, Gannier 2000, 2002). However, the record of MHWs from the Tuamotu Islands (Perrin 1976) is based on a specimen (USNM 504250) that was actually collected south of Hatuauta Bay, Nuku Hiva (08°52'S, 140°00'W) on 1 May 1971 by R. Richard and B. J. David. In the Indian Ocean, MHWs are known from La Reunion Island, Mayotte (Comoros Archipelago), the Seychelles, the Maldives, and Sri Lanka (Leatherwood *et al.* 1991, Ballance *et al.* 2001, Dulau-Drouot *et al.* 2007, Kiszka *et al.* 2007). In the Atlantic Ocean, MHWs are best known from off Dominica (Watkins *et al.* 1997) and the northern Gulf of Mexico (Mullin *et al.* 1994), but other records include the Cape Verde Archipelago (Reiner *et al.* 1996), and Brazil and Senegal (Jefferson and Barros 1997).

In the Gulf of Mexico, MHWs have been found in waters ranging from 835 m to 3,201 m in depth (Mullin *et al.* 1994). MHWs have been seen off all the main Hawaiian Islands and show a preference for deeper offshore waters (Huggins *et al.* 2005, Southall *et al.* 2006, Ligon *et al.* 2007). However, MHW sightings are uncommon in Hawaii. In 2,515 h of search effort between 2000 and 2006, Ligon *et al.* (2007) recorded only 23 sightings of MHWs. These encounters occurred over waters with an average depth of 1,811 m, with a median of 1,610 m and a range of 148–4,779 m (Ligon *et al.* 2007). While 32.2% of effort was spent searching in waters less than 200 m, only one MHW encounter (4.3%) occurred in waters this shallow.

In French Polynesia, MHWs have been recorded around six of the 15 Marquesa Islands (Eiao, Nuku Hiva, Ua Huka, Hiva Oa, Tahuata, and Fatu Hiva), with the majority of observations off Nuku Hiva (Gannier 2002) from November to April (Soury 1996, Oremus *et al.* 2007). MHWs sometimes concentrate and rest off the southeastern side of Nuku Hiva within 100 m of the cliffs.[2] MHWs have been observed as close as 400 m from Moorea's barrier reef, and as far offshore as 30 km, placing the animals in depths ranging from not less than 100 m to over 2,500 m. However, most observations have occurred 3–8 km offshore, in water 1,000–2,500 m deep (MMP, unpublished data).

At Palmyra, MHWs were observed resting in the vicinity of the atoll's outer reef during 39 encounters and 26 h of daytime observations (SB, unpublished data). The group of MHWs generally remained close to the reef (Fig. 1A, 2A), in water around 400 m deep, until approximately 1500 hrs and then began moving offshore to deeper waters, up to 1,300 m, later in the afternoon. Water depth where the whales were observed was significantly correlated with time of day (ANOVA, $F_{1,76} = 199.5$, $P < 0.001$). Sighting effort was not correlated with time of day. In the Philippines, MHWs have been sighted loafing in deep water very close to shore during the day near Siquijor Island in the Bohol Sea; they would bowride at slow speeds (1.85 km/h); and "one school of 50–100 animals stayed with us for hours and was very curious while bowriding."[3]

Diet

MHWs prey on pelagic species of fishes and squids. Jefferson and Barros (1997) reported on stomachs from some of the 240 *P. electra* that stranded 16–19 April 1987 on Piracanga Beach, Bahia, Brazil (14°14′S, 39°00′W). Twenty-one stomachs were examined and 18 contained food (Barros *et al*. 1990), including fishes from the families Myctophidae, Paralepididae, and Scopelarchidae. The most abundant otolith was from a myctophid, *Lampadena* sp., which was found in 12 stomachs and accounted for 95.4% of the otoliths. Myctophids are important in the diet of many pelagic small cetaceans (Fitch and Brownell 1988). They are deep-water fish, known to undertake daily vertical migrations over hundreds of meters. Members of this family generally descend to a depth of about 700–3,000 m during the day, rising to about 200 m or less during the night (Clarke 1973). The MHWs examined by Barros *et al.* (1990)

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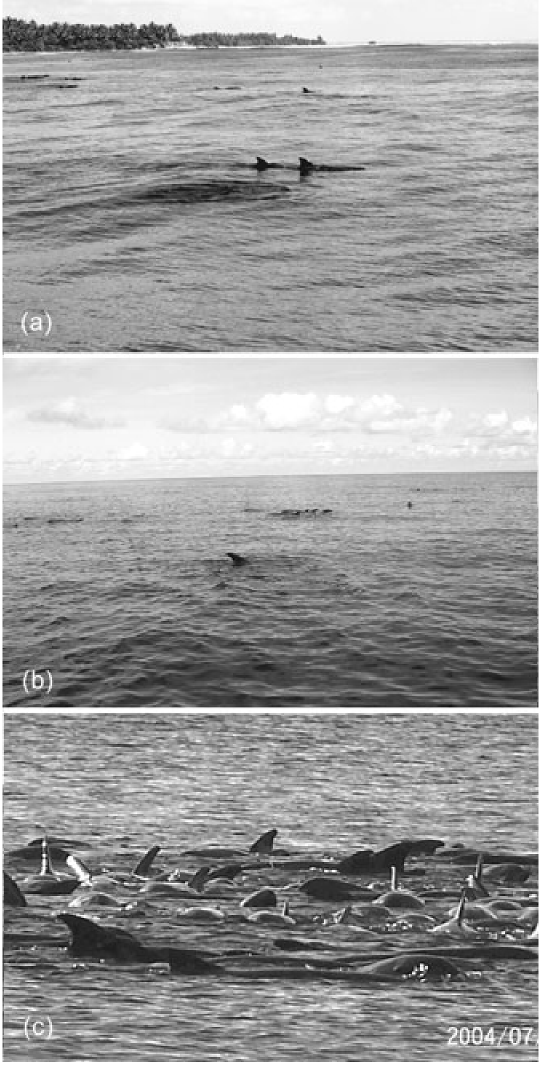

Figure 1. (A) MHWs swimming behavior off Palmyra Atoll on 22 July 2006. Photograph by SB. (B) MHWs swimming behavior in Sasanhaya Bay, Rota, Northern Mariana Islands on 4 July 2004. Photograph courtesy of Mark Michael. (C) MHWs "milling" in a tight cohesive group in Hanalei Bay, Kauai, Hawaii on 3 July 2004. Photograph courtesy of Gretchen Johnson.

also consumed squid from the following families: Ommastrephidae, Loliginidae, Onycoteuthidae, Chiroteuthidae, Mastigoteuthidae, Cranchiidae, Enoploteuthidae, and Histioteuthidae. In Hawaii, these squid, especially the enoploteuthids, also exhibit extensive vertical migrations, moving from daytime depths of 400–700 m to about 100–150 m during the night (Young 1978).

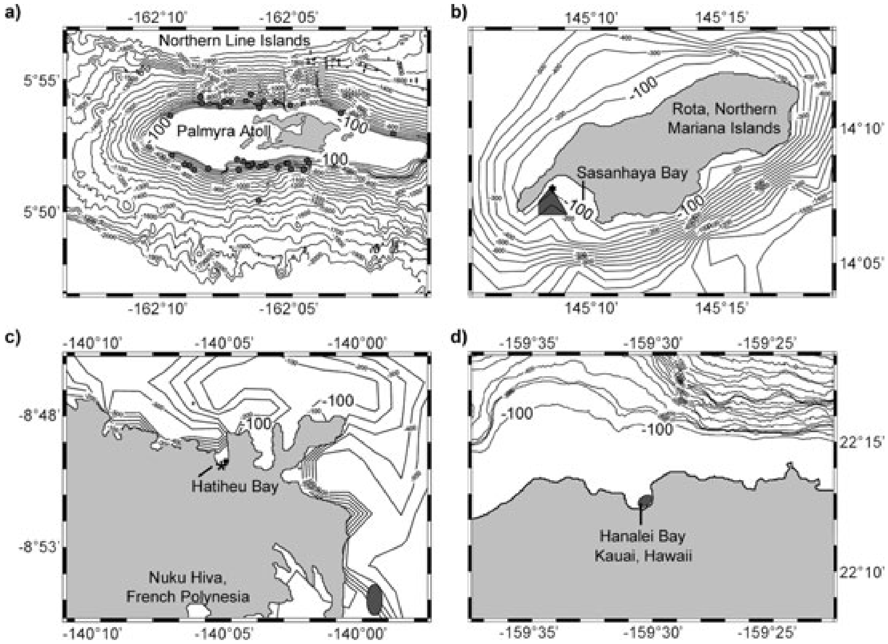

Figure 2. Coastline and bathymetry in 100-m increments of (A) Palmyra Atoll, Northern Line Islands, dark circles indicate sightings of MHW; (B) Sasanhaya Bay, Rota, Northern Mariana Islands, star indicates location of MHW at time of initial sighting and dark polygon shows region of observation (from fig. 1 in Jefferson *et al*. 2006); (C) Hatiheu Bay, Nuku Hiva, French Polynesia, dark circle shows location of MHWs near end of Bay, asterisk shows killer whale stranding, and dark area offshore in the southeast shows where MHWs are regularly observed resting; (D) Hanalei Bay, Kauai, Hawaii, dark area shows location of MHWs (from fig. 3 in Southall *et al.* 2006). Resolution of all coastlines and data origin: 1" or 30 m; National Geophysical Data Center, NOAA Satellite and Information Service, WVS Coastline Database. Resolution and data origin of bathymetry: (A) 40 m, Pacific Islands Benthic Habitat Mapping Center, SOEST, University of Hawaii; (B and C) 1′ or 1,852 m; Gobal Topography, TOPEX, Scripps Institution of Oceanography, University of California, San Diego; (D) 3′ or 90 m, National Geophysical Data Center, Coastal Relief Model Volume 10.

Group Size

Large groups of MHWs (up to 800–1,000 individuals) have been observed around several Pacific oceanic island groups. It appears that these large schools consist of many smaller subgroups that coalesce into large groups, especially during the day, in a fission-fusion type of social organization (Soury 1996, Jefferson and Barros 1997).

MHW schools of 7–210 animals have been observed from the Sula Sea and Tanon Strait near the coast of the Philippines. At times they are seen in mixed schools with either short-finned pilot whales (*Globicephala macrorhynchus*) or Fraser's dolphins (*Lagenodelphis hosei*) (Dolar *et al*. 2006).

Groups estimated to be as large as 1,000 individuals are frequently seen at Nuku Hiva, in the Marquesa Islands of French Polynesia (Reeves *et al.* 1999, Poole 1993, Soury 1996) and at Palmyra in the central Pacific (SB, unpublished data). Groups of 200–500 MHWs have been observed off Moorea in French Polynesia's Society

Islands (Poole 1993; MMP, unpublished data). These schools are often monospecific, but MHWs at Moorea also form mixed species aggregations with smaller numbers of rough-toothed dolphins, and/or Fraser's dolphins. During the austral winter MHWs are also observed in the presence of humpback whales (*Megaptera novaeangliae*).

The mean size of 23 groups encountered around the main Hawaiian Islands was 305 individuals, with a range of 17–800 individuals (Huggins *et al.* 2005). Approximately 300 distinctive individuals have been documented from photographs taken in 2000–2005 (Huggins *et al.* 2005) and interisland movements from Kauai to Hawaii have been documented based on photo-identified individuals (Huggins *et al.* 2005).

Behavior and Daily Activity Pattern

Normal resting and near-surface behavior of MHWs in the southeastern Caribbean near Dominica during the day was observed on four occasions by Watkins *et al.* (1997). Even though the ship approached carefully and stopped quietly near the animals, the MHWs were silent for about 20 min after its arrival. Then they began to move about, vocalize occasionally, and engage in social interactions. Affiliative social interactions included swimming in contact, with two animals often linked by extended flippers, and gentle rubbing as seen also off Nuku Hiva (Soury 1996). Underwater vocalizations included whistles and click sequences. The whales also stopped vocalizing when the ship's propeller was engaged and after three local fishing boats with outboard motors arrived, swimming silently away and surfacing only briefly. The whales occurred in groups of 10–14 individuals and, when not disturbed, remained at or near the surface, resting and traveling slowly, and engaging in social activity. During the second hour they became more energetic and were sometimes seen swimming rapidly, splashing vigorously, diving with flukes-up, and even jumping out of the water. This high level of activity was accompanied by bursts of clicks and occasional whistles. Off Moorea in French Polynesia, the most common behaviors are directional travel (both slow and fast) and deep rest. During deep rest the animals do not move at all, remaining motionless at the surface ("logging"). This is sometimes punctuated by occasional spy hopping. Approximately 100 individuals have been photographically identified and repeated observations of the same known individuals suggest a resident community (MMP, unpublished data).

Repeated observations of MHWs near some oceanic islands such as Nuku Hiva and Palmyra indicate that this species displays a distinct daily activity pattern. At Nuku Hiva, large groups of MHWs apparently make daily inshore–offshore movements. According to Soury (1996), the MHWs can be seen traveling toward the same location in subgroups of 15–20 individuals every morning around 1,000. They gather in groups as large as several hundred individuals about 300 m to 1 km off the cliffs on the southeast coast, exposed to the trade winds. There they rest or swim: merging and swimming in concert before dispersing and then forming more compact groups a few minutes later. At times they stop swimming and rest floating at the surface, sometimes in contact with other individuals, and forming what Norris (1958) described as a "loafing group" in short-finned pilot whales. Occasionally, several individuals simultaneously spy hop. These activities last until early afternoon, after which the animals break up into small groups and depart to feed in deeper offshore waters.

The MHWs off Palmyra Atoll seem to stay close to the reef during morning to midday, even early afternoon, to rest. They can be observed resting along the north and south shore in the vicinity of land, never around the open eastern or western terrace. They remain in waters at least 100 m deep but never enter the atoll's lagoon. They do not come to a complete "logging" rest (Norris 1958, Norris and Prescott 1961), but always keep moving very slowly. They can be regularly observed defecating while resting, suggesting that they had eaten the previous night, as passage time in captive bottlenose dolphins is short, averaging about 235 min (Kastelein *et al.* 2003). MHWs at Palmyra are very vocal, even when resting, producing clicks, burst pulses, and whistles. They tend to become more vocally active in the afternoon. However, their vocalizations cannot be heard by humans who are not in the water, except through the hull of the boat when the animals are bow-riding.

At Palmyra, the MHWs are habituated to the only boat operated regularly by the research facility at the atoll. The normal resting and near-surface behavior of most of the animals in the group is not interrupted by the approach of the vessel. However, a few individuals usually approach the boat and bow-ride. When the propeller of the boat starts up, MHW vocalizations increase, and a few individuals alter their swimming direction and move toward the boat. The group is loosely stretched over 0.5–1 km. The animals stay in one general area by swimming back and forth along the reef line—very slowly traveling in one direction and then turning and swimming in the other direction. During the morning hours all animals are resting and quite inactive. In the afternoon hours they are more active and engage in more social activities. Behaviors such as tail slapping and spy hopping are more common in the afternoon. On two days with high swells, the whole group was seen actively surfing the waves. During two other encounters, both later in the afternoon, the whole group of MHWs or some subgroups was seen swimming in a "chorus line" or wavelike formation for about 2–5 min, suggesting that multiple individuals were reacting simultaneously in a similar way to some unknown stimulus. On one occasion the group was observed chasing a bait ball late in the afternoon in deeper water.

Similarities and Differences Between MHWs and Spinner Dolphins

Although still poorly known, the behavior of MHWs near some oceanic islands appears similar in some respects to those of another pelagic species, the spinner dolphin, *Stenella longirostris*, near islands. At the island of Hawaii, spinner dolphins travel to offshore feeding grounds at dusk and feed at night upon scattering layer fishes, squid, and shrimp (Würsig *et al.* 1994*a, b*). In the morning, they come close to shore in one of several habitual areas such as Kealakekua Bay. They gradually become less active, rest during the middle of the day, and become more active and begin to socialize in the afternoons (Norris and Dohl 1980, Würsig *et al.* 1994*b*). In Hawaii, small schools of spinners often seem to coalesce into larger groups upon arrival in the bay (Würsig *et al.* 1994*b*). At Midway Atoll, however, spinner dolphins appear to live in stable, bisexually bonded societies of long-term associates rather than the fusion-fission social organization seen in Hawaii (Karczmaarski *et al.* 2005).

Arriving schools often come to the bows of vessels. Arriving animals are often seen to defecate and do not feed while in the bay (Norris and Dohl 1980). After arrival the dolphins subside "slowly into rest, a process sometimes requiring two hours or more" (Norris and Dohl 1980). Vocalization is at a high level in arriving schools, subsiding gradually as the rest period approaches, and resting schools are nearly silent.

In the South Pacific at Moorea in French Polynesia, spinner dolphins have a daily activity pattern similar to that of Hawaiian spinners (Poole 1995, Oremus *et al.* 2007). They feed offshore at night and in the early morning approach Moorea's shoreline. By swimming through the passes that pierce Moorea's barrier reef, they enter the protected bays of Moorea's lagoon where they socialize in the morning, rest during midday, socialize in the afternoon, and move offshore in the late afternoon or evening for the nighttime feeding. And as in Hawaii, Moorea's spinners use some bays as rest areas significantly more frequently than others (Poole 1995).

The behavior of MHWs resembles that of spinner dolphins in several ways. Both species appear to feed in deep water on mesopelagic prey during the night and have been seen to defecate during the day, suggesting that they fed the previous night (Norris and Dohl 1980, Jefferson *et al.* 2006; SB, unpublished MHW data from Palmyra). At least some groups of both species take advantage of protected waters near islands to rest during the day and many small groups seem to coalesce into larger groups daily at specific locations near some island groups (Würsig *et al.* 1994*b*, Soury 1996, Jefferson and Barros 1997). However, there are also major differences between the two species. MHWs tend to rest in deeper waters, close to the reef line or shelf break (*e.g.*, Palmyra, fig. 1A, 2A; Nuku Hiva, fig. 2C), during the day and do not regularly enter shallow bays to rest like spinner dolphins (Würsig *et al.* 1994*b*). In addition, spinner dolphins use their resting areas year-round, while the occurrence of large groups of MHWs near some oceanic islands is reportedly seasonal, although quantitative data are lacking.

ARE MSES AND OBSERVATIONS OF MHWS CORRELATED WITH LUNAR CYCLES?

Mass stranding events (MSEs) of MHWs, defined as strandings of three or more animals, were reviewed by Brownell *et al.* (2006). They listed 29 MSEs, five of which occurred in the Pacific islands: Hilo, Hawaii in 1841, Palmyra Atoll sometime before 1964, Malékoula Island, Vanuata (New Hebrides) in 1972, Kwajalein Atoll, Marshall Islands in 1990 (not 1993 as reported in Reeves *et al.* 1999), and Hanalei Bay, Kauai in 2004. The Hilo event was not a true MS because the animals were driven ashore by natives. However, the animals must have been relatively close to shore since the natives were able to drive them using canoes. The events at Palmyra and Kwajalein Atolls were unusual because the stranding occurred inside the atoll's lagoon and only a small number of animals were involved. The Palmyra event was likely possible only because a channel was blasted in the atoll's reef to allow the passage of ships (Dawson 1959) and thus a small subgroup of a larger aggregation of MHWs was able to enter the atoll's lagoon and strand.

We used an updated version of the data set in Brownell *et al.* (2006) to test for a possible association between MSEs and phases of the lunar cycle. We eliminated the putative MS on 17 February 1998 because we determined that it involved pygmy killer whales, *Feresa attenuata*, rather than MHWs. We included the Kauai event because it was classified as a MS by the U. S. National Marine Fisheries Service (NMFS) (Southall *et al.* 2006), but not the Rota event because the MHWs showed no signs that they were in any danger of stranding (Jefferson *et al.* 2006). We analyzed these data with and without the Hilo stranding as these animals did not strand naturally but were driven ashore. We were able to determine exact stranding dates for 21 of the 29 strandings listed in Brownell *et al.* (2006) plus an additional four MSs. These modifications resulted in a list of 33 MSEs, 23 of which had information on the exact date of stranding, thus enabling us to determine the phase of the moon during which the stranding occurred. Eight of the 23 MSEs occurred during the full moon, three during the first quarter, seven during the last quarter, and five during the new moon. The number of MSEs was unrelated to the phase of the lunar cycle both with the Hilo stranding ($\chi^2 = 2.57$, df $= 3$, $P = 0.464$) and without it ($\chi^2 = 2.36$, df $= 3$, $P = 0.500$).

MHWs were observed at Palmyra for various periods of time between July 2006 and October 2007 during 31 d of sighting effort. MHWs were seen on 27 of these days. The daily sighting success was 100% during the full moon and the last quarter, 90% during the new moon, and 67% during the first quarter. The four survey days without sighting success all occurred during sea states between three and five, which lowered the probability of sighting MHWs from the small survey boat. The MHW sightings were distributed across all phases of the moon, with 6 d with sightings during the first quarter, 8 during the full moon, 4 during the last quarter, and 9 during the new moon. There was no significant relation between sightings of MHWs close to the atoll's reef and the phase of the moon ($\chi^2 = 2.185$, df $= 3$, $P = 0.535$).

Although some have speculated that the entry of MHWs into Hanalei and Sasanhaya bays may have been related to changes in the behavior of their prey due to the nearly full moon (Anonymous 2007, Mobley *et al.* 2007), this seems unlikely. MHWs use deep nearshore waters around oceanic islands irrespective of lunar cycles and we found no relationship between the phase of the moon and the occurrence of MHW MSEs or MHW sightings at Palmyra. Furthermore, it is unclear how possible changes in prey behavior related to the phase of the moon, such as squid remaining in deeper waters at night during the full moon, could influence the probability of stranding during the day. Because MHWs feed offshore at night, those that use nearshore waters during the day do so to rest rather than to feed.

Descriptions of the Events at Rota, Nuku Hiva, and Kauai

Sasanhaya Bay, Rota

A description of the MHWs observed in Sasanhaya Bay, Rota is provided by Jefferson *et al*. 2006. A school of approximately 500 to 700 MHWs was already in the Bay when they were first detected (Fig. 2B). The school also included an unidentified number of rough-toothed dolphins. Seas were calm and underwater observation conditions were excellent. Small subgroups of three to 20 individuals, mostly adult females and juveniles, could be observed "as far as the eye could see" (Fig. 1B). Behaviors observed across the subgroups included "riding the bow wave of a vessel, animals rotating repeatedly on their long axis while bow-riding, occasional defecations and penis extrusions." Throughout the approximately 5.5 h encounter, "the individuals moved to the south, towards the mouth of the bay." Jefferson's group took several minutes of video footage and over 100 photographs, two of which are published in Jefferson *et al*. (2006). These authors considered the sighting at Rota significant for three reasons: (1) because of the paucity of cetacean records from the Northern Marianas, (2) the close encounter in clear water enabled them to take excellent photographs of the color patterns of live individuals belonging to several different age classes, and (3) they believed it was "somewhat unusual" for MHWs to frequent relatively shallow waters ranging from 77 m to 1,100 m in depth. However, they presented no comparative data to support this point.

Other records of the Rota event include numerous photographs taken by Monty Keel. Keel described the behavior of the MHWs as follows: "They tended to swim in coordinated groups of up to 6 maybe 7 or more, very synchronized. No hurry at all. Some swam alone. I wasn't able to observe whether those individuals continued to swim alone or moved from one group to another. The only activity above the surface that I remember is them surfacing for air but sometimes breaking the surface as they rode the bow wave. I never saw one jump, breach, or spy hop or anything remotely like that."[4] Another observer of the Rota event, Mark Michael, a coauthor of the Jefferson *et al.* (2006) report, noted that the whales "paid no attention to us and went about their business of playing, diving, or just resting on the surface."[5]

Hatiheu Bay, Nuku Hiva

A usual event involving both MHWs and killer whales at Nuku Hiva island in French Polynesia was reported to one of us (MMP) by local observers. Although MHWs are present off the southeastern coast of Nuku Hiva all year, the largest groups are seen from November through April.[6] Approximately 100 MHWs entered Hatiheu Bay (08°48′S, 140°05′W) on the northeast side of the island around 1200 local time on 6 July 2005, during the new moon. According to local residents, MHWs had never before entered any of the island's bays, although spinner dolphins were known to regularly enter this and other bays of the island. Almost the entire bay is <50 m in depth (Table 1), indicating that MHWs would be unlikely to use it on a normal basis. Traversing the entire length of the bay, the MHWs approached to within 10–30 m of a small cliff on the extreme southeast end of the bay (Fig. 2C). During the afternoon they remained in a tightly spaced group there in the shallow water. Several people went into the water and swam near the MHWs, which were milling[7] (swimming in circles) the entire time they were in the bay. The MHWs showed no particular interest in the humans.

Around 1230, approximately 30 min after the MHWs entered the bay, three killer whales, entered the bay. They swam in a straight line southward until, completely ignoring the MHWs in the SE corner of the bay, they stranded on the beach to the west of MHWs ("deliberately," according to local observers). Before this event, three

[4]Personal communication from Monty Keelvia *via* e-mail to RLB 30 August 2006.

[5]Personal communication from Mark Michael, Dive Rota, P. O. Box 941, MP 96951, Northern Mariana Islands, *via* e-mail to RLB on 3 September 2006.

[6]Personal communication from Xavier Curvat, Center de Plongee Marquises, BP100, 98742 Nuku Hiva, Marquesa Islands, French Polynesia *via* phone conversations with MMP in July 2005.

[7]Potential for confusion exists over the use of the term "milling" to describe the behavior of the MHWs because this word has been used to describe two different forms of cetacean behavior. While some authors, such as Geraci and Lounsbury (1993), use the term to describe typical prestranding behavior, others use it to describe the frequent changes in heading sometimes observed in schools of small cetaceans during their normal daily activities (Shane *et al.* 1986). This type of "milling" can be "associated with feeding, socializing or play, if rapid, or with resting or idling, if leisurely" (Shane *et al*. 1986) and is not a warning that stranding may be imminent. The "milling" behavior seen in Hatiheu Bay and Hanalei Bay was the type described by Geraci and Lounsbury (1993).

Table 1. Observations of MHWs near reef lines or in island bays. Observations on the killer whales that stranded in Hatiheu Bay, Nuku Hiva, shortly after the MHWs entered the Bay are included for comparison. Distances and water depths for Palmyra, Kauai, and Rota were estimated from Figure 2, where accuracy for Palmyra and Hawaii is much higher than for Rota and Nuku Hiva. As the depth contours for Nuku Hiva shown in Figure 2 did not correspond well with local observations, distances for this location were estimated from a nautical chart for Hatiheu Bay (Chart 7352, created by the French "SHOM" [Service Hydrographique et Océanographique de la Marine] based on data taken from 1981 to 1993 and published in 1995; www.shom.fr).

	Location and species				
	Palmyra MHWs	Rota MHWs	Nuku Hiva MHWs	Nuku Hiva KWs	Kauai MHWs
Phase of moon	All	Full	New	New	Full
Width of bay (m) (min–max)	N/A	3,000–5,000	750–1,000	750–1,000	1,500–2,000
Water depth (m) at entrance to bay	N/A	350	<50	<50	20
Distance (m) from 100-m contour to bay entrance or land (min–max)	250–900	150 (max)	2,000	2,000	4,000–4,200
Distance (m) from 100-m contour to end of bay	N/A	1,500	5,200	5,200	6,000
Entry into bay	N/A. Near reef line but not inside lagoon	Not observed	Swam to within 10–30 m of shore	Swam rapidly in straight line toward shore until they stranded	Swam rapidly toward shore in wavefront formation
Water depth (m)	100–1,300	77–1,000	To 5–10	To 0	To 4+
Group size	800–1,000	500–700	Over 100	3	150–200

Group dispersion	Spread out in many small subgroups over large area	Spread out in many small subgroups over large area	Single, tight cohesive group, even when humans were in the water	Single, tight cohesive group	Single cohesive group; group scattered when humans entered water
Group composition	MHWs only	MHWs and rough-toothed dolphins	MHWs only	KWs only	MHWs only
Swimming behavior	Swam slowly back and forth along reef line	Moved slowly in same general direction for >5 h	Swam in tight circles at times, that is, milling[3]	Straight toward beach; stranded on beach	Swam in tight circles at times, that is, milling[3]
Other behaviors	Occasional tail slapping, spy hopping, surfing	Bow-riding, penis extrusions, curious toward humans	Occasional tail slapping, spy hopping	None observed	Frequent tail slapping, spy hopping; no bow-riding or penis extrusions, not curious toward humans
Vocalizations	Numerous vocalizations not audible above water	None mentioned	None mentioned	None mentioned	Numerous whistling vocalizations audible above water
Exit from bay	Not applicable-never inside lagoon	Left bay at first attempt without human assistance	Left bay without human assistance	Human assistance required at high tide	Attempted to leave but turned back at exit; human assistance required
Deaths	None	None	None	None	1 calf

killer whales were known to enter some of the island's bays to feed on manta rays but none had been seen previously in Hatiheu Bay.[8] While the killer whales were stranded on the beach at the south end of the Bay, the MHWs remained near the cliffs in the southeast end of the bay. Around 1630 the MHWs swam northward and left the bay. Later still (around 1700) and during high tide, the local residents were finally able to pull the killer whales off the beach. The male did not exit the bay until about 1800 and the other two killer whales did not leave the bay until 1830. Although three killer whales had been repeatedly observed around the island from 1998 to 2005, none have been seen since this incident.

Hanalei Bay, Kauai

A detailed report on the Hanalei Bay, Kauai, event is provided by Southall *et al*. (2006). About 150–200 MHWs, swimming rapidly side-by-side in a wavelike formation, entered the bay at 0700 local time on 3 July 2004. Two Rim of the Pacific Exercises (RIMPAC) units tested active MFS from 0645 to 0715 (table 1, Southall *et al.* 2006). The animals were first seen near the middle of the shoreline of the bay and then moved to the SSE portion of the bay, where they formed a tight group (Southall *et al.* 2006, fig. 3). An all-day Naval exercise using MFS started at 0800 and continued until 1647. At 0900, the "whales moved cohesively from the east side of the bay to the center and then headed out of the bay but immediately turned around and returned to the east side of the bay" (table 4, Southall *et al.* 2006). The approximate location of the whales is shown in Fig. 2D. As the public began to interact with the whales, the whales formed into smaller subgroups and spread out over a larger area. Robert Braun, an observer of this event and a coauthor of the Southall *et al.* (2006) report, noted that the animals were often in water <4 m in depth and displayed little, if any curiosity toward humans.[9] However, at 1600, when authorities ordered the public away from the animals, the MHWs formed into one cohesive group and were "milling" around in a tight circle (Fig. 1C). Tail slapping, large numbers of whistling vocalizations that were audible by humans who were not in the water, and some spy hopping continued for several hours. MFS transmissions were terminated by the Navy at 1700 at the request of the NMFS. The next morning, 16.5 h after the sonar stopped, the whales were successfully moved out to sea by two canoes using a traditional *lau* (a strand of woven beach morning glory vines [= *pohuehue*, *Ipomoea pes-caprae*] ~700 ft (213 m) in length floating on the surface of the water that was tied between the two canoes), which were assisted by an additional 30–40 kayaks as the animals moved toward open waters. A single MHW calf was observed in the bay on 4 July about 2.5 h after the others had departed and was subsequently found dead. It must have been separated from its mother at some point during the event and died from dehydration.

Which Events were Unusual?

There were many differences between the Rota sighting and the events at Nuku Hiva and Kauai (Table 1, Fig. 2), including the local geography and bathymetry.

[8] Personal communication from Xavier Curvat, Center de Plongee Marquises, B. P. 100, 98742 Nuku Hiva, Marquesa Islands, French Polynesia *via* telephone to MMP on 30 October 2008.

[9] Personal communication from Robert Braun, 47–928 Kamakoi Road, Kaneohe, HI 96744 *via* e-mail to RLB on 19 October 2006.

Sasanhayna Bay at Rota is considerably wider than Hatiheu Bay at Nuku Hiva and Hanalei Bay in Kauai (Fig. 2), with a minimum width of about 3,000 m compared to a maximum width of about 1,000–2,000 m at the other two locations (Table 1). In addition, it is only a short distance (a maximum of about 150 m) from the 100-m depth contour to the entrance of Sasanhayna Bay compared to minimums of about 2,000 m at Hatiheu Bay and 4,000 m at Hanalei Bay (Table 1). The 100-m depth contour extends into Sasanhayna Bay in some places (Fig. 2B), which, together with the wide entrance to the bay, would make it easy for MHWs following this approximate water depth to enter the bay.

The behavior of the MHWs at Rota also was different from that of MHWs at Nuku Hiva and Kauai. The MHWs at Rota appeared calm and unagitated. They were dispersed into many small subgroups over a large area as observed at other oceanic islands. They never coalesced into one compact group or swam in tight circles. They were curious about the humans in their midst and observers noted many instances of playful behavior. They moved in the same general direction for about 5.5 h and left the bay without human assistance. Although Jefferson *et al.* (2006) believed it was "somewhat unusual" that the MHWs at Rota were observed in relatively shallow waters ranging from 77 m to 1,100 m in depth, MHWs at Palmyra routinely frequent similar depths of 100–1,300 m (Table 1, Fig. 2A). In sum, the animals at Rota were displaying aspects of normal diurnal resting behavior similar to that seen near other islands such as Moorea, Nuku Hiva, Palmyra, and Dominica and the local geography and bathymetry made it easy for them to enter and exit Sasanhaya Bay while engaged in their customary daily activities.

In contrast, the entry of MHWs into Hatiheu Bay at Nuku Hiva was unusual in several ways. MHWs had never been observed deep inside this bay (or any other bay on island) previously and most of the bay is <50 m in depth, so MHWs would be unlikely to use it on a regular basis. The entry of a second species, killer whales, about 30 min later, also into a bay they had never been known to use before, makes this event even more unusual. The Nuku Hiva MHWs swam in a single tight, cohesive group, as did the killer whales. The MHWs also exhibited the type of "milling" often observed prior to MS, while the killer whales almost immediately stranded on the beach and required human assistance to reenter the water. If the killer whales were chasing the MHWs, it is not clear why, once in the Bay, they ignored them and instead swam in a straight line toward the beach until they stranded away from the MHW, but perhaps they became disoriented and confused once they entered the Bay. However, both the killer whales and the MHWs at Nuku Hiva had been observed for several years by local observers with no observed instance of killer whale predation on MHWs. Another possibility is that the killer whales approached the Bay looking for one of their known prey species, such as manta rays, inadvertently frightening the MHWs into the Bay, and then entered the Bay themselves in a continuing search for prey. However, this scenario does not explain why both MHWs and killer whales behaved as if they were fleeing from some strong aversive stimulus. Perhaps this was the case but we have been unable to identify a likely candidate for such a stimulus, so the cause of the Nuku Hiva MHW event remains unknown.

Many aspects of the Kauai event were unusual (Table 1, Fig. 2). The presence of the MHWs near the island prior to the event may or may not have been unusual. They may have moved to this area in response to sonar use during the previous night (Southall *et al.* 2006) or they may have been gathering in the vicinity of the island for their diurnal resting period. However, the entry of the MHWs into Hanalei Bay definitely was usual. MHWs had never been seen in this Bay before and they would be unlikely to enter it in the course of their normal diurnal activities, as its entrance is about 4,000 m from the 100-m depth contour, and the water depth at its entrance is only about 20 m (Table 1). Furthermore, the manner in which the MHWs entered the bay, in a large group swimming at high speed in a straight line, wavelike formation oriented toward shore (Southall *et al.* 2006), was unusual and suggests that they were fleeing from a stimulus. The stimulus could have been produced when ships located about 46 km from the bay tested their active sonar equipment briefly at 0645 local time (table 1, Southall *et al.* 2006), about 15 min before the whales were seen entering the Bay at 0700. Southall *et al.* (2006) found no evidence for a variety of other possible factors that might have influenced the whales, such as unusual weather conditions, prey, predators, and harmful algae blooms. A wide variety of small cetacean species are known to actively avoid even low levels of anthropogenic sound (Brownell *et al*. 2008), so it is quite plausible that the whales entered the Bay in an attempt to avoid the sound of the MFSs and other sonar activity from the various naval vessels concentrated in the area. Of course, direct causation could not be established without experimental data. An alternate suggestion, that the MHWs entered the bay in pursuit of fish (Anonymous 2007), is unlikely because MHWs are not known to feed by chasing prey near the surface during the day, rather they dive at night to catch their deep-water prey.

Once in Hanalei Bay, the behavior of the MHWs differed markedly from that of the MHWs at Rota and known resting locations such as Palmyra. Instead, their behavior corresponded to the typical prestranding "milling"[3] behavior described by Geraci and Lounsbury (1993), with a single, cohesive pod swimming in tight circles accompanied by frequent behaviors such as spy hopping, fluke slapping, and audible vocalizations, suggesting a high level of agitation (Pryor and Shallenberger 1991). They did not display curiosity toward humans or playful behaviors as seen at Rota. However, the behavior of the MHWs at Hanalei Bay did resemble that seen in the unusual event at Nuku Hiva (Table 1). The Nuku Hiva MHWs swam in a single tight, cohesive group and exhibited the type of "milling" often observed prior to MS, while the killer whales immediately stranded on the beach and required human assistance to reenter the water.

Observers noted that the whales in Hanalei Bay turned back near the entrance to the Bay while the MFS were active (one attempt at 0900–0930; table 1, 5, Southall *et al.* 2006). According to Navy modeling, sound pressure levels from MFS operating at a distance of more than 46 km were in the range of 138–149 dBRMS re: 1 μPa at the mouth of the bay (Anonymous 2006). These estimated received levels at the mouth of the bay were about 60–80 dB above the expected background noise and should have been well above auditory limits of the animals. Southall *et al.* (2006) conclude that "if the animals responded negatively to these signals, it may have contributed to their continued presence in the Bay." The sonar was operated all day from 0645 to 1647 local time (with a short interruption between 0715 and 0800) and several vessels were operating to the north of the bay's entrance (table 5, Southall *et al.* 2006). That the whales in the Bay reacted to the sonar noise as an acoustic barrier is consistent with observations from drive fisheries targeting small cetaceans (Brownell *et al.* 2008). Small cetaceans are reluctant to move toward sources of anthropogenic noise as evidenced by the success of acoustic drive fisheries using a variety of low-level sound sources, such as banging on underwater "trumpets" on poles or pounding rocks together, in driving them ashore to be killed throughout the world (Brownell *et al*. 2008). After the MFS was turned off at 1647 (table 5, Southall *et al.* 2006), the MHWs remained in the Bay overnight. However, the next morning people were able to move them out of the Bay.

The rapid entry of MHWs into Hanalei Bay and their later movement into extremely shallow waters (<4 m deep) thousands of meters from the 100-m contour (Fig. 2D, Table 1), their typical prestranding milling behavior while in the Bay, and their reluctance to leave the Bay while the sonars were operating and even after they stopped, clearly constituted an unusual event. However, the MHW sighting at Rota (Jefferson *et al.* 2006) was neither unusual nor similar to the Kauai event. This sighting was very similar to repeated observations of MHWs at Palmyra, and the water depths the whales used at Rota (77–1,100 m) were very similar to those used at Palmyra when resting during the day (100–1,300 m). Thus, the nearly simultaneous occurrence of the Rota sighting and the Kauai event does not, as Fromm *et al.* (2006) and Mobley *et al.* (2007) argued, call into question the conclusions of Southall *et al.* (2006) that MFS use was a "plausible, if not likely contributing factor" to the occurrence of the Kauai event. In fact, based on our review of MHW behavior near oceanic islands, we believe the case is even stronger that the primary reason the MHWs entered and remained in Hanalei Bay until humans induced them to leave was use of MFS on 3 July 2004.

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