Final report of the Independent Scientific Review Panel investigating potential contributing factors to a 2008 mass stranding of melon-headed whales (*Peponocephala electra*) in Antsohihy, Madagascar

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Executive summary

A highly unusual event involving the long-term displacement and mass stranding of approximately 100 melon-headed whales (*Peponocephala electra)* occurred in May-June 2008 in the Loza Lagoon system in northwest Madagascar. This typically open-ocean cetacean species had never previously nor since been reported in this shallow tidal estuarine system, nor in any other in Madagascar, although previous strandings of this species in embayments have been documented. A coordinated effort was organized for response to live animals, and to collect information through physical samples from stranded animals and a structured interview process. This mass stranding response involved local officials and citizens, conservation organizations, oil and gas exploration companies working in the area, and international marine mammal experts. Despite the remote location of the stranding event and the challenging logistics of operations, field efforts were mounted within days and a significant amount of information about the stranding event was collected.

After several years, a formalized process for investigating the known facts associated with this event was established through a partnership among many of the organizations involved in the mass stranding response effort, the International Whaling Commission (IWC), and U.S. federal agencies with relevant expertise and interest in the event; this process was undertaken in direct communication with the government of Madagascar. An Independent Scientific Review Panel (ISRP) reviewed all available information provided by responders and those analysing the events. Following a face-face meeting of the ISRP with information providers, all potential primary or secondary contributing factors to this atypical mass stranding were considered relative to all available information given to the ISRP.

The extent to which causality may be unequivocally determined here is limited by: (1) the remote and harsh conditions of the stranding area; (2) the time required to mount the stranding response and investigation; (3) the time that has passed since the event; (4) the fact that the location and behavioral state of the animals just prior to the first known observations of them within the lagoon system is unknown; and (5) limited information on the type and nature of behavioral responses of melon-headed whales to multi-beam echosounders.

There is no unequivocal and easily identifiable single cause of this event, such as those that have been implicated in previous marine mammal mortalities (*e.g.,* entanglement, vessel strike, identified disease) or mass stranding events (*e.g.*, weather, extreme tidal events, predator presence, anthropogenic noise). Based on information provided to the ISRP these animals apparently entered the bay on 30 May 2008 following some initial triggering event, following which at least 75 mortalities resulted over the following weeks, ultimately as a result of multiple secondary factors (*e.g.*, emaciation, dehydration, sun exposure) related to their being

out of their normal habitat for such an extended period. In such a stranding scenario where the initial response may be behavioral, but the ultimate cause of mortality relates to being out of typical habitat (of which there are a growing number of examples discussed in the report), there may not be clear forensic evidence of causality. Assessing such situations inherently requires some subjective assessment by experts of the weight of the evidence regarding the temporal and spatial association with some potential disturbance and the stranding event, as well as a science-based approach to systematically consider all possible primary or secondary contributing factors (as in Southall *et al*., 2006; Jepson *et al*., 2013; Wright *et al*., 2013).

While aspects of this event will remain unknown, the ISRP systematically excluded or deemed highly unlikely nearly all potential reasons for the animals leaving their typical pelagic habitat and entering the Loza Lagoon (an extremely atypical area for this species). This included the use of seismic airguns in an offshore seismic survey several days after the whales were already in the lagoon system, which was originally speculated to have played some role but in the view of the ISRP clearly did not. The exception was a high-power 12 kHz multi-beam echosounder system (MBES) operated intermittently by a survey vessel moving in a directed manner down the shelf-break the day before the event, to an area ~65 km offshore from the first known stranding location. The ISRP deemed this MBES use to be the most plausible and likely behavioral trigger for the animals initially entering the lagoon system. This conclusion is based on:

(1) Very close temporal and spatial association and directed movement of the MBES survey with the stranding event. The MBES vessel moved in a directed manner transmitting sounds that would have been clearly audible over many hundreds of square kilometers of melon-headed whale deep-water habitat areas (and extending into some shallower waters along the shelf break) from 0544 until 1230 local time on 29 May and then intermittently in a concentrated offshore area (located ~65 km from the mouth of the lagoon) between 1456 and 1931 on 29 May; these preceded the first known stranding during the day of 30 May and sighting of live animals within the lagoon at 2300 on 30 May.

(2) The unusual nature of this type of stranding event coupled with previous documented apparent behavioral sensitivity in this pelagic species (albeit to other sound types - discussed in more detail below).

(3) The fact that all other possible factors considered were determined by the ISRP to be unlikely causes for the initial behavioral response of animals entering the lagoon system.

This is the first known such marine mammal mass stranding event closely associated with relatively high-frequency mapping sonar systems. However, this alone is not a compelling reason to exclude the potential that the MBES played a role in this event. Earlier such events may have been undetected because detailed inquiries were not conducted, given assumptions that high frequency systems were unlikely to have such effects because of relatively greater sound propagation loss at high frequencies. It is important to note the relatively lower output frequency, higher output power, and complex nature (100+ directional but overlapping sound beams) of the MBES used here relative to most conventional lower-power and often much higher-frequency fish-finding or shallow-water bathymetric mapping systems. Similar MBES systems to the 12 kHz source used in this case are in fact commonly used in hydrographic surveys around the world over large areas without such events being previously documented. In fact, a very similar MBES system was apparently used in a survey in the general area (and particularly the Mahajanga harbor area to the south) for some period during April and early-mid May 2008. This in fact could have played some contributing factor by sensitizing animals in the vicinity to such sources, but information on where and how this system was used was unavailable despite efforts to obtain it.

There may well be a very low probability that the operation of such sources will induce marine mammal strandings - animals may simply avoid them or even ignore them most of the time. In this case, environmental, social, or some other confluence of factors (*e.g.*, shoreward-directed surface currents and elevated chlorophyll levels in the area preceding the stranding) may have meant that this group of whales was oriented relative to the directional movement of the transmitting vessel in such a way that an avoidance response caused animals to move into an unfamiliar and unsafe out-of-habitat area. It is important to note that, especially for odontocete cetaceans that hear well in the 10-100 kHz range where ambient noise is typically quite low, high-power active sonars operating in this range may in fact be more easily audible and have potential effects over larger areas than lower-frequency systems that have more typically been considered in terms of anthropogenic noise threats. The potential for behavioral responses and indirect injury or mortality from the use of similar MBES systems should be considered in future environmental assessments, operational planning, and regulatory decisions.

1. Introduction and Overview

Beginning on 30 May 2008 a highly unusual event involving the long-term displacement and mass stranding of approximately 100 melon-headed whales (*Peponocephala electra)* occurred in northwest Madagascar. Following an initial stranding of two animals on the coastline near Analalava on 30 May multiple observations from local residents that night and throughout 31 May indicate the directed movement of a large group or groups of animals through the Loza Lagoon region, including Grand Lac, into the mangrove estuaries near the village of Antsohihy some 65 km inland from the mouth of the lagoon and estuary system. Over the following month, whales remained in this atypical habitat (for this generally open-ocean species), during which at least 75 died from various factors secondary to their being in unusual habitat.

This was a complex, atypical, and geographically-dispersed event in a remote and difficult area in which to operate. Nevertheless, thanks to many local efforts and international collaboration and coordination with the government of Madagascar and various private parties (described below), a response team including experts from around the world was rapidly dispatched. This team included participants from local and regional Malagasy authorities and communities, and staff from the Wildlife Conservation Society (WCS), the International Fund for Animal Welfare (IFAW), and Woods Hole Oceanographic Institution (WHOI). An ExxonMobil Exploration and Production (Northern Madagascar) Limited (EMEPNML) contractor (TL Geohydrographics Pte. Ltd.) was preparing to conduct a geophysical site survey in the general area and was also operating a multi-beam echosounder systems (MBES) in the same general area. EMEPNML provided support to the initial stranding response effort. The stranding response team assisted in both live animal rescue and in the collection of data and samples with which to document the event. This was done both through necropsies and also through a systematic and dedicated interview campaign (described in greater detail in WCS-MMSE-1) regarding observations of animals and strandings. The stranding response team contributed information to a

Joint Information Center (JIC) that aggregated information about ongoing events and coordinated an ad hoc committee of government representatives, stranding responders, and industry personnel. The original reports submitted to the Malagasy Government in 2008 were not available to the Independent Scientific Review Panel (ISRP) and, therefore, some potentially relevant information was lost and was reconstructed, to the extent possible. EMEPNML was able to provide a duplicate copy of its data to the ISRP. The extensive efforts of the stranding response team, as well as the results of their findings are summarized in two reports discussed in greater detail here (WCS-MMSE 1; WCS-MMSE-2 -- see Appendix III for full reference). Additional information about known human activities in the area (*e.g.*, EM-1; EM-2; EM-3; EM-4 -- see Appendix III for full reference) was also aggregated and analysed (also discussed in greater detail in sections below).

Shortly after this remarkable event several of the organizations involved in the stranding response and investigation, as well as local and federal entities within Madagascar, submitted preliminary technical reports about the stranding, nearby activities at the time, and their findings to date. Efforts were initiated by these entities to conduct a formal scientific investigation of this event and potential contributing factors, based upon these preliminary findings. However, this process was not completed prior to the March 2009 change in the government of the country. This development significantly delayed efforts to undertake such an investigation, although significant interest remained to see this take place. While this took longer than expected to come to fruition, following a series of discussions within the context of the International Whaling Commission (IWC) and other interactions concerned with potentially human-induced marine mammal strandings, a formal process was initiated. A number of organizations involved in the response and investigation (notably WCS, IFAW, and EMEPNML) along with several U.S. federal agencies (National Oceanic and Atmospheric Administration, Marine Mammal Commission, and Bureau of Ocean Energy Management) and the IWC continued to seek an objective investigation using independent, scientific analysis of the available information. These organizations agreed to collaborate in forming a Multi-Stakeholder Steering Group (MSSC) whose primary role would be to organize and support an Independent Scientific Review Panel (ISRP) to meet and evaluate this unusual event. This process was undertaken and conducted in communication with the Government of Madagascar. The roles and terms of reference for both the MSSC (and it's membership) and the ISRP, as well as operating ground rules for the review process, may be found in Appendix I.

Available information collected during the initial response and investigation and as much information as possible obtained from other sources about the event and any potentially related activities was aggregated and provided to the ISRP. This group, which consisted of five independent, international scientists who are expert in various related disciplines (the authors of this report), were tasked with objectively reviewing all the available information, meeting to ask questions of and interact with some of those involved in the response, and ultimately assessing the potential triggers and/or contributing factors to this event. It should be recognized at the outset that the extent to which these may be unequivocally determined is limited given: (1) the remote and harsh conditions of the stranding area; (2) the time required to mount the stranding response and investigation; (3) the time that has passed since the event; (4) the fact that the location and behavioral state of the animals just prior to the first known observations of them within the lagoon system is unknown; and (5) limited information regarding the type and nature of behavioral responses of melon-headed whales to MBES signals in different exposure contexts.

Despite these acknowledged limitations, the ISRP met, reviewed the significant information that was obtained, and with this report provides what it deems an objective, scientific report on the incident. The ISRP met both independently and in open sessions to discuss the information and ask questions of a number of information providers in early February 2013 at the offices of the U.S. Marine Mammal Commission in Washington D.C (discussed in detail below; also see Appendix II). In preparing the report, the ISRP had follow-on questions and discussions with a number of the information-providers to clarify and fact-check specific aspects of the documents and discussions at the ISRP meeting. The present document comprises the technical report of the ISRP based on the information provided and discussed with information providers that prepared the accompanying reports. It reviews the physical and biological characteristics of the area (section 2), timeline and details of known stranding and concurrent environmental events (3), available information on necropsy results (4), and considers the range of all potential contributing factors to this atypical occurrence (5) in coming to conclusions and recommendations (6). As described in Appendix I, a series of fact-checking review processes with selected information providers and stranding responders was completed in accordance with the terms of reference for the MSSC and ISRP. Advance copies of this publically available report were made available to the organizations within the MSSC and to the Government of Madagascar.

2. Description of Physical and Natural Environment

The stranding event took place in various locations throughout the Loza Lagoon system, which is located in the Sofia region of northwest Madagascar and just inland of Narinda Bay. A general map of the area (which also appears as Fig. 1 in WCS-MMSE1) showing northwest Madagascar and the Mozambique Channel is given here.

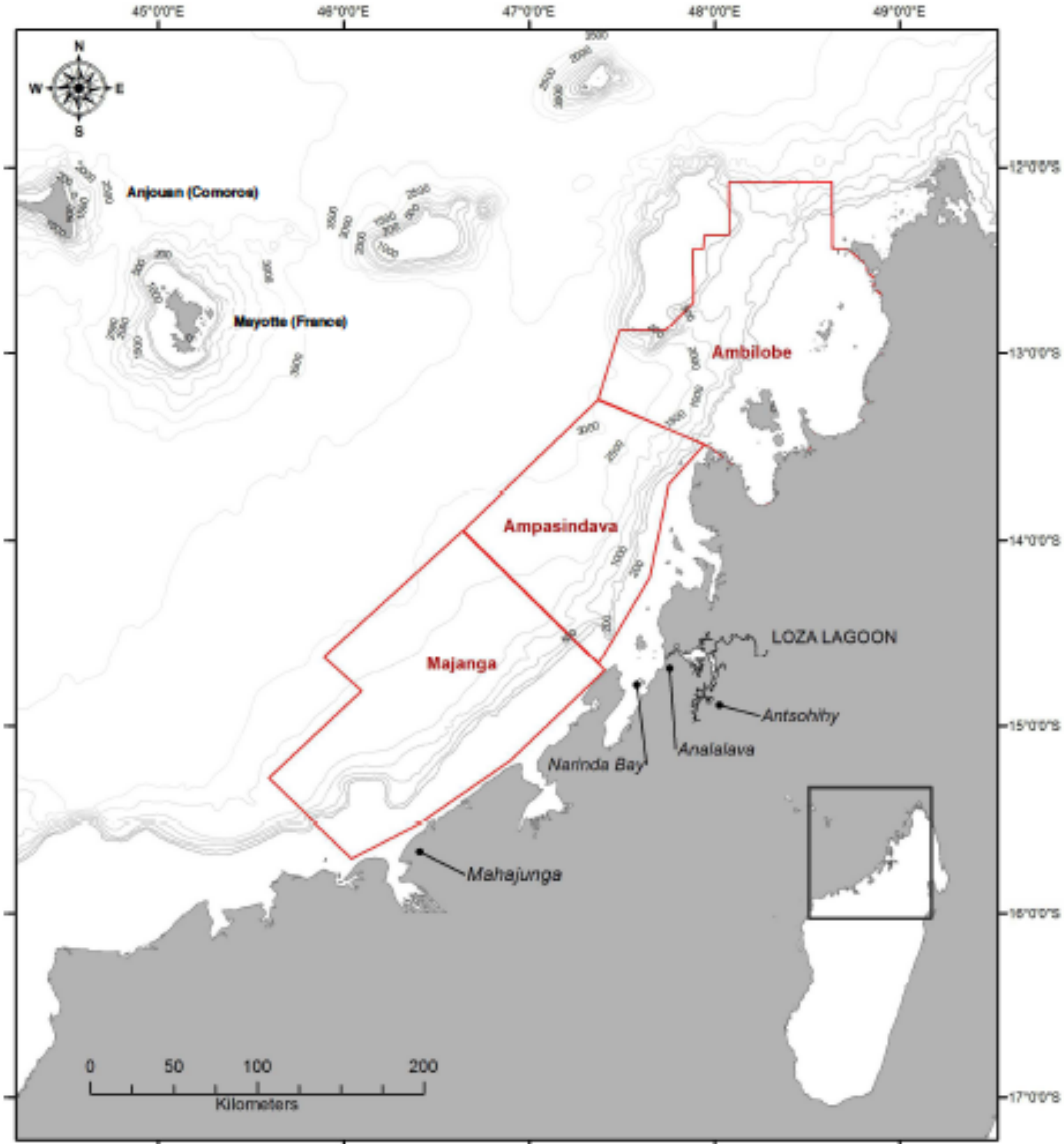

Figure 1. Broad-scale map of the Loza Lagoon area showing key towns mentioned in this report and offshore hydrocarbon lease block areas

The locations of specific villages where key events described below took place are given, as well as the offshore oil concession blocks (in red) in which some of the surveys described below were occurring (specifically Ampasindava) and Mahajunga Harbor.

2.1 Loza Lagoon System: Physical Description and Conditions in May 2008

A description of the physical habitat around and in the Loza Lagoon system was provided in WCS-MMSE-1 and most of the description below is taken directly from that source. In addition, coastline data from GADM (www.gadm.org) and bathymetry data from the NOAA National Geophysical Data Center (www.ngdc.noaa.gov) were used to measure distance from the mouth of Loza Lagoon to various coastal and bathymetric features. The entrance to the Loza Lagoon system is on the inland side of the Baie de Narinda in northwestern Madagascar. Seaward of the lagoon entrance the area extending approximately 14 km is a relatively shallow (<20 m) area with extensive shoals. There are two small islands with large areas of emergent reef 7 km (Nosy Lango) and 6.7 km (Nosy Faohina) due west of the mouth of the lagoon, and a larger island, Nosy Lava, extending 8.6 km from south to north, located 13.5 km WNW of the mouth of the lagoon, directly in between the lagoon entrance and the Sifaka survey area in the Ampasindava block. The closest straight line distance to the 100 m depth contour is 40.7 km; but the closest distance over water (around Nosy Lava) is 42.2 km. To the shelf break (the 200 m depth contour) the closest straight-line distance is 43.8 km and over water is 45.1 km. Given what is known about habitat use of melon-headed whales elsewhere (described below), the distance to the 100 m depth contour (42.2 km) is the closest that melon-headed whales would likely normally be found to the mouth of the lagoon.

Tides in the area off NW Madagascar are typical semi-diurnal tides with a normal range of approximately 4 m. Tides off NW Madagascar on May 30, 2008 were moderate, with a low of 1.46 m and a high of 3.2 m[1]. The shoreline around the mouth of the lagoon is characterized by wide expanses of sandy beaches interspersed with rocky reefs. The village of Analalava is at the entrance to the lagoon, and the lagoon channel is 670 m wide at its narrowest point, and approximately 30 m deep. The

[1] Tidal data obtained from the Hell-Ville prediction site through: http://tides.mobilegeographics.com/locations/2499.html

channel opens into the Grand Lac, the widest area of the lagoon system with a surface area of over 100 km^2 on a spring tide. A number of large and small tributaries connect to the Grand Lac and are highly bifurcated, with shorelines of mudflats and mangroves. The lagoon system is fed by three freshwater rivers but remains estuarine with brackish waters extending inland more than 65 km from the mouth of the lagoon system.

The climate of the Loza Lagoon area throughout the year is relatively mild with daily maximum temperatures around 30° C and minimum temperatures of around 20° C all year. The rainy season is typically November to April, whereas May to October is typically dry with moderate northwest winds (known locally as "Varatraza"), especially in June through August. While conditions deep within the lagoon channels were relatively sheltered and more affected by tidal currents moving through the mangrove estuaries than by prevailing wind, the combination of these strong winds and certain (incoming) tidal conditions complicated stranding response efforts in larger parts of the system, especially Grand Lac. This could have affected observations of animals at certain periods in this area, particularly for those in small groups, as local boaters typically avoid these areas during such conditions.

The period before and just following the stranding (including the stranding response interval) was characterized by variable weather conditions, with periods of weaker and stronger winds. Information on the local conditions experienced during the stranding response is described in some detail in WCS-MMSE 1. Additionally, EMEPNML supported a detailed assessment of broad-scale meteorological conditions (completed by MDA, Inc.) that provided daily regional and local atmospheric and oceanographic data from 5 May to 5 June 2008. This included prevailing air temperature, precipitation, and wind patterns as well as oceanographic conditions including sea surface temperature, currents, chlorophyll-a and ocean productivity patterns. Additionally, to compare both regional and local conditions relative to historical patterns, daily hindcasts and data images were conducted for the period from 10-31 May 2008. A presentation of this broad assessment and changes in prevailing conditions was given during the ISRP meeting by MDA, Inc. followed by a discussion of the implications. This presentation revealed that there were disturbed upper level atmospheric conditions prevalent during the mid- to late-May timeframe, but that these were generally typical of this period of the year with dry and intermittently windy conditions.

Analysis of the ocean temperature data and simulated surface currents indicated that earlier in May there were some occurrences of eddies passing by that regularly occur as prevailing easterly large-scale currents move past the northern tip of Madagascar. Such events can generate transient local upwelling and downwelling events associated with cooler and warmer water temperatures, respectively, which were observed, but no particularly unusual conditions occurred during the first 3 weeks of May. Melon-headed whales have been known to utilize convergence zones created by downwelling and upwelling eddies (Woodworth *et al*., 2012). One of these eddies passed by the region of interest offshore from the Loza Lagoon systems on 12 May 2008, changing an upwelling condition to a downwelling one. This would be associated with the development of a coastward surface current directed toward the lagoon. Sea surface temperatures in the region near the entrance to the lagoon rose by more than 0.5° C over a three-day period, peaking on 15 May associated with the strongest incoming surface current, and staying warm for several days. This is notable as previous marine mammal stranding events have been associated with the transition from upwelling to downwelling conditions (Walker, *et al*., 2005), although these eddies and associated downwelling conditions are regularly episodic along the northwest coast of Madagascar.

As described in detail below, this downwelling event occurred a full two weeks prior to the melon-headed whale stranding event in Analalava and the Loza Lagoon system, and any association would thus seem unlikely. Interestingly, a similar surge of inshore surface current forcing downwelling conditions occurred near the northern tip of Madagascar on 25-27 November 2007, just prior to the discovery of a stranded group of melon-headed whales near Nosy Hara in extreme northwest Madagascar. However, the exact timing and details of that stranding are very poorly known (discussed in detail below) and the condition of the whales when discovered could suggest that they actually died earlier in November before these downwelling conditions and inshore surface current conditions.

Sea surface temperatures were slightly (~ 0.5° C) below the historical norm on average during May 2008, but were clearly within the normal variation for the period from 1988-2012 for this location. However, unusually cold conditions prevailed across the broad region of the western Indian Ocean and the Mozambique Channel during the March-May time frame with strongly below normal conditions noted for northwestern Madagascar during the last week of May (sea surface temperatures ~1.5° C below normal). Conversely, chlorophyll-a levels estimated during May were slightly above (<0.1 mg/m^3) the historic average. While this appeared to be within historical normal variance on an annual basis, this level exceeded the May average for any other year during the period from 1998-2012. Overall, there were no atypical atmospheric or oceanographic conditions or major storms during May 2008 aside the increased local chlorophyll and the downwelling conditions associated with coastward surface currents in the middle of May.

2.2. Sofia region (including Loza Lagoon): Human use and impacts

In terms of human use of the area, there are a number of small villages and fishing camps along the shoreline of the Loza Lagoon and mangrove system (described in greater detail in WCS-MMSE-1). These are quite remote areas typically accessed by boat as local road systems are challenging and many villages lack electricity and communication services. The isolated nature and limited services in these remote locations complicated stranding response efforts in this event and made the systematic and dedicated effort to obtain reliable information clearly necessary.

Most villagers subsist through fishing, farming, and making charcoal. There are a variety of predominately artisanal fisheries within the lagoon system, including small-mesh gillnets and casting for shrimp and crab as well as fishing from unpowered small boats. Commercial fisheries are uncommon in the area, although there are occasional regional offshore shrimp fisheries and there were local reports of a 30-ton catch of sharks over an unspecified area off Northwestern Madagascar during May 2008.

There is limited mining and chromite ore produced inland from the Loza Lagoon region with transport out by barge and trucks. A larger port is being planned in Narinda Bay that reflects an overall slow but generally increasing industrial presence and development of the area. Offshore exploration for oil and gas deposits has occurred with increasing regularity in the Sofia region, with at least nine seismic surveys conducted during the period from 2004-08, most occurring in the Ampasindava and Mahajanga lease blocks (Fig. 1). Additional exploration activity including mapping sonars and shallow hazard surveys using various sensing methods have also occurred in these areas. French hydrographic surveys were conducted using MBES in northwest Madagascar in April and May 2008. The M/V *Teknik Perdana* used an MBES to transit along the northwest Madagascar coast and calibrated their equipment in the Ampasindava block on 29 May 2008. An EMEPNML geophysical site survey was conducted 3-6 June 2008. These are discussed in greater detail in section 5 below. There is limited information on local bathymetry and hydrography, and it has been recognized that the hydrographic surveys will need to be supplemented with satellite imagery to image local silting conditions. There is particular interest in obtaining increased hydrographic data, independent of oil and gas exploration and development, to better understand local bathymetric conditions for navigational reasons and to better predict tsunami risk.

2.3. Sofia region (including Loza Lagoon): Natural history

The natural history of Loza Lagoon is typical of that of shallow estuarine low-latitude areas. Waters are brackish throughout the system and exceedingly turbid with suspended sediment. Mangroves become increasingly dense with distance from the mouth of the lagoon, and further reaches of the system include shallow creeks and intertidal mudflats. These systems support warm-water estuarine fish and invertebrate species and serve as breeding estuaries for sharks and other fish species that migrate out to the ocean later in life.

One species of marine mammal is known to occur regularly in the Loza Lagoon system, the Indo-Pacific humpback dolphin (*Sousa chinensis*). Sightings of this species in the lagoon were reported in WCS-MMSE-1 during the response effort. A second species, Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), likely occur in the lagoon system, though apparently with less regularity. Despite the lack of any historical record of sighting within the Loza Lagoon or any other such body of water in Madagascar prior to the 2008 mass stranding, the primary species considered here (because it was involved in the stranding event) is the melon-headed whale. Their general life history (based on information from other areas) as well as recorded information for this species in the local offshore areas of northwest Madagascar is considered below.

Melon-headed whales are a tropical oceanic delphinid. The only areas where they are known to occur nearshore are where there are steep slopes resulting in deep-water relatively close to the coastline (Jefferson and Barros 1997), for example around some oceanic islands (Brownell *et al*., 2009; Aschettino *et al*. 2012). Because of their distribution in relatively inaccessible tropical areas far from shore, the species is poorly studied worldwide, with the exception of Hawaiian waters. Around the main Hawaiian Islands there are two known populations, one resident to the Kohala area of the island of Hawaiʻi and another that moves among the islands and offshore (Aschettino *et al*. 2012; Woodworth *et al*. 2012; Schorr *et al*., in prep). Satellite tag data from six individuals from the Kohala resident population indicate they spend the majority of their time (71% of recorded locations) in depths of 300-700 m, corresponding to between about 5 and 20 km from shore in that area (Schorr *et al*. in prep). The tagged individuals from the Kohala resident population had 97% of their locations in depths greater than 200 m (Schorr et al. in prep). Taking into account only the highest quality locations from the satellite tags (Location Class 3, with an estimated error of +/- 150 m), the shallowest depth documented for individuals from that population was 151 m. This is the only population of melon-headed whales known to be resident to a relatively small area, although there are likely resident populations off other oceanic islands in the central and South Pacific (Brownell *et al*. 2009).

Information available to assess the presence of melon-headed whales and other cetaceans off western Madagascar comes from two primary sources: the Wildlife Conservation Society's (WCS) Ocean Giants Program, which primarily involved small-boat surveys off the west coast of Madagascar from 2004 through 2012 (Cerchio *et al*. 2009; 2012), and a larger regional aerial survey (the REMMOA surveys) undertaken in December 2009 through January 2010 by La Rochelle University (Laran *et al*. 2012a; 2012b).

WCS small-boat surveys were undertaken off SW Madagascar (near Anakao in southwestern Madagascar) from June to October in 2004 through 2009, and off NW Madagascar (Nosy Be, Nosy Mitsio, Nosy Iranja) from July to December in 2007 through 2012. These surveys were primarily undertaken in relatively shallow waters focusing on humpback whales and coastal dolphins. WCS surveys also involved a combined visual and acoustic survey in September 2010 that covered from Toliara in the south to Mahajunga in the north. Combined in all three surveys there were 660 cetacean sightings, with 17 species documented, but only a single sighting of melon-headed whales, in deep water offshore of Anakao. Indo-Pacific bottlenose dolphins and humpback dolphins were the two species of odontocetes sighted most-frequently in nearshore areas.

The REMMOA surveys covered six broad regions in the southwest Indian Ocean, including three regions off the west coast of Madagascar: Comoros-NW Madagascar (15,198 km surveyed in an area of 275,636 km^2); W Madagascar (9,776 km surveyed in an area of 123,680 km^2) and SW Madagascar (9,785 km surveyed in an area of 152,763 km^2). Surveys in the NW and W covered shelf (0-200 m), slope (200-2000 m), and oceanic (>2000 m) waters, and the Comoros-NW Madagascar survey area spanned the area from Mahajanga to the northern tip of Madagascar and offshore to encompass Mayotte and the Comoros Islands. Melon-headed whales and pygmy killer whales (*Feresa attenuata*) can be difficult to distinguish in the field. In the REMMOA Indian Ocean surveys there was only a single sighting of pygmy killer whales, 75 sightings of melon-headed whales, and a further 33 sightings that were considered to be either melon-headed whale or pygmy killer whales (Laran *et al*. 2012b). Within the Comoros-NW Madagascar survey area melon-headed whales were the most frequently encountered globicephalid, with sightings both off the NW Madagascar coastline, off Mayotte and Comoros and in open-ocean waters between (Laran *et al*. 2012a). Density estimates and habitat modeling from these surveys combined known sightings of both species as well sightings that were either melon-headed or pygmy killer whales. Given the proportion of sightings of these two species that were identified to species (99% melon-headed whales), and the relative rarity of pygmy killer whales world-wide where the two species are known to overlap (*e.g.*, Barlow 2006; Baird *et al*. 2013), it is likely that the majority of the "melon-headed whale/pygmy killer whale" sightings were in fact melon-headed whales. Throughout the three REMMOA survey areas off western Madagascar, combined densities for these two species were greatest in the general area off NW Madagascar, and in particular off the Comoros, having the highest density of any species of cetaceans seen (Laran *et al*. 2012a). Combined densities were greatest in slope waters, followed by oceanic waters, with lowest densities in shelf waters (Laran *et al*. 2012a).

Relatively little is known regarding marine mammal strandings in Madagascar; prior to 2012 there were no organized stranding networks in the country. However, considerable recent effort, in part resulting from interest in the 2008 mass stranding, has provided some information. At the ISRP meeting, WCS provided the panel with a summary of known information to date (see Appendix II). From 2008-2012, WCS (using experienced Malagasy interviewers) conducted systematic surveys of over 800 local fishermen at 68 villages along the entire west coast of Madagascar. Fishermen reported marine mammal strandings at all locations surveyed from 1960-2012 (with more than 90% occurring since 1990) with a minimum of 152 reports after removing potential duplicates. These strandings most commonly included humpback whales (*Megaptera novaeangliae*) and small coastal dolphins and almost all were single animals (all < 3 with one exception). Mass stranding events in western Madagascar are thus apparently exceedingly rare and were not reported in the fisher surveys conducted by WCS. However, the only known stranding of melon-headed whales to ever occur in Madagascar prior to the incident outlined here was a mass stranding of 15 animals in November-December 2007. These individuals apparently stranded on an ocean-facing beach in several phases and were located over a period of ten days near Nosy Hara in the extreme northwest of Madagascar. The information on this event is limited to a single newspaper account (picked up by a wire agency and subsequently reprinted in several online locations). However, photos of fairly decomposed carcasses obtained by local officials and described to the ISRP by information providers working on marine mammal strandings in Madagascar were sufficient to confirm the animals as melon-headed whales but suggested that they may have been dead for days prior to being discovered.

3. Integrated Timeline and Description of Known Events

As with most marine mammal stranding events, the ISRP efforts to understand the potential contributing factors focused heavily on recreating the sequence of known events. The ISRP spent considerable time reviewing the detailed information provided from the extensive efforts of WCS and IFAW in the mass stranding response team (see: WCS-MMSE 1; WCS-MMSE 2) and the large volume of detailed information provided by EMEPNML (see Appendix III). The most comprehensive assessment of the known events possible was assembled based on reviews of the available documents, presentations and discussions at the ISRP meeting, and follow-up questions and clarifications with information providers. The available information included in the integrated timeline given here includes all information available about environmental and human activities in the area before and during the event and animal observations and physical samples obtained during the stranding response and in dedicated interviews with responders and local villagers.

This is segregated here into (1) events preceding the first known sightings of the whales; (2) a detailed discussion of the animals' apparent entry into and movement through the lagoon system on 30-31 May 2008; and (3) events relating to stranding response thereafter. As the role of the ISRP was to investigate potential contributing factors to these pelagic animals entering a very atypical habitat, more detailed review and assessment is given to the events leading up to and at the onset of the event (sections 3.1. and 3.2). Readers are referred to the detailed documentation in the WCS-MMSE 2 report for much greater detail about the specific stranding response efforts in June 2008, although the timeline of major events is given in 3.3 and a description of the known mortality and necropsy results is given in section 4.

3.1. Known Environmental and Anthropogenic Events Before 30 May

April through mid-May: A French Naval Hydrographic and Oceanographic Service vessel (*Beautemps-Beaupré*) was conducting hydrographic surveys in the general area of the Comoros, Mayotte, and Glorieuses area off northwest Madagascar, as well as the Mozambique Channel (Fig. 2). The exact timing and location of transmissions could not be determined by the ISRP (despite multiple requests for information). The vessel left Reunion on 4 April and arrived in Cape Town, South Africa on 24 May. During this period the vessel followed the course shown below, presumably using the MBES system throughout this transit as is often the case with such surveys. Based on the limited information on the course of the vessel and it's arrival in Cape Town on 24 May and given the nominal cruising speed of the vessel (from public record), the vessel was likely in the area of the stranding event several weeks or more prior to it's occurrence. There was also apparently extensive bathymetric work done at the port of Mahajanga including detailed mapping of offshore approaches to the port. The Mahajanga survey could not be completed during a 5-week period in 2008 and was finished in 2010. The *Beautemps-Beaupre* is equipped with both shallow-water and a deep-water MBES, the later having identical model numbers (Kongsberg Simrad EM 120) as equipment aboard the *M/V Teknik Perdana* used in the 29 May M/V *Teknik Perdana* transit and MBES calibration and 3-6 June 2008 EMEPNML geophysical site survey. The *Beautemps-Beaupré* may have used the deep-water system during the transit down the northwest coast of Madagascar and appears to have followed a generally similar course to the 29 May EMEPNML transit and calibration (described below). No detailed information on the location and timing of

MBES (similar to what was provided openly by EMEPNML) is available to directly assess areas that were ensonified.

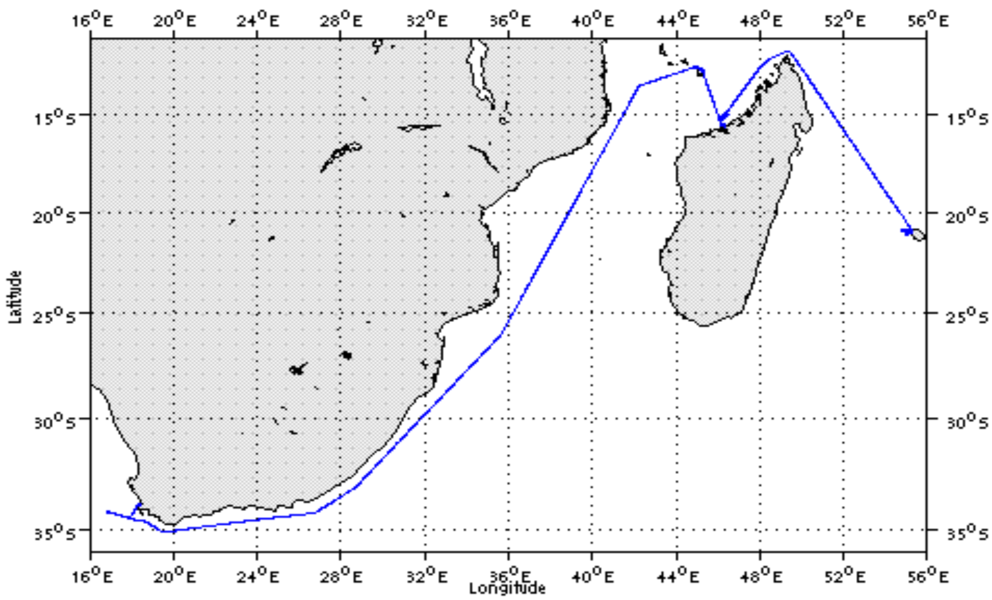

Figure 2. Course of the *Beautemps-Beaupré* during April and May 2008. The only dates known are that the vessel left Reunion on 4 April and arrived in Cape Town, South Africa on 24 May.

~20-27 May: A total of 30 tons of sharks was taken by a commercial fishing boat in the area during this period, although no details are available as to the precise location or nature of fishing.

24 May: Magnitude 4.4 earthquake occurred at 1119 local time at lat/long: -12.189; 41.671, which is approximately 700 km from the mouth of the lagoon system (Fig. 3).

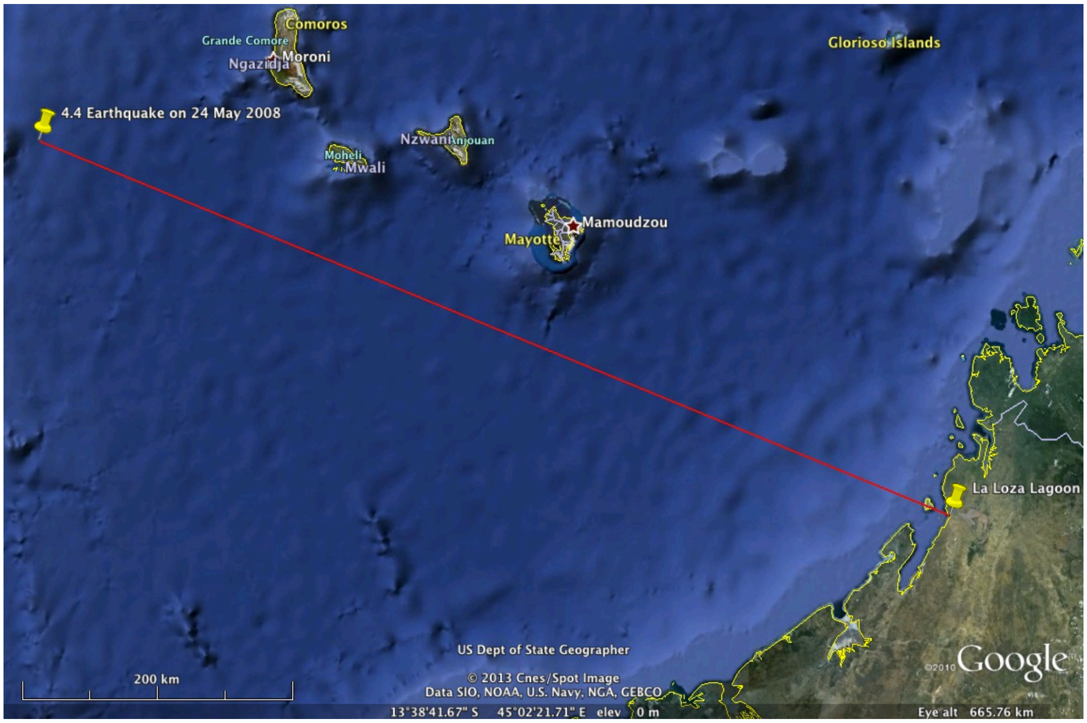

Figure 3. Map showing approximate proximity of 24 May magnitude 4.4 earthquake to Loza Lagoon system (~700 km)

This was a relatively mild earthquake that was not an atypical occurrence for areas to the northwest of Madagascar. Magnitude 3.5 or higher earthquakes reported for this region from June 2007 to the end of 2008 are shown below (Fig. 4).

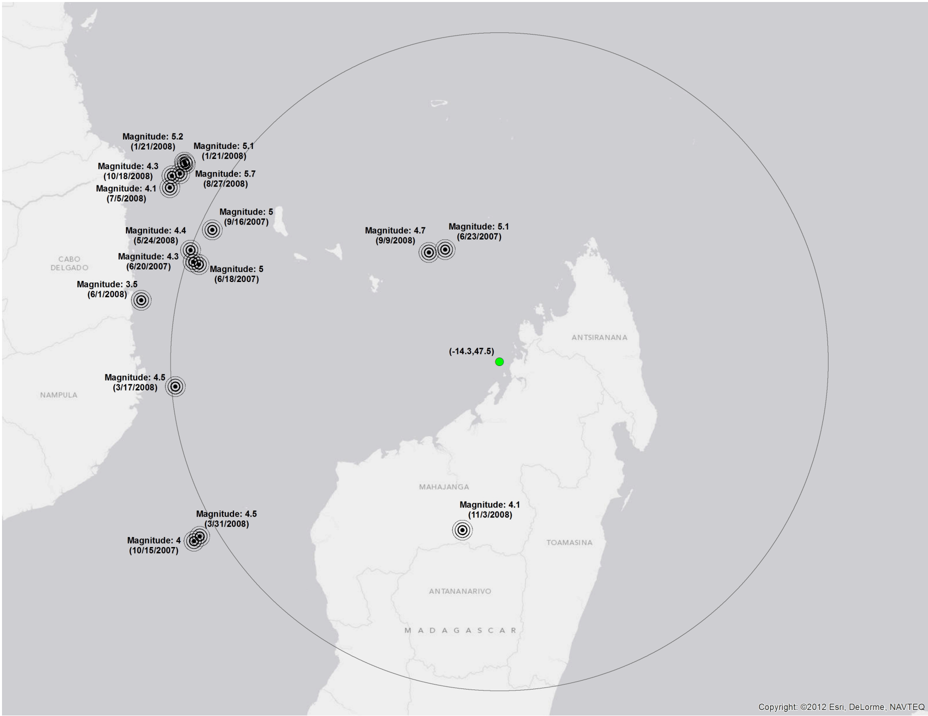

Figure 4. Map showing magnitude 3.5 or higher earthquakes reported in the vicinity of northwest Madagascar from June 2007 through 2008 (radius of the circle is ~700 km)

28 May: During mobilization from Malaysia to Ampasindava block en route through poorly charted waters to conduct a geophysical site survey to detect geohazards for EMEPNML, the contractor vessel *M/V Teknik Perdana* leaves Diego Suarez.

29 May: *M/V Teknik Perdana* transits from Diego Suarez on the north end of Madagascar heading south. EMEPNML provided the ISRP with detailed reports from the visual monitoring observers aboard the *M/V Teknik Perdana* (EM-3) from 28 May through 6 June. No marine mammals were detected by the visual observers at any point while they were on duty during daylight hours on 29 May, although observations ceased due to darkness prior to the end of MBES transmissions described below. During a portion of the transit of the *M/V Teknik Perdana* from Diego Suarez to the Sifaka site in the Ampasindava block during 29 May down the shelf break roughly along the 1,000 m depth contour, the ship's Kongsberg EM 120 MBES was used; the capabilities of the system are given in Table 1. These MBES transmissions begin at 0544 local time with a relatively continuous period of transmissions until 1230 local time, and then occurred intermittently between 1456 and 1931 in a concentrated area in the Ampasindava block on the shelf break to the northwest of the initial stranding location (straight-line distance is ~65 km). During transmissions on 29 May a 2° beamwidth was used.

Table 1. Source operating parameters for the Kongsberg Simrad EM120 MBES used on the *M/V Teknik Perdana*

Output carrier frequency (kHz)	**12**
Pulse duration (ms)	**2, 5, or 15**
Pulse rate (Hz)	**≤5**
Transducer beamwidth	**1 or 2°**
Output source level (RMS SPL) (dB re 1 µPa @ 1 m)	**242-236**
SEL per pulse (dB re 1 µPa^2·s @ 1 m)	**224-218***
Number of beams	**191**
Across-track beam fan width	**150°**

* source SEL calculated using a pulse duration of 15 ms

The overall timeline of the transit and operations of the *M/V Teknik Perdana* beginning on 28 May, including the transmissions on the 29th and later operations involving both MBES and seismic airgun surveys, is shown below (Fig. 5).

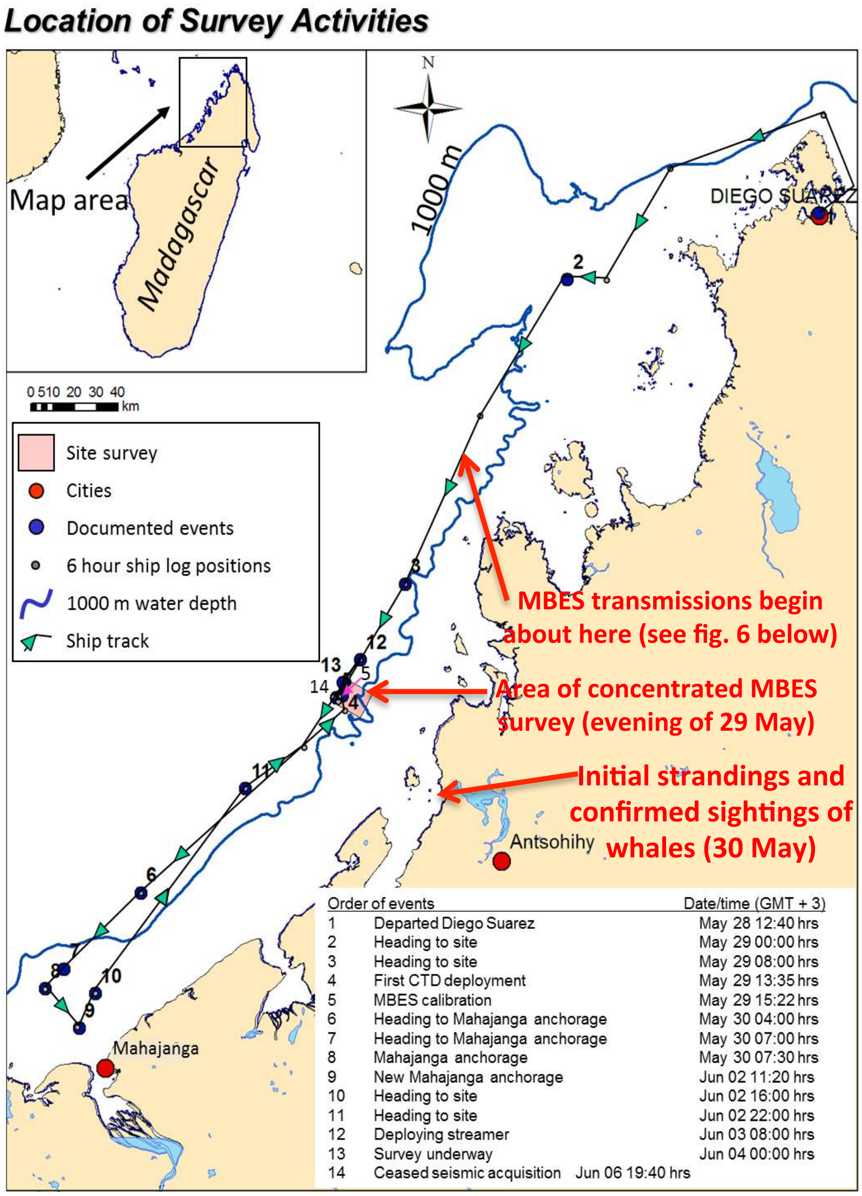

Figure 5. Overall timeline of known movements and active sound transmissions (MBES and seismic surveys) of *M/V Teknik Perdana* beginning on 28 May 2008.

The ISRP was provided an extremely detailed description of the 29 May MBES transmissions, including specific locations and calculated depths at regular time intervals (EM-1). Additionally, given observations of the relatively close proximity in time and space (~65 km) of the point of closest transmissions to the first known stranding events (during the day on 30 May), in 2012 ENEPNML commissioned detailed post hoc sound propagation modeling of the *M/V Teknik Perdana* MBES operations on 29 May 2008 to provide a basis to evaluate the degree of ensonification of the area near the stranding site resulting from known MBES operations. The modeling methodologies and resulting analyses were presented and discussed with the ISRP in detail, including modeled received sound levels from these operations along the course of the *M/V Teknik Perdana* while in the proximity of the initial stranding. During the mobilization of the *M/V Teknik-Perdana*, the first MBES transmission was at 0544 local time (position 1 on Figure 6) and continuously operated until 12:30 except for approximately a 10 minute shutdown at 0906 hours (6 hours and 36 minutes of operations over a 6 hour and

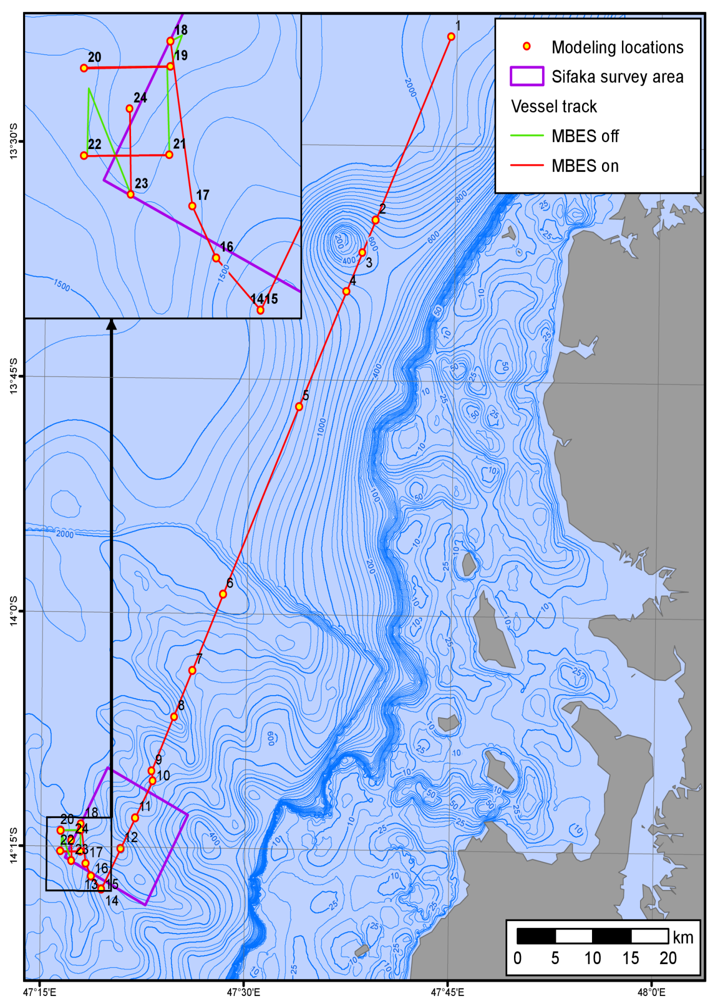

Figure 6. Detailed track of *M/V Teknik Perdana* during operations on 29 May 2008

46 minute period). This was followed by a cessation of MBES between 1230 and 1456 followed by seven short calibration runs each lasting from 12-20 minutes, completing at 1931. The total time MBES was operating during the calibration was 104 minutes over a 4 hour and 35 minute period.

The modeling assumptions, methods, and results are discussed briefly here, but are provided in greater detail in EM-2. Three scenarios of multibeam sonar operation were modeled: (1) A single sonar pulse emitted at the Sifaka survey area in the Ampasindava block at the point on the vessel track closest to the deep channel; (2) Twenty-four sonar pulses emitted from various source locations along the vessel track to estimate the limits of the area ensonified to various rms SPLs; and (3) A total of 566 pulses emitted along the vessel track and received at various fixed receiver points along the deep channel to determine the temporal variation in received rms SPLs throughout the sonar operations. Modeling results predict areas over which received sound levels (at 12 kHz) reached the 160 (top), 140 (bottom left) and 120 dB re 1μPa (RMS) (bottom right) isopleths (Fig. 7, also in EM-2).

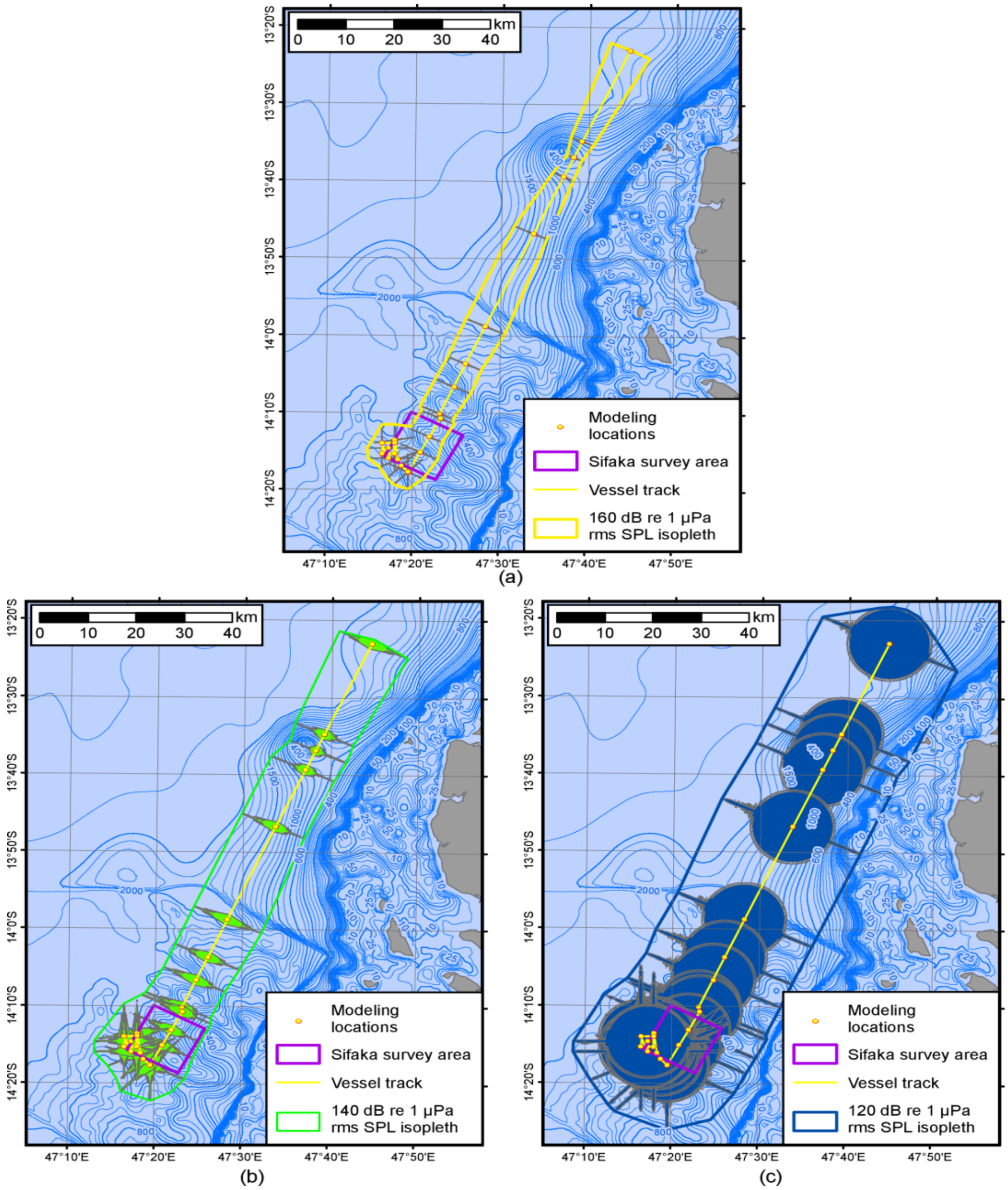

Figure 7. Modeled sound levels resulting from *M/V Teknik Perdana* MBES operations on 29 May 2008

The combined results of the propagation modeling indicate that there was a large area (~30-35 km) straddling the continental slope area over which received sounds from the MBES transmissions exceeded 120 dB re 1μPa. Because of the large number of overlapping MBES beams, the sequential transmissions were presented as an intermittently wide swath of sound as the vessel moved to the south-southwest, followed by concentrated transmissions on the Ampasindava block in the afternoon and evening of 29 May. Propagation modeling was not conducted out to lower received sound levels (below 120 dB) across the entire track and ambient noise data for the area are not available. However, based on the modeling results presented, the ISRP concluded that these sounds would likely have exceeded ambient noise and been detectable by odontocete cetaceans (with excellent hearing in the ~12 kHz band - discussed below) over a much larger area, extending closer to (though almost certainly not fully reaching) the stranding location. Modeling was conducted to explicitly consider sound propagation from the intermittent and localized transmissions in the Ampasindava Block on 29 May relative to the first known stranding location during the day on 30 May and confirmed sightings that evening (Fig. 8 below and see EM-2 for more detail).

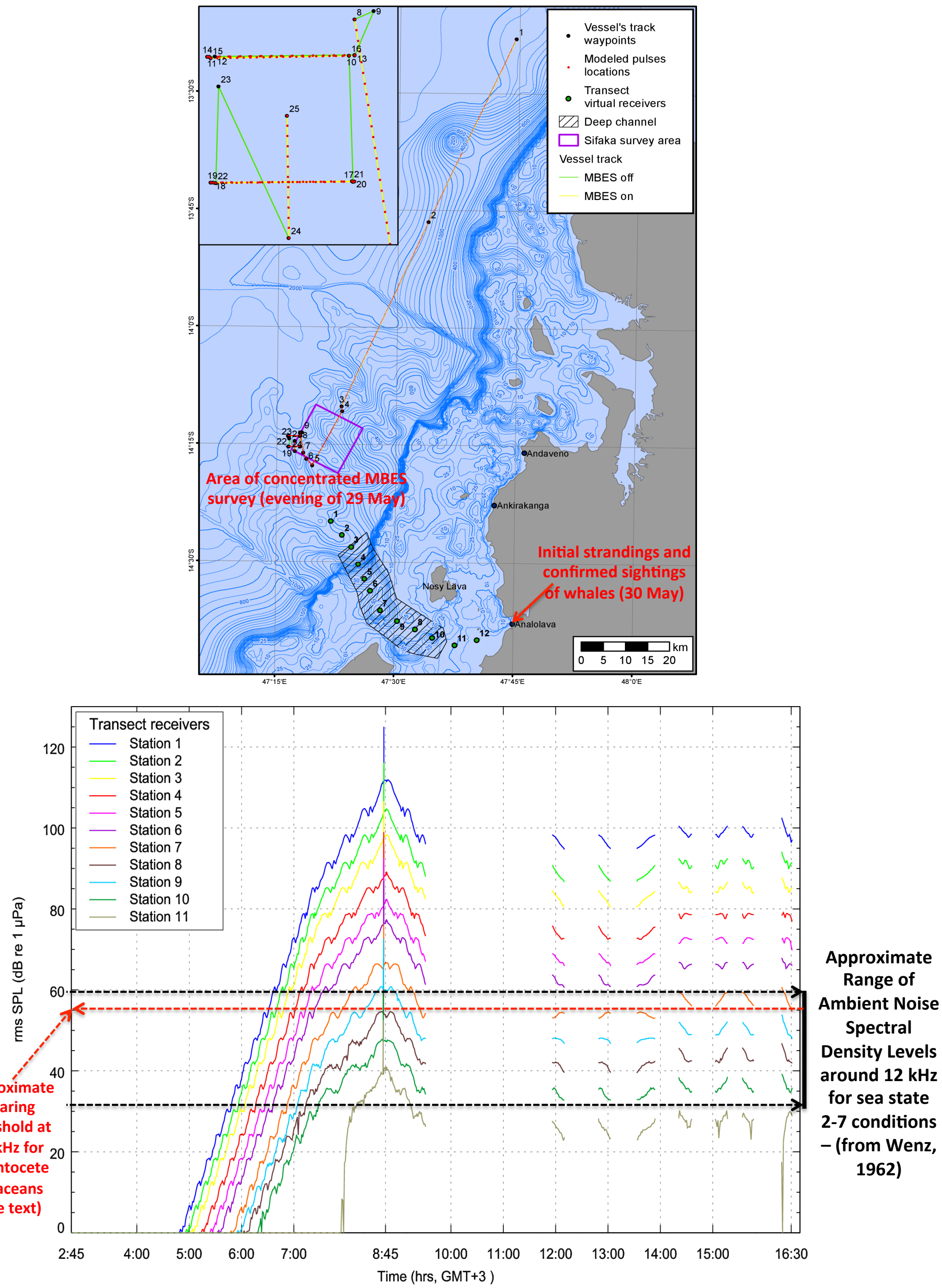

Figure 8. **Top**: Modeled transect "stations" in a deep channel between the position of *M/V Teknik Perdana* MBES transmissions on 29 May and confirmed stranding location. **Bottom**: Predicted received sound levels at each transect "station" for various transmissions (note: add 3 hours for local time).

As discussed in detail below, the exact location of the whales prior to their stranding on 30 May is unknown. Thus, whether they may have transited this deep channel in the shelf break, or moved along more of a direct path further north across shallower water, is speculative. What there are limitations to the predictions that can be made given that far-field measurements of MBES signals and ambient noise were not obtained *in situ*, the modeling shown in Fig. 8 for one specific transect of points extending from deeper to shallower water suggests is that some of the narrow-band 12 kHz sounds from 29 May MBES transmissions very likely exceeded predicted ambient noise spectral density levels in the 12 kHz band over large areas along the shelf break (~1,000m contour) and into some shallower water areas. Determining a range of audibility in this situation is challenging for the reasons given above, but in general most marine mammals typically integrate sound energy within critical frequency bands that are about 1/3-octave in width, within which a narrow band stimulus signal level needs to exceed ambient noise spectral density level by a critical signal-to-noise ratio to be detected - on the order of 15-25 dB for most marine mammals (*e.g.*, Finneran *et al*., 2002). While the predicted propagation from these transmissions into shallower waters and how far animas on the shelf could have heard these sounds is difficult to estimate directly with the information available, as shown in Fig. 8 at least some of the modeled signals from transmissions at ranges of several tens of kilometers are well above the typical hearing threshold around 12 kHz for odontocete cetaceans (and would be expected for melon-headed whales - discussed below) and the likely range of typical ambient noise conditions. The ISRP concluded from the information provided that they were very likely audible well beyond the 120 dB isopleth but were almost certainly not detectable at the stranding location ~65 km away from the closest point of transmission.

2 June: M/V Teknik Perdana moved anchorages and used a 100 kHz active sonar near Mahajanga

3-6 June: *M/V Teknik Perdana* survey intermittently operating seismic airgun array in 2D shallow hazard survey and 12 kHz MBES (same as on 29 May) in Ampasindava block. The seismic array has a total volume of 760 cu-in and consists of 4 x 40 cu in I/O sleeve guns and 4 x 150 cu in Sodera G guns, suspended at a depth of 4m. The airguns are charged to a pressure of 2000 psi and fired at 18.75m intervals along the vessels transit. As the vessel travels at a speed of approximately 4.5 knots the array is fired at approximately 8-s intervals.

6 June: Upon being informed of the stranding event, EMEPNML ordered all sound operations on the *M/V Teknik Perdana* to cease.

3.2. Melon-headed whale related events and observations on 30-31 May

Based on accounts of local villagers obtained through a dedicated effort of systematic interviews to collect information, a directed pattern of movement of whales from the sea into the lagoon system emerges. Details regarding the design and process for obtaining this information, with relevant caveats about the nature and limitations of the interview process, are given in WCS-MMSE 1. The overall pattern and apparent sequence of events that resulted are given below (Fig. 9).

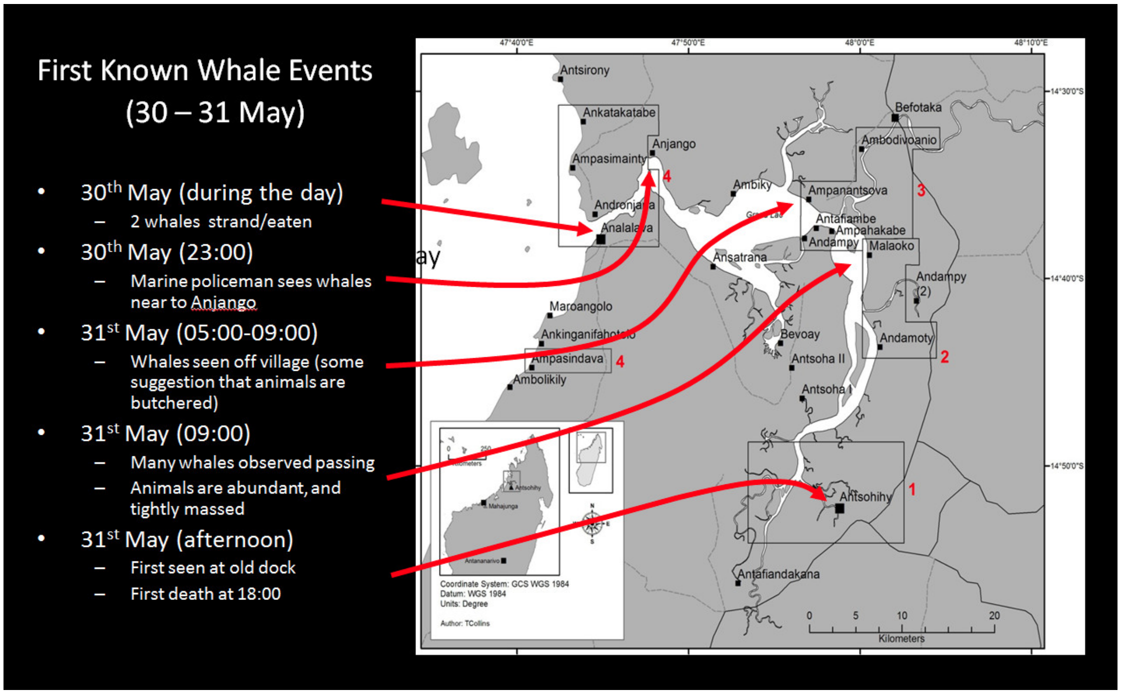

Figure 9. Time series of locations of observations of groups of melon-headed whales as well as stranded individuals beginning on 30 May 2008

The first known event involving the whales was observation of two dead whales near Analalava on the coast near the lagoon entrance during the day on 30 May that were taken for meat by local villagers. The exact timing of this during the day is unknown. This initial stranding was followed by a night-time sighting on 30 May near Anjango of melon-headed whales in unusual areas inside the lagoon system. On 31 May, live animals in a large group or groups (of variable sizes but all estimated at dozens to hundreds) were reported, with a high degree of agreement amongst independently obtained information, many of which indicate animals in sub-groups were tightly cohesive as they traveled. The time pattern of sightings strongly suggests the whales were moving progressively deeper into the Loza Lagoon system reaching Antsohihy by the afternoon of 31 May.

3.3. Stranding response and related events 31 May to mid-July 2008

31 May: First whales died at Antsohihy.

1 June: Stranding response efforts involving local volunteers begin to try and save animals; local announcements are made regarding not killing whales for health and ethical reasons.

2 June: Two dead whales reported at Antsohihy - probably more occurring in the channel.

3 June: WCS in Tana receives initial report of event; word begins to spread outside Madagascar of event in part from local media coverage.

6 June: WCS and Ministry Officials arrive at stranding location and begin coordinating response; efforts continue to push animals back to water; Government of Madagascar approves deployment of Mass Stranding Response Team (MSRT).

9 June: Beginning of visit of international MSRT - meeting with government officials (continues through 13 June)

10 June: Beginning of field operations of international MSRT - continues through 13 June

11 June: MSRT and local efforts continue to push animals back to water until 22 June

14 June: Satellite images obtained by EMEPNML (who commissioned satellite images of Narinda Bay and the area around Antsohihy and in 2012 acquired 0.5m resolution satellite images from DigitalGlobe (discussed by B. Brovey with the ISRP - see appendix II)) show coarse images of (~3.5m) objects on beach south of mouth of Loza

River near Ampasindava. These objects were in very close proximity to indigenous settlements and in similar configuration, but somewhat more dispersed as 20 May images obtained by EMEPNML. The ISRP considered the satellite images provided and concluded that they were not stranded whales that remained in the same location for this period and were otherwise undetected by the residents of the local village. This was based on: (1) the complete lack of indication from the WCS interviews that there was any basis for rumored strandings in the area despite the immediate proximity of this site to a local settlement clearly visible in the images; (2) the fact that many of the other known stranded whales were salvaged for meat within a matter of hours not left in place for three weeks; (3) the lack of detection of carcasses from an aerial survey (looking for stranded whales) of the area during the same period; (4) expert assessments of information providers for this event and experienced marine mammal stranding responders indicating the linear patterns of distribution were inconsistent with stranded animals that would have remained in an intertidal area for a period of three weeks; (5) the similarity of the images to how indigenous vessels known to be used in the area are typically kept on a beach (and evident in some of the pictures shown); (6) inconsistency between the size of the images (estimated as 3-3.5m) relative to the median body length of melon-headed whales (~ 2.5m). The potential that these were stranded melon-headed whales is not considered further as the ISRP concluded there was no evidence to support this.

14 June: WCS staff questioned local residents in Analalava to investigate rumored reports of an additional group of 20 stranded whales in the area around Ampasindava. All accounts indicated this rumor was inaccurate and there were no reports of any stranded whales in the area.

15 June: Interviews conducted in Ampasindava (involving 12 of 25 households) by Bemahafaly *et al.* (see: WCS-MMSE 1). All accounts indicated that no stranded whales had been seen in the area (one individual reported seeing a dolphin ‘with a beak’ in a local fishing weir, suggesting it was a different species).

16 June: An extensive aerial survey flown by WCS of the general area beaches (including Analalava and Ampasindava) failed to reveal any stranded whales.

21-22 June: Interview surveys conducted by WCS team across the Loza Lagoon area.

23 June: No further attempts are made to free whales pending a decision on next steps by the *ad hoc* committee.

28 June: Four melon-headed whales observed heading toward Analalava toward open ocean.

30 June to 10 July: Post-hoc monitoring phase of stranding response. A small WCS team returned to Antsohihy to assess if whales were still in the Loza Lagoon, and to collect museum specimens; boat transects between 30 June and 4 July conducted from Antsohihy and in areas to the north within the lagoon system. Observations were of humpback dolphins but no melon-headed whales were seen or located live or dead.

4. Summary of Stranding Events, Response, and Necropsy Results

Whales were first reported within the Loza Lagoon at the Antsohihy dock on 31 May, based upon multiple credible and highly consistent eyewitness accounts, interviews and web searches. Due to the complexity of the lagoon topography, the exact number of whales in the lagoon was not determined but was estimated by the stranding response team to be between 100 and 200 animals. The first deaths in Antsohihy were reported on 31 May by interviewees to the stranding response team, but Dr. Zafera performed the first necropsies on 3 June. Whales continued to die in the Loza Lagoon for weeks afterwards. The exact number of deaths will never be known, as some carcasses were eaten, others were sold at local markets, and likely some were not discovered. However, the expert stranding response team estimated at least 50 whales died, and about 23 were buried. The majority of whale deaths were reported between 5 and 9 June (Fig. 10 below, also appears in WCS-MMSE-2).

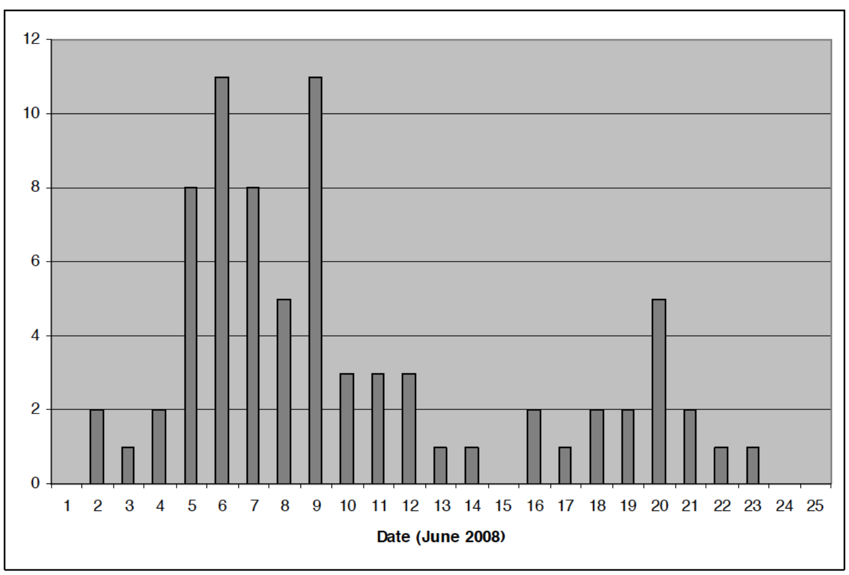

Figure 10. Time series of number of known melon-headed whale mortalities per day in June 2008.

From early June until 23 June, efforts to save animals by extracting them from the mud, pushing them into deeper water, and herding them with small boats were made by local people and the international stranding response team. Reports during herding attempts indicate that some animals appeared disoriented or confused and unresponsive to herding efforts. Post mortem examinations were conducted on some of the dead animals; this was limited to a subset of the carcasses due to logistic difficulties and advanced autolysis. Following the period of attempted herding, the expert stranding response team conducted interviews in the area, and monitored the lagoon system for cetacean sightings. Thus, the response to this mass-stranding event consisted of five phases:

I. Preliminary response: 1 June – 8 June;

II. Expert MSRT response: 9 June – 13 June;

III. Post-Expert MSRT: 14 June—20 June;

IV. Village Interviews: 21 June—22 June;

V. Biological monitoring: 30 June - 10 July.

The preliminary response by people on site involved efforts to save animals by pushing them off the mud, and limited post mortem examinations due to use of dead animals for subsistence purposes. When the international mass stranding response team arrived, efforts to herd animals out of the lagoon in a coordinated fashion were initiated. In general, the whales responded well initially to herding, but their responses decreased on successive days, and by the third day the whales were not very responsive to herding.

During herding attempts, some animals swam strongly away from the boats, while others broke away from the group and fell behind the boats. Herding efforts were focused on the more responsive and stronger appearing animals. During herding attempts, a small group of humpback dolphins were observed within the lagoon on 13 June 2008.

On 9 June one live whale was rescued off the mud, examined and sampled, and released following treatment. It had severe skin lesions that likely were caused by sun damage and dehydration. A blood sample collected from this animal contained antibodies to *Brucella* spp and *morbillivirus*, indicating previous exposure to these cosmopolitan marine mammal infectious agents.

Post mortem examinations were performed by the MSRT on three intact carcasses and one head. All three animals were moderately decomposed, with tissue autolysis that limited histological examination. Ear bones from these animals were removed on site, frozen, and transported to the United States for detailed CT scans. A further two animals were examined *post mortem* by Dr Zafera, one prior and one subsequent to the arrival of the MSRT and tissues submitted to the MSRT for histological examination. Results of these post mortem examinations are summarized in Table 2 below. In summary, the three animals examined grossly by the MSRT were all males, were moderately underweight based on blubber thickness, and had hepatic lipidosis indicating food limitation prior to death. One animal had puffer-fish remains in its stomach, and detectable levels of tetrodotoxin in samples of this fish's liver as well as the whale's kidney. Another whale had a mild multifocal pneumonia that likely developed several days to a week prior to death. Samples of brain and lung from these four animals examined by the MSRT were negative by immunohistochemistry for morbillivirus. The external ear structures of these four animals contained adult nematode parasites (*Stenurus*), and trematode ova (*Nasitrema*).

Heads of four animals were dissected by the MSRT necropsy team which included Dr. Darlene Ketten from Woods Hole Oceanographic Institution. One head had been previously removed and frozen (MAD308-Pe001), two others were separated from the bodies in Analalava on 10 June 2008 for ease of examination. Dissections on these could not be completed on 10 June, so the heads were stored on ice until the next day. On 11 June the necropsy team examined three heads and collected tissues in a warehouse at the port of Antsohihy. A fourth animal was examined at post mortem by the MSRT on 12 June. Tissues from all animals were shipped to WCS in New York for histological examination by Dr. McAloose. Ear bones were subsequently shipped to Dr. Ketten at WHOI for CT examination.

Tissues in each of the three carcasses, the head and tissue submitted by Dr. Zafera were moderately to severely autolyzed. Autolysis presented grossly in several ways including tissue discoloration, crepitus, dissolution of blubber with manual handling, and increased fragility. Histologically, tissue architecture and cellular detail was considered good to poor (often dependent on tissue type). Tissues from all animals contained bacteria that were multifocally associated with gas formation consistent with gross evidence of crepitus. Ear bones stored in formalin were CT scanned using an ultra high-resolution spiral protocol on a Siemens Volume Zoom at the WHOI CT Facility. Scan parameters employed were kV120, effective MAS 200, acquisition table speed 0.5-mm at 0.5 seconds. Scans were obtained in the transaxial, paramodiolar plane, and images formatted using a 90 UH kernel for bone windows. Images were obtained with 0.1-mm slice thickness image formats. Details of the scans were reported by Dr. Ketten, and are summarized in Table 2 and included in the Appendix (see KET-1 for significantly more detail). The CT scans were examined by a second independent radiologist who had not been present at the sample collection in Madagascar (Dr. Sophie Dennison, BVM & S, MRCVS, DACVR). The CT scans revealed several features of the ear bone complexes that were associated with age, parasitism and possibly collection artifact, but no significant lesions that could have compromised the whale's survival were detected (see DEN-1, -2, -3, and -4 for significantly more detail).

Table 2. Gross necropsy and CT imaging results and interpretation for individual melon-headed whale carcasses investigated

Animal ID	Date of carcass detection (condition code)	Sex/ size	Location of carcass	Necropsy findings	Ear bone CT imaging results	Interpretation
MAD10 8-Pe003	11 June 2008 (3)	Male/ length 240 cm	Transported to Antsohihy for necropsy	Thin, puffer fish remains in stomach, intestine empty, hepatic lipidosis, IHC of brain negative for morbillivirus, tetrodotoxin in liver of pufferfish and kidney of whale, *Stenurus* and *Nasitrema* parasites in peribullar sinuses bilaterally.	Right ear complex has separation of the tympanic and periotic bones, with multiple tympanic bone fractures, Left ear has small peribullar, free-standing nodules and left cochlear canal gas, right tympanic bone rugosities (irregular margins), VIII cranial nerve normal.	Puffer fish ingestion presumed to have occurred in the lagoon. Ear bone separations and fractures are presumed collection and handling artifacts, and sinus and peribular parasites are common incidental findings in other odontocetes
MAD30 8-Pe001	Head from freezer 9 June 2008 (frozen 3)	NA/NA	Hotel in Antsohihy	*Stenurus* nematodes and *Nasitrema* ova in peribullar sinuses bilaterally. IHC of brain negative for morbilliviruses.	Peribullous and middle ear mineralized fragments, demineralization, roughening of the periotic bone surface, cochlear canal gas.	No infectious disease, toxicosis or trauma detected in head tissues, other than parasites in sinuses and right middle ear with associated changes. Changes in ears are not significant to mortality as are chronic and associated with parasites common in odontocetes.

MAD308-Pe002	9 June 2008 (3)	Male/ length 261 cm	Antsohihy dock	Thin, stomach and intestine empty, hepatic lipidosis, multifocal (broncho) pneumonia, *Stenurus* nematodes and *Nasitrema* ova in peribullar and pterygoid sinuses bilaterally. IHC negative for mobillivirus.	Nodules (mineralizations) within peribullar soft tissues, cochlear canal gas, demineralization, tympanic bone chronic lysis/malacia, surface rugosities (roughening of surfaces).	No infectious disease, toxicosis or trauma detected, other than parasites in peribullar sinuses. Changes in ear are not significant to mortality: gas is likely due to decomposition, roughened edges may be indicative of past infection, and parasites are common in other odontocetes.
MAD-308-Pe003	9 June 2008 (3)	Male/ length 265 cm	Antsohihy dock	Thin, hepatic lipidosis, stomach empty, scant material in intestines, IHC negative for morbillivirus, *Stenurus* nematodes in peribullar sinuses. Few *Monorygma* sp. in caudal abdominal soft tissues	Peribullous soft tissue nodules (mineralizations), tympanic and periotic bone rugosities (surface roughening), areas of demineratlization or lysis	No infectious disease, toxicosis or trauma detected, other than parasites in sinuses. Changes in ears not significant to mortality, likely represent an older animal, parasites are common in other odontocetes.
MAD308-Pe004	10 June 2008 (4)	Male/ no morpho-metric data	Antafiampatsa	No cause of death determined due to carcass decomposition.	N/A	
MAD308-Pe005	2 June 2008 (N/A)	Male/ no morpho-metric data	NA	No cause of death determined, only skin and muscle samples obtained.	N/A	

MAD308 Pe006	14 June 2008 (N/A)	Female/ no morpho-metric data	NA	No cause of death determined, only skin and muscle samples obtained. Protozoal cyst in skeletal muscle (IHC positive for *Sarcocyst* sp.)	N/A	Protozoa is an incidental finding

5. ISRP Assessment of potential contributing factors

Upon reviewing all of the information provided by the various sources and information providers in advance and at the ISRP meeting (see appendix III), participating in discussions with the information providers and responders to the event, the ISRP deliberated in closed sessions to assess the known events, physical evidence, and analyses conducted regarding the 2008 Madagascar melon-headed whale stranding. The ISRP conducted a systematic and comprehensive assessment of all plausible contributing factors to this highly anomalous event. It considered all known causes of previous marine mammal strandings and assessed the relative strength of evidence regarding whether each factor could have played a role in either contributing directly or secondarily to the stranding. This segregation within the assessment was important given that this event apparently involved an initial response that caused the animals to clearly depart their natural habitat *en masse* in such an unusual manner, and a number of secondary, interacting factors that ultimately contributed to later strandings and mortality once the animals were compromised in an out-of-habitat situation. The ISRP considered a host of potential explanatory factors, including:

* Receding tide
* Large-scale topographical features
* Geomagnetic anomalies
* Disturbance of echolocation by reverberation in bays
* Animals following prey close to shore
* Animals fleeing predators

* Disease in one or more individuals in social group
* Biological or chemical toxins
* Unusual environmental conditions (*e.g.*, hurricane, storm surge, electrical storm)
* Vessel strike
* Fisheries interactions
* Lunar cycles and solar anomalies
* Intense acoustic event

Table 3. Potential explanatory factors and ISRP assessment of the relative likelihood of their potential contribution as a primary trigger or secondary contributing factor to the 2008 Madagascar melon-headed whale mass stranding event.

Potential Explanatory Factors	Mechanisms of Injury or Stranding	Previous Stranding Event Examples	Possible role as primary trigger for 2008 Madagascar MSE?	Possible contributing or secondary factor in 2008 Madagascar MSE?
Receding tide	Entrapment	Balsiger (2003) Wiley *et al* (2001)	**No** – melon-headed whales are offshore species not found in inter-tidal areas	*Tidal factors secondarily contributed* to mortality once animals out of natural habitat
Large-scale topographical features	Entrapment	Wiley *et al*. (2001) Brabyn (1991)	**No** – no history of MSEs in area or topographical factors similar to other areas	*n/a*
Geomagnetic anomalies	Disorientation	Klinowska, 1986	**Unlikely –** no information to assess geomagnetic anomalies but no history of MSEs in area	n/a
Disturbance of echolocation by reverberation in bays	Disorientation	Sundarama *et al*. (2006)	**No** – melon-headed whales are offshore species not found in inter-tidal areas	*Echolocation potentially compromised* once animals out of natural habitat
Animals following prey close to shore	Entrapment	Geraci (1978)	**Highly unlikely** – melon-headed whales typically feed on mesopelagic squid and fish not found inside 200m isobath	*n/a*

Animals occur closer to shore as a result of oceanographic conditions	Increased likelihood that behavioral response directed inshore	Walker *et al*. (2005)	**Unlikely** primary cause of stranding as such conditions occur regularly, but period before stranding has downwelling conditions with coastward currents and elevated chlorophyll-a levels	***Possible but speculative*** that such conditions affected whale distribution, causing them to occur closer to shore and move inshore with subsequent disturbance; ***deemed unlikely*** based on period of strong inshore currents two weeks before stranding.
Animals fleeing predators	Disorientation or entrapment	Geraci and Lounsbury (2005)	**Highly unlikely** – no evidence for killer whales in area (see Laran et al. 2012a, 2012b); no evidence of shark predation in the necropsies	*n/a*
Disease in one or more individuals in social group	Inflammation leading to compromised health	Rogan *et al*. (1997) Morimitsu *et al*. (1987)	**Cannot be excluded, but considered unlikely** evidence pathological investigation; stranding pattern inconsistent with pathogen-related mortality events	*Little empirical scientific evidence exists for "sick-leader" hypothesis where a diseased "lead" animal potentially leads other social group members to strand.* *None of the animals necropsied had lesions severe enough to account for stranding, parasites observed were considered incidental.*

Biological or chemical toxins	Toxicosis leading to compromised health	Fire and Van Dolah (2012) Dierauf and Gulland (2001)	**No** known algal blooms; majority of animals examined were negative for biotoxins **Unlikely** that iron chromium oxide from local chromite ore mining was a contributing factor because animals were apparently feeding very little while in the bay; no data on pollutants in the estuary was available	*One animal tested had elevated levels of tetrodotoxin from pufferfish consumed well after animals were inside lagoon system*
Unusual environmental conditions (e.g., hurricanes, storm surge, electrical storms)	Disorientation or entrapment	Hurricane Katrina report	**Unlikely** – analysis of meteorological and oceanographic conditions in May 2008 reveals no remarkable or atypical events, although there was a major cyclone 3 months earlier	*n/a*
Vessel strike	Trauma	Berman-Kowaleski *et al.* (2010) Moore *et al.* (2012)	**No** supportive evidence from stranding response observations or pathological investigation	*n/a*

Fisheries interactions	Trauma	Read *et al*. (2006) Moore *et al*. (2012)	**No** supportive evidence from stranding response observations or pathological investigation	*n/a*
Lunar cycles/solar anomalies	Lunar cycles and solar anomalies potentially causing near-shore behavior of otherwise "offshore" species		**Unlikely** – little supportive evidence of normal lunar or solar cycles causing MSEs in melon-headed whales (Brownell *et al*., 2009) or other cetacean species (*e.g.*, Jepson *et al*. 2013)	*n/a*
Intense acoustic event	Non-auditory physical injury (barotrauma)	Danil and St. Leger (2011) Ketten *et al*. (1993)	**Unlikely** - no supportive evidence from pathological investigation; general decomposition state of carcasses hinders detection	*n/a*

Intense acoustic event	Non-auditory physical injury (gas/fat embolism)	Jepson *et al*. (2003) Fernandez *et al*. (2005)	**Unlikely** - no supportive evidence from pathological investigation; general decomposition state of carcasses hinders detection	*n/a*
Intense acoustic event	Physical injury (auditory)	Reviewed by: Southall *et al*. (2007); Also see: Finneran, J. (2012)	**Unlikely** - no supportive evidence from pathological investigation and observational evidence of live animals suggests hearing not compromised; decomposition and lack of auditory screening hinders detection	*n/a*
Intense acoustic event	Behavioral responses	Southall *et al*. (2006) Cox *et al*. (2006) Wang *and Yang* (2006) Brownell (2008) Brownell *et al*. (2009) D'Amico *et al*. (2009) Jepson *et al*., (2013) Wright *et al*., (2013)	**Most plausible and likely initial behavioral trigger for animals stranding and entering lagoon system** – based on close proximity, timing, and directed movement of 29 May *M/V Teknik Perdana* high-intensity MBES operations relative to known stranding location (see detailed discussion below)	*French hydrographic survey using identical MBES not primary trigger based on timing some weeks earlier, but could have sensitized animals in the area to MBES* *Seismic airguns were used after initial strandings and animals entering the lagoon; clearly had no role as initial trigger and no evidence that airguns dissuaded animals from leaving*

6. ISRP Summary and Recommendations

The May 2008 Madagascar melon-headed whale stranding event occurred in a very remote location in extremely difficult physical and logistical conditions in which to stage a modern marine mammal stranding response and investigation. At the time there was no marine mammal stranding network anywhere in the country, much less in the immediate vicinity, and such an event involving a large group of apparently healthy, live-stranded pelagic whales transiting far up into an estuarine system had never been recorded previously. These complex physical, logistical, and communication factors clearly limited the speed and nature of the response as well as critical information early in the event that would be of great value in investigating its potential causes (*e.g.*, more resolution on and necropsy analysis of fresh animals from the onset of the mass stranding). However, the integrated efforts of local citizens, local and federal Malagasy officials, the Mass Stranding Response Team, and the support provided by EMEPNML during and following this event were remarkable, resulting in a remarkably rapidly assembled international mass stranding response, especially given the very remote location. This response to support the immediate goals of saving as many of the compromised and dying whales as possible in challenging conditions was thorough, professional, and well- documented. Similarly, there was a profound effort to coordinate and document the physical samples and individual observations obtained through a dedicated interview process, and compile, analyze, and interpret the available information. The amount and detail of data obtained and provided through the collective and dedicated efforts of WCS, IFAW, EMEPNML, and other experts was remarkable given the circumstances, and only with these data was the ISRP able to make a scientifically-objective assessment of the stranding.

Other than those resulting from demonstrable physical or pathological impacts (*e.g.*, ship strike, infectious disease, toxicoses), many marine mammal strandings lack unequivocal conclusions regarding causality, particularly in complex situations where animals abandon their natural habitat for some reason that may be difficult to determine, and then die as a result of other factors related to being out of their normal habitat. That appears to be the case in this situation, where apparently initially healthy animals appeared in a very unusual place and their presence in out-of-habitat areas resulted in a range of physical ailments (sun exposure, lack of prey, disorientation) that were the ultimate causes of mortality. Melon-headed whales are typically open-ocean animals, essentially never occurring naturally in shallow embayments, particularly mangrove estuaries some 65 km from the open sea. There was a mass-stranding of melon-headed whales reported on an ocean-facing beach in Madagascar in November and December 2007 (discussed more below), although information regarding this event (including any potential human activity in the proximity of that event) is extremely limited. However, an event like that in May 2008 with a large number of apparently healthy but tightly grouped pelagic animals traveling so far up into and remaining for weeks in an estuarine systems had never been observed in Madagascar. This clearly appears to be an atypical event with fundamental distinctions from the 2007 stranding. As discussed in detail below, the ISRP concluded that the most plausible and likely sequence of events included a multi-stage interaction of factors with some initial, likely behavioral, trigger causing the animals to move from their pelagic habitat and enter the Loza Lagoon system, following which their presence in such an unusual place without their typical prey items or physical characteristics contributed to the demise of many (but apparently not all) individuals.

As the ISRP investigated the potential factors, given the information available, that may have been involved in this unusual event, we systematically considered all possible physical, environmental, and anthropogenic factors that could have been involved in the initial reason this large group entered the lagoon system and could have interacted to result in mortality. Stranding events that are apparently mediated by an initial behavioral response in apparently healthy animals often lack a physically identifiable diagnostic cause. We acknowledge that we lack key pieces of information with which to come to unequivocal conclusions regarding the initial trigger and secondary contributing factors, including the spatial configuration, direction of movement, and other mediating factors (such as the presence of predators) for the animals in the days and hours preceding their arrival within the mouth of the lagoon (and for two individuals on nearby beaches) on 30 May. We also lack certain relevant information regarding the behavioral context of exposure, such as clarity on the extent to which these animals had prior experience with previous exposure to intense human sounds. Such information ranges from difficult to impossible to obtain, particularly in such a remote area with relatively little scientific investigation of local species, but may be relevant if the event was in fact behaviorally mediated as appears to be the case. Finally, some reports originally submitted to the Malagasy government were not available to the ISRP and some information had to be reconstructed; some key data including details on the French hydrographic survey were not available for the ISRP.

That being said, thanks to the detailed information, analyses, and efforts of many of the groups involved, there is a surprisingly large amount of information with which the ISRP was able to make what we regard as clear and substantiated assessments given in Table 3 above. As shown in Fig. 9 and described in greater detail in WCS-MMSE-1, based on a series of detailed interviews reconstructing the timing of observations of the animals, there appears to be a very clear pattern to their initial stranding (two animals) and entry into the lagoon on 30 May and movement into the system on 31 May. What is clear (as described in more detail in WCS-MMSE-2) is that once the animals were well out of their natural habitat, they died from a number of secondary interacting factors related to malnourishment and dehydration, sun exposure, and disorientation in the shallow, tidal mud flats.

In terms of identifying the initial triggering event that caused the animals to react in a way that resulted in their entering the lagoon system, the evidence does not support natural events such as entrapment of foraging animals due to tidal factors, or strong storms as contributing factors. Other natural forces such as the presence of a minor earthquake 700 km away a week prior, or lunar/tidal patterns were also deemed very unlikely to have a primary or contributing role in the event. In considering potential human causes, none of the available evidence supports any kind of vessel strike or fishery interaction. Neither does the evidence support any of the direct physical auditory or other trauma to non-auditory tissues that has been observed in other stranding events (see Table 3 above). The anthropogenic event that cannot be ruled out as playing a contributing role in the initial movement of the whales into the lagoon system is the use of MBES during transit and calibration along the continental shelf on the day before known stranding events. An active acoustic 12 kHz MBES system with a wide swath of many high-amplitude sources, moved down the shelf break areas on 29 May intermittently projecting sounds fairly continuously for over six hours while moving toward the stranding location, with additional intermittent transmissions later in the day (ending at 1931 local time) in a relatively concentrated area on the Ampasindava block in an area ~65 km from known strandings during the day near Analalava on 30 May and confirmed sightings within the lagoon that night. Again, the precise location of the whales during the period of MBES transmissions on 29 May is unclear. However, as shown in Fig. 7, a broad (30-35 km) swath of sounds was likely presented at levels (120 dB and above) that would have clearly been audible to the animals, based on what is known about hearing in odontocete cetaceans. Modeling of a specific scenario between the point of closest MBES transmission to the location of the whales (~65 km) suggests sounds would have likely exceeded background noise levels and may have been detectable in areas considerably shallower than the 1,000m depth contour, extending well beyond the 120 dB modeled isopleth but almost certainly not fully to the mouth of the lagoon (see Fig. 8). While hearing in melon-headed whales has not been measured directly in the laboratory, sufficient information exists from behavioral and electrophysiological measurements of hearing in other odontocetes cetaceans (*e.g.*, Yuen *et al*., 2005; Houser and Finneran, 2006; Houser *et al*., 2008) to make some reasonable assumptions. These would include the high likelihood that 12 kHz sounds are within the region of best hearing sensitivity for this species and these sounds at the 120 dB level would be well above (~50 dB or more) the expected hearing threshold for these odontocetes. While ambient noise measurements were not made *in situ* during MBES transmissions nor are systematic measurements available for the area of interest in other periods, based on expected nominal ambient noise conditions for a wide range of sea state conditions (based on Wenz, 1962), 120 dB levels at 12 kHz would also be well above (~30 dB or more) ambient noise. Given the movement and nature of the sources as demonstrated through the modeling conducted, these sources would have been audible to the whales over an area of many hundreds to thousands of square kilometers during the combined transmissions (well beyond the modeled 120 dB isopleths). However, given the extensive shallow shelf area and distance from the closest point of transmission to the mouth of the lagoon (~65 km) it is highly unlikely that sounds from MBES transmissions would have been audible fully to the mouth of the lagoon.

The exact sound exposure level or "threshold" at which melon-headed whales respond to this type of sound is not known. In fact, there is unlikely to be a simple threshold point at which this occurs. Rather, behavioral response probability is a complex interaction of exposure conditions and context (Ellison *et al*., 2011). The ISRP is not thus suggesting that response would occur at the 120 dB exposure level. Responses to lower levels are possible or lack of response at higher levels is also possible. Contextual factors including the relative spatial orientation and movement of the source and the whales likely mediate responses as much or even more than the specific received sound level (see Ellison *et al*., 2011).

The ISRP concludes that the use of this 12 kHz MBES appears to be the most plausible and likely initial behavioral trigger of the stranding event, but that a variety of secondary factors contributed to or ultimately caused mortalities. These conclusions are based on:

- The direction of movement and timing of the MBES transmission events (moving progressively southward down the shelf break in the direction of the stranding location throughout the day and then in a concentrated area offshore and to the northwest of the site) in such close relative time (< 24h from the first confirmed mortalities at Analava and slightly more than 24 from the first confirmed sighting of a large group of live whales in the lagoon) and space (~ 65 km) to the known location and timing of the whales directed and progressive movement into the lagoon system;

- The fact that these sounds would have been clearly audible to whales (and other marine mammals) over a very large area (hundreds to thousands of square km) of expected melon-headed whale pelagic habitat along the shelf break, likely extending into shallower water areas much closer to the initial stranding location at the mouth of the lagoon;
- Previous observations of similar stranding events involving melon-headed whales exposed to different kinds of sounds (e.g., military mid-frequency sonars: Southall *et al*., 2006; other human-generated sounds - see: Brownell *et al*., 2009);
- The fact that numerous cetacean species are hunted using directed movement of sound sources as a key element in drive fisheries (see Brownell *et al*., 2008); and
- Documented evidence from stranding responders of animal conditions deteriorating during their continued time in the lagoon system, including sun exposure, emaciation, and dehydration that were identified as ultimate causes of death.

While it is speculative, the ISRP concludes that the most likely scenario is that as the MBES moved in a directed manner down the shelf-break through typical habitat areas and completed a concentrated series of transmissions in the evening, the whales responded (likely on 29 May in this scenario) by avoiding this source and began moving inshore. Once they moved into unfamiliar shallow water areas as a result of this avoidance response, they may have continued toward the lagoon system even if sounds from the transmissions were no longer audible because of propagation conditions or because they were no longer being transmitted. That is, it appears from the timing of events and spatial proximity that an initial avoidance response may have continued beyond the period where the animals could detect the sounds. Once the animals entered the lagoon they were in wholly unfamiliar habitat and all events that happened subsequently were secondary to the initial reason they entered the lagoon, though ultimately responsible for the mortalities that occurred. It is possible, though deemed unlikely by the ISRP that their response was independent of the ongoing MBES transmissions and may have been related to following a sick or disoriented leader. It is also possible, although again speculative, that some environmental conditions (*e.g.*, downwelling oceanographic conditions affecting prey distribution) may have resulted in their already being oriented closer to the lagoon, increasing the chances that an avoidance response might have been directed inshore rather than more innocuously further down the shelf or offshore. While the exact sequence of events and spatial orientation of the whales prior to their stranding will never be known, the ISRP concludes that the available evidence is compelling in suggesting that the MBES transmissions were the most plausible and likely behavioral trigger causing the whales to initially leave their typical pelagic habitat and move toward the lagoon system.

Such MBES systems have not been previously identified as being associated with marine mammal stranding events. It is important to note that these systems, while regularly used throughout the world in hydrographic surveys, are fundamentally different than most other high-frequency mapping or navigational systems. They have relatively lower source frequencies (12 kHz is within the range of likely best hearing sensitivity for all marine mammals), very high output power, and complex configuration of many overlapping beams comprising a wide swath. Intermittent, repeated sounds of this nature could present a salient and potential aversive stimulus. This might be particularly true for sources operated in a directional manner similar to that employed in dedicated drive fisheries using sound. The fact that no similar such situations have been observed previously despite previous operations of such systems is not a compelling reason to conclude they did not play a role in this case. Given the extensive use of these operations without widespread observations of mass strandings previously, there may well be a very small probability that these or other social, pelagic whales would respond in a manner that put them in a dangerous situation. In this case they may have reacted by moving away from an intermittent, aversive sound stimulus moving progressively down the general depth contours they normally inhabit and turned into the lagoon system to avoid an aversive stimulus. In doing so, they may have placed themselves in an inescapable situation once in such an unfamiliar and unnatural habitat. The use of such sources in these areas around Madagascar appears to be relatively recent and uncommon. It is possible but speculative that the potential use of another MBES system from the French hydrographic vessel *Beautemps-Beaupré* just a few weeks prior could have had an initial impact on animals in the area altering their subsequent reaction and particularly sensitizing them to the sources used by the *M/V Teknik Perdana*.

The ISRP concludes that the use of seismic airguns in the shallow hazard surveys for a short period in early June clearly played no role as either an initial trigger or secondary factor in this event. This conclusion is based on the timing of the stranding and lack of evidence that any the melon-headed whales animals attempted to leave the lagoon system and aborted such an attempt (as occurred in the 2004 melon-headed whale stranding in Kauai - see: Southall *et al*., 2006).

Given the observations here, with the caveats given, there should be increasing realization that powerful active sonar systems other those previously scrutinized (namely military tactical mid-frequency sonars) may have detrimental effects on marine mammals. This is particularly true of systems with output frequencies in the 10-50 kHz range with output levels exceeding 230 dB and complex multi-beam arrays of sources. Such sources may in fact be more relatively audible and potential disturbing to some marine mammals than lower frequency sources previously considered, particularly for odontocete cetaceans that are acoustically most sensitive in these frequency regions. This event suggests that there may be a risk of causing strong behavioral reactions and even harm from such systems. While this risk may arguably be very low given the extensive use of such MBES systems historically and the lack of direct evidence of such responses previously, environmental planning and assessment of such operations should account for this potential and consider local species and spatial relationships of operations relative to local topographical features in planning operations. Furthermore, melon-headed whales may be among the more reactive and potentially vulnerable marine mammal species to impacts from powerful acoustic systems based on the combined observations of their movements to date (see: Southall *et al*., 2006; Brownell *et al*., 2006; 2009). Finally, the ISRP emphasizes that only with the kinds of careful and comprehensive data collection and analyses conducted here are these kinds of systematic analyses even possible. The ISRP recommends that rapid response contingency plans should be in place to support such responses, particularly in areas of MBES surveys in the future.

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Appendix I. ROLES & TERMS OF REFERENCE OF THE: MULTI-STAKEHOLDER STEERING COMMITTEE (MSSC) & INDEPENDENT SCIENTIFIC REVIEW PANEL (ISRP) INVESTIGATING THE 2008 MASS STRANDING OF MELON-HEADED WHALES IN MADAGASCAR

1. OVERVIEW AND OBJECTIVE

On May 31, 2008 approximately 100 individuals of melon-headed whales (*Peponocephala electra)* entered into La Loza Bay, a small estuary of inter-tidal flats and mangroves on the northwestern coast of Madagascar. In coordination with the Government of Madagascar, which established an emergency fund for the mass stranding effort, an international mass-stranding response team was dispatched to the site including participants from local and regional Malagasy authorities and communities, as well as staff from the Wildlife Conservation Society (WCS) and the International Fund for Animal Welfare (IFAW). ExxonMobil Northern Madagascar (Ampasindava) Holding Limited was simultaneously conducting an exploration survey in the general area and provided support to the Government's initial and subsequent stranding response effort. The stranding response team consisted of a live rescue unit and a necropsy analysis unit. By late June some 75 individuals had died as a result of stranding, and approximately fifteen were still in the bay. Rescue and monitoring efforts continued through July 9 2008 but no melon-headed whales were observed after June 30.

Shortly thereafter, several of the organizations involved in the response and investigation as well as agencies within the Government of Madagascar submitted initial and preliminary technical reports about the stranding event, ongoing activities in the area at the time, and their findings to date. Efforts were initiated by many of the involved organizations and the Government of Madagascar to conduct a formal investigation into the potential causes for this event, based upon these preliminary findings. This process was not completed prior to the March 2009 change in the government of the country. The organizations involved in the response and investigation remain committed to conducting and completing an objective investigation using independent, scientific analysis of the available information regarding the event. The involved organizations are consequently collaborating in supporting an independent scientific review panel to evaluate this stranding event. This will be done in communication with the Government of Madagascar.

The objective of this work is to finalize the formal investigation into any potential natural and/or anthropogenic factors that may have been involved in this stranding event. A technical report of an independent scientific review panel will be based on initial and preliminary technical reports and related findings about the nature of the event and ongoing activities in the area at the time. This report will be produced and made openly available by early 2013.

This document describes the approach to the investigation that has been formulated through a series of planning discussions among a number of the multi-stakeholder groups (industry, conservation, government, inter-governmental) involved and interested in seeing this investigation completed. The roles and terms of reference for both a multi-stakeholder steering committee (MSSC) and an Independent Scientific Review Panel (ISRP) are given below, as well as operating ground rules for the review process, a notional work schedule, and a list of available summary documents and reports regarding the stranding.

2. ROLES & TERMS OF REFERENCE: MULTI-STAKEHOLDER STEERING COMMITTEE (MSSC)

The role of the MSSC is to (1) provide guidance in setting up and structuring the ISRP; (2) assist the ISRP in securing all available and accessible information; and (3) ensure completion of the process and public release of the final report. The MSSC will:

- Agree on these terms of reference for both the MSSC and ISRP prior to inviting subject matter experts for the ISRP
- Agree on the chair of the ISRP and those invited to serve as panel members
- Interact with the ISRP through the chair rather than with individual panel members, preferably by email with cc to all MSSC members
- Agree and approve the schedule of work and financial arrangements for the ISRP
- Serve as representatives of their respective organizations to make all efforts to make currently available reports and documents, as well as any additional information requested, available to the ISRP
- Ensure that the appropriate communication is established and maintained with the Government of Madagascar
- Participate in one or more planning conference calls before the ISRP meeting to ensure the above and obtain additional information as needed
- Receive the ISRP report prior to final release and, in coordination with the ISRP Chair and according to the process described below, ensure the appropriate public release of the ISRP report.

The MSSC will consist of the following individuals who will serve to provide information about the status of the project to their respective organizations:

- Dr. Howard Rosenbaum (WCS)
- Dr. Rodger Melton and Dr. Linda Zimmerman (ExxonMobil)
- Dr. Teri Rowles (NOAA Marine Mammal Stranding Network)
- Dr. Jason Gedamke (NOAA Ocean Acoustics Program)
- Dr. Peter Thomas (Marine Mammal Commission)
- Jill Lewandowski (BOEM)
- Dr. Greg Donovan (IWC)
- Dr. Brandon Southall (SEA) – also head of ISRP

ROLES & TERMS OF REFERENCE: INDEPENDENT SCIENTIFIC REVIEW PANEL (ISRP)

The role of the ISRP is to conduct an objective, scientific investigation into all possible causes of the 2008 stranding event in Madagascar. The objective is for the ISRP to come to a consensus statement on the possible cause(s) of the stranding event, with the recognition at the outset that the available data may ultimately not support an unequivocal assessment. The ISRP will:

- Review and agree to these terms of reference (any subsequent discussion or interpretation of the TOR will occur through the chair with the MSSC).
- Participate in an initial conference call to discuss the overall process, currently available information, additional information to request, and schedule of work (deliverable: notes from call)
- Read and review all materials provided by no later than one month ahead of the face-face review meeting.
- Participate in a second conference call two to three weeks ahead of the face-face meeting to discuss the available information and request any additional information that should be provided ahead of or at the ISRP (deliverable: notes from call).
- Participate in a three-day ISRP meeting (described in greater detail below) in Washington DC in order to:
    (1) Review and discuss the available information with selected experts involved in the actual event and response in the field;
    (2) Reach a consensus assessment of possible cause(s) and/or contributing factors to the event;
    (3) Provide specific recommendations for assessment and monitoring and response protocols to reduce the risk of and/or respond to subsequent such events;
    (4) Identify data or science gaps that would have been useful in differentiating the causes or contributing factors of this event; and
    (5) Complete a draft investigative report with these findings and recommendations (deliverable: meeting notes and draft report).
- Collaborate in reviewing, revising, and finalizing the report within one month of the ISRP meeting (deliverable: final report).
- The ISRP chair will, in coordination with the MSSC and according to the process described below, ensure the appropriate public release of the ISRP report.

The ISRP chair will be Dr. Brandon Southall (SEA) who will serve as the primary liaison with the MSSC (bi-weekly status updates on progress to be provided to the MSSC) and be the person primarily responsible for scheduling conference calls, the ISRP meeting, and the drafting and finalization of the report. Other members of the ISRP (3-4 individuals) will serve in their personal capacities acting as independent experts (*e.g.*, not requiring the approval or clearance or expressing the views of their affiliated organizations). Funding for member participation in the ISRP (if required) will be provided from an account established and administered by the International Whaling Commission (IWC)

Secretariat and open to outside contributions. To the extent possible, the group will collectively include the below areas of expertise. It is expected that some individuals may cover multiple areas whereas other areas may require expertise from several ISRP members

- Biology and ecology of melon-headed whales
- Pathology, toxicology, infectious diseases, epidemiology, causes of marine mammal strandings
- Acoustics/bioacoustics, including the interpretation of acoustic modeling
- Behavioral responses of marine mammals to sound
- Ecologist/Environmental Biologist, including the interpretation of physical ocean models

Information providers will (in person or via video/teleconference) provide specific information on:

- Biology and ecology of the area, including local whales species and specifically melon-headed whales
- An overview of the timeline and details of how the stranding event transpired
- Specific information on the necropsy results associated with the stranding event
- Acoustic modeling of the specific event and known sound sources in the area
- Modeling of physical oceanography, ocean chemistry, and other environmental data
- Marine operations such as those that may have occurred around the time of the stranding event (e.g. oil/gas operation activities, marine construction)
- Use of seismic and sonar and/or other sound sources associated with offshore industrial activities
- Any other relevant anthropogenic activities (*e.g.*, large scale fishing operations)

OPERATING GROUND RULES FOR THE ISRP REVIEW PROCESS

Workshop *modus operandii*

* Workshop attendees will include: the ISRP; members of the MSSC who wish to observe; scientists presenting available information; other interested parties approved by the MSSC may also participate as observers.

* The primary language of the Workshop will be English but French translation will be provided if necessary.

* The ISRP Chair will develop an agenda in co-operation with the MSSC.

* The ISRP Chair is responsible for the level and nature of participation of the scientists presenting information but not members of the ISRP. The role of information providers will be limited to: (1) providing a brief overview of information to the Panel of the material contained in the available (or requested) documents; and (2) answering

questions posed by the Panel. In exceptional circumstances the ISRP Chair may decide to allow observers to speak on a specific issue.
* At the discretion of the Chair, the general procedure will be for morning sessions to be devoted to receiving presentations and asking questions about specific items on the agenda, with afternoon sessions being closed sessions of the Panel. Depending upon the topic, the Chair may vary this schedule.

Workshop report
The Panel is responsible for its report, which will become publicly available. In addition to the full technical report, a non-technical executive summary will be prepared; the MSSC may assist in matters of style to ensure that it is suitable for non-technical as well as technical readers. It is expected that factual background introductory sections will be drafted in advance of the Workshop itself, based on written submissions; this will facilitate completion of the final report.

The Panel will attempt to reach consensus on matters but if this is not possible, the rationale behind any disagreements will be clearly stated in its report. Consensus does not necessarily imply agreement on a single cause for the mass stranding – it may involve specifying a number of plausible hypotheses, potentially excluding certain hypotheses if more than one is presented, or further work that would be required to make these assessments. A complete draft report shall be completed by the end of the Workshop and a final report completed within a period of one month. It will be circulated *confidentially* to the MSSC members and appropriate information providers for fact checking within a limited timeframe prior to broader circulation but the ultimate content is the responsibility of the ISRP.

Circulation of the report
The final report (in English and French) will be circulated to the Government of Madagascar and to the institutions participating in the MSSC through their representatives, two weeks before its intended public release. The ISRP Chair will present its report to the Government and to the institutions participating in the MSSC in an appropriate way (either in person or via video link) at least one week before public release. On the agreed date, the report may be made available on the websites of the entities participating in the MSSC.

Appendix II. ISRP meeting final agenda

Madagascar Stranding Independent Scientific Review Panel (ISRP)

U.S. Marine Mammal Commission - Bethesda, MD

5-7 February 2013

Tuesday 5 February

0900	Introductions, ground rules, perspective on presentations to guide discussions, welcome from Tim Ragen (Executive Director, Marine Mammal Commission)
0945	*"*Overview of Northwest Madagascar Natural History and Biology" (Salvatore Cerchio, WCS)
1030	*Break*
1045	"Review of melon-headed whale mass stranding event Antsohihy, Madagascar May–June 2008: stranding event timeline and stranding response " (multiple WCS presenters)
1200	Summary of am discussions - panel questions
1230	*Lunch*
1330	"Overview of Weather and Other Environmental Conditions Northwest Madagascar May 2008" (Stephen Jascourt, Senior Meteorologist and Climate Change Specialist, MDA Information Systems, Inc.)
1400	"Overview of Site investigation Operations: Purpose, Data Types and Geohazards" (Linda Zimmerman, Geophysical Advisor ExxonMobil)
1420	"Overview of Marine-related Economic Activities and Industrial Development in Northwest Madagascar" (Rodger Melton, Chief Environmental Scientist ExxonMobil (retired))
1445	"Timeline of Known Industrial Activities Offshore Northwest Madagascar in May and June 2008" (Rodger Melton, Chief Environmental Scientist ExxonMobil (retired))

1515 Discussion of marine mammal observer reports from EMEPNML survey (with Desray Reeb - lead environmental officer on *M/V Perdana*)

1545 ISRP Closed Session Deliberations (including discussion of satellite imagery presentation with Bob Brovey, independent contractor)

1715 *End day I*

Wednesday 6 February

0900 Review/discuss day I and follow-up questions

0915 *"*Review of necropsy results and forensic analyses" (Dee McAloose, WCS)

1045 *Break*

1100 "Multibeam Operations off the Coast of Madagascar: Post-Survey Modeling of Underwater Sound" (Mike Jenkersen, Geophysical Advisor ExxonMobil)

1230 *Lunch*

1330 Continued discussion of AM sessions

1430 Review/discuss integrated timeline and summarize nature of information available

1530 ISRP discussion and final questions for information providers

1600 ISRP Closed Session Deliberations

1700 *End day II*

Thursday 7 February

ISRP Closed Session Deliberations ALL DAY

Appendix III. LIST OF DOCUMENTS MADE AVAILABLE TO THE ISRP

ISRP Document #	Specific Reference (if applicable)	Provided by	General Description
MMSE-1	Collins, T., Moore, K., Cerchio, S., McAloose, D., Harry, C.T., Calle, P., Razafindrakoto, Y., Randriamanantsoa, B., McClave, C., Rosenbaum, H. 2009. Madagascar Melon-headed whale mass stranding event Antsohihy, Madagascar May-June 2008. Final report Part I - Site Description and Timeline. WCS and IFAW	**WCS/IFAW**	Timeline: Evolution and status of MMSE including list of participants and observer interviews
MMSE-2	Collins, T., Moore, K., Cerchio, S., McAloose, D., Harry, C.T., Calle, P., Razafindrakoto, Y., Randriamanantsoa, B., McClave, C., Rosenbaum, H. 2009. Madagascar Melon-headed whale mass stranding event Antsohihy, Madagascar May-June 2008. Final report Part II - Stranding response and health assessment	**WCS/IFAW**	Stranding Response and Health Assessment, including pathology and diagnostic investigation for tissues collected by the International MSRT and local veternarians
EM-1	TIimeline of geophysical sound-producing operations in May-June 2008: *M/V Teknik Perdana*, Offshore NW Madagascar	**EMEPNML**	Information related to timing of *M/V Teknik Perdana* Sound Source Utilization
EM-2	Multibeam Operations off the Coast of Madagascar: Post-Survey Modeling of Underwater Sound	**EMEPNML**	Acoustic Modeling of MBES used on *M/V Teknik Perdana*
EM-3	Weekly MMO Report (28 May- 6 June) – ExxonMobil Madagascar Survey, Sifaka Site, Madagascar	**EMEPNML**	Marine Mammal Observer Report and Daily MMO Sheets from *M/V Teknik Perdana*
EM-4		**EMEPNML**	*M/V Teknik Perdana* Daily Ship Reports
EM-5		**EMEPNML**	Data Files Used to Generate Timing and Location Plots of *M/V Teknik Perdana* MBES operation
EM-6		**EMEPNML**	Information on an 24 May 2008 earthquake northwest of Madagascar
EM-7		**EMEPNML**	Multiple files with satellite imagery of local meteorological and oceanographic conditions
EM-8		**EMEPNML**	Summary of analysis of satellite imagery showing unidentified objects on beach near Antsohihy

			20 May and 16 June 2008
EM-9		**EMEPNML**	Area-specific whale stranding Reports
EM-10		**EMEPNML**	Information on French Navy Hydrographic Studies in area
EM-11	ENVIRONMENTAL IMPACT ASSESSMENT SIFAKA GEOHAZARD SEISMIC SURVEY ENVIRONMENTAL BASELINE STUDY COASTAL BATHYMETRIC SURVEY Report No.: 2008-01 ExxonMobil Exploration and Production (Northern Madagascar) Limited Authors: Frederick Rittelmeyer: EMEP(NM)L Lalanirina Rasoanandrianina: Environmental Consultant	**EMEPNML**	EIS conducted for exploration surveys in the Sifaka block area of Ampasindava offshore area
KET-1	D. Ketten. Final CT report for 2008 Madagascar melon-headed whale samples	**D. Ketten**	Final CT report for 2008 Madagascar melon-headed whale samples
DEN-1	S. Dennison. WCS_011213_MADAGASCAR_01	**S. Dennison**	Final imaging report for subject N2008-0624-MAD308-Pe002
DEN-2	S. Dennison. WCS_011213_MADAGASCAR_02	**S. Dennison**	Final imaging report for subject N2008-0623-MAD308-Pe001
DEN-3	S. Dennison. WCS_011213_MADAGASCAR_03	**S. Dennison**	Final imaging report for subject N2008-0625-MAD308-Pe003
DEN-4	S. Dennison. WCS_011313_MADAGASCAR_04	**S. Dennison**	Final imaging report for subject N2008-0626-MAD108-Pe003