Indian Journal of Geo Marine Sciences
Vol. 47 (10), October 2018, pp. 2077-2086

Biosonar dysfunction and mass stranding of short-finned pilot whale *Globicephala macrorhyncus* at Manapad, southeast coast of India- An emphatic key in demystifying the enigma?

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Received 29 December 2016; revised 27 February 2017

A mass stranding of 81 short-finned pilot whale (SFPW) *Globicephala macrorhynchus* along Manapad coast from 11th to 15th January, 2016 was reported. Along the same coast, 147 SFPW were reported to have stranded in the same month, 43 years ago. Morphometric measurements of stranded specimens were taken. Based on the necropsy and subsequent findings, the animals showed no obvious signs of health problems. The single most predominant cause to have triggered the recent mass stranding could be possibly biosonar dysfunction.

[**Keywords:** Gulf of Mannar, stranding event, morphometry, kinship behaviour, necropsy]

Introduction

The short-finned pilot whales (SFPW) *Globicephala macrorhynchus* are one of the large gregarious dolphins found in tropical and temperate seas of the world. Their average group size is around 20 whales and often the pod size is up to several hundred. The species was named by Gray in 1846 based on a skull collected from South Seas[1]. They occupy the slot of top predator in marine ecosystem and their mean trophic level has been calculated as 4.3[2]. Mature males range from 4.5 to 7 m in length and mature females have a measure ranging from 3.5 to 5 m in length[3]. The maximum longevity of male is 45 years and female is up to 63 years, which has been reported in Japan. The fully matured calf at birth has a length of 140 cm born out of 14.9 months' gestation period. The SFPW male matures at the age of 7 to 17 years and females at 7 to 12 years and produce only 4 - 5 calves during their lifetime[4]. The SFPW prefer to live in deeper waters at the depth of 500 – 1000 m and their preferred niches include the areas of island slopes, continental shelf breaks and high topographic relief [5]. They mainly feed on migrating squid and other deep-dwelling species[6]. It has been reported that a 5.26 m male ate 45 kg of squid and mackerel per day, and a > 4.0 m female ate 36 kg/day during captivity[7]. The teeth arrangement of SFPW is adapted to suction-feeding on cephalopods. Usually, the SFPW spend most of their time at surface ((mean=76.3%, SD=18.6) during day time hours[8].

Cetacean vision is very limited in underwater and odontocetes (toothed whales) such as SFPW produce sounds to enable them to use active echolocation or biosonar[10] for navigation, communication, environment exploration, detection of prey. Mysticetes (true whales) are not known to use echolocation[9]. Echolocation comprises three distinct processes viz. sound production, sound reception from some object such as the seabed or fish, and signal processing. Delphinid vocalizations are generally divided into the categories of 'clicks' which are used for echolocation, and whistles and burst-pulses which are used for communication[11]. Short-finned pilot whale (*G. macrorhynchus*) clicks showed distinct spectral peaks at 12 and 18 kHz[12].

In the northern Indian Ocean, short-finned pilot whale has been reported from Sri Lanka, Maldives, eastern African sea and India. The occurrence of short-finned pilot whale in India was reported by Blyth[13] based on stranded specimen from Hooghly River in Kolkata. It was described as *Globicephala indica* and later synonymized with *G. macrorhyncus*. This species is most likely to be common throughout the Indian waters including Lakshadweep and Andaman Islands. The sighting of the species was more frequent in Lakshadweep[14,15]. There were a few mass stranding records of this species from northern Bay of Bengal, Gulf of Mannar and Andaman[13, 16-18]. The sighting and stranding records reported from India and adjacent region are tabulated (Table 1) and the details depicted in figure 1. Globally, short-finned pilot whales are notorious for mass stranding. The event ‘stranding’ means when alive or dead marine mammal swims or floats onto shore and becomes “beached” or incapable of returning to sea[19]. If more than two animals of the same species extend the stranding for one or more days and over miles of shoreline, it is termed as mass stranding[20]. Mass stranding of dolphins, whales, and other marine mammals has been reported from Aristotle’s time about 2300 years ago. Cetacean mass stranding events were linked to disasters and bad warnings until 17th century and sometimes viewed as divine messages. The largest known mass stranding of cetaceans is 1000 pilot whales on Chatham Island, New Zealand[21].

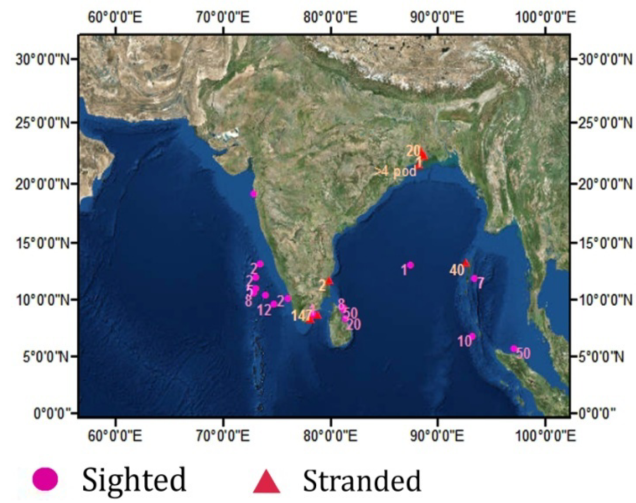

Fig. 1 — Stranding and sighting record map of Short-finned Pilot Whales in India and adjacent seas (numbers denote the SFPW stranded/sighted in the respective area)

Table 1 — Sighting & stranding records of Short-finned Pilot Whale in India and adjacent seas

Record	Period	Place	Coordinates	No. of Animals	Source
Sighting	26.01.1923	Bombay	19° 13’N; 72° 81’E	3	Leatherwood[54]
Sighting	14.12.1980	Malabar coast	12° N; 73° E	2 pod	Harwood[55]
Sighting	16.12.1980	Malabar coast	11° N; 73° E	5	Harwood[55]
Sighting	30.02.1981	- -	8° 45’N; 78° 17’E	1	Leatherwood[54]
Sighting	14-16.04.1982	Bay of Bengal	--	37	Leatherwood[56]
Sighting	5.04.1983	- -	9° 22’N; 81° 03’E	8	Alling[57]
Sighting	31.01.1984	- -	13° 14’N; 73° 33’E	2	Leatherwood[54]
Sighting	11.03.1984	- -	8° 35’N; 81° 31’E	50	Alling[57]
Sighting	25.04.1984	- -	9° 10’N; 81° 07’E	20	Alling[57]
Sighting	3.05.1984	- -	5° 41’N; 96° 55’E	50	Alling[57]
Sighting	2003-2007	- -	6° 48’N; 93° 08’E	10	Afsal[58]
			10° 10’N; 75° 58’E	2	,,
			11° 53’N; 92° 77’E	7	,,
			13° 03’N; 86° 80’E	1	,,
Sighting	3.02.2013 6.03.2013	Minicoy Island Lakshadweep	10° 20’N; 75° 39’E 9° 21’N; 74° 39’E	12 12	Sajikumar[14]
Sighting	19.04.2015	Pitti Island, Lakshadweep	10° 38’N; 72° 46’E	9	Sajikumar[15]
Stranding	June, 1850	Salt-water lake, Calcutta	--	20	Blyth[59]
Stranding	July 1852	Salt-water lake, Calcutta	--	Several dozens	Blyth[13]
Stranding	July 1858	Hugly near Serampore	--	1	Blyth[60]
Stranding	July 1859	Cacutta fish bazar	--	1	Blyth[60]
Stranding	14-15.01.1973	Manapad	8° 39’N; 78° 32’E	147	Alagarswamy*et al*[16]
Stranding (Bycatch)	29.07.1986	Pudukuppam, Cuddalore	11° 78’N; 79° 76’E	2	Nammalwar[61]
Stranding	21-22.10.2012	Elizabeth Bay, Andaman	13° 29’N; 92° 54’E	40	Raghunathan*et al*[18]
Stranding	11-15.01.2016	Manapad	8° 39’N; 78° 32’E	81	Present study

Mass stranding of *G. macrorhyncus* (n = 147) was reported from Manapad coast (Thirunelveli District, Tamil Nadu) on 14th Janauary, 1973. After 43 years, precisely in the same location of Manapad coast, mass stranding of short-finned pilot whales was observed on the same date, i.e., from 11th to 15th January, 2016. This event attracted much attention to the public, media and scientific community and several hypotheses of mass stranding cause were broadcasted in TV and in newspapers. To investigate the exact reason for the cause of mass stranding, a team of CMFRI scientists visited the place and collected relevant data. The results of the study are reported in the paper in detail.

Short-finned pilot whales stranded alive at Alanthalai-Pathuvai Nagar beach (8° 49′ 45″ N; 78° 32′ 03″ E) on 11.01.2016 (Monday) afternoon. The area is located at a distance of 58 km south of Tuticorin (Tamil Nadu). Fishermen first noticed an entire pod of whales swimming close to shore at 1700Hrs. The video footage taken by local media showed that strong wind force and wave action towards beach forced the whale towards the shore. They were swimming parallel to shore and did not show any behaviour like spy-hopping or tail-slapping. By night, nearly 40 of them were washed ashore alive. By Tuesday (12.01.2016) morning 81 pilot whales had stranded along the Kallamozhi-Kulasekharapatnam (8° 40′ 235″ N; 78° 32′ 927″ E) and Manapad (8° 39′ 215″ N; 78° 32′ 326″ E) coastal stretch. Of the 81 whales washed ashore, 45 were dead by the afternoon despite efforts by the fishermen and government agencies to save them. Of these, 37 were adults and eight were sub-adults. All the 45 were buried in the shore by earth-moving machines in the evening. The remaining 36 whales, which survived beaching, were rescued in a joint operation by several government agencies and fishermen, and pushed back to the sea by Tuesday (12.01.2016) night using mechanized boats. On Wednesday (13.01.2016) morning, carcasses of 28 whales, which were once pushed back to the sea found on the Manapad beach (8° 37′ 888″ N; 78° 32′ 708″ E). The fresh 6 pilot whales stranded alive in <50cm depth were rescued and pushed them to deeper region. They were very aggressive and showed tail-slapping behaviour several times and resisted the rescue efforts. The whales' slapping water surface using ventral part of tail (fluke) is called tail-slapping. During the period, tail-slapping was observed 8 times in single stretch. All of them were female of ~215cm length. By Wednesday evening, total 73 carcasses were buried in the shore (Kallamozhi – Manapad). Again, carcasses of two pilot whales were washed ashore in Kooduthalai coast (8° 29′ 979″ N; 77° 92′ 696″ E) on 15.01.2016 morning. In all, 75 dead pilot whales stranded along the Manapad coast. The fate of other 6 female pilot whales is not known and believed to have survived in the rescue effort.

Materials and Methods

The total body length (TL) of stranded specimens (n = 30) were taken (Table 2). Body length was measured to the nearest 1 cm distance of a parallel line from the tip of the upper jaw to the notch between the tail flukes[22]. Photographs of each individual were taken. The sex of the each specimen was identified. Of the 30 animals, 16 were female and 14 were male. Total length of male specimen ranged from 408cm to 582cm (505±44), whereas the females were 214 to 427 cm (353±65). One newborn male calf (TL: 127cm) with umbilical cord was found in Manapad (Figure 2a). Recently-calved mother with prolapsed uterus was found in Kulasekharapatnam, about 3.5 km away. Length and weight of fully mature newborn calf was reported as 140cm and

Table 2 — Total Length (cm) of stranded Short-finned Pilot Whales (n = 30) distributed in different length groups

Length range (cm)	Number of male	Number of female
127-218	1	1
218-309	0	4
309-400	1	7
400-491	3	4
491-582	9	0

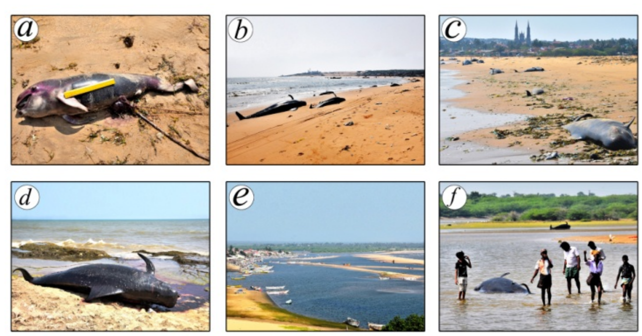

Fig. 2 — *a*, A premature male newborn calf. *b*, Manapad bay & headland. *c*, Mass stranding of SFPW at the beach of Manapad. *d*, Largest male SFPW stranded on the headland. *e*, Sand bars with intermittent channels of Manapad bay during low tide period. *f*, Stranded SFPW in the river mouth.

37 kg respectively in Japan[4]. Teeth of upper and lower jaws of all specimens were counted. The total number of teeth was in the range of 28-36 and had 7-9 teeth per row.

The sex could be differentiated easily because in all male specimens, the penis was extruded and visible. The maximum size of penis extruded was measured as 42 cm. Morphometric characters of a male (TL: 475) was analyzed and the results are shown in Table 3. Morphometric characters are very much essential to identify the species in different region. The ratio of flipper length to total body length was 15.6% and in Japan, it was reported to range from 15.0 to 18.9% [23]. All the stranded animals looked very healthy externally and no visible damage. Small scratches were found on the skin of the animals, which might have been inflicted during the stranding.

Necropsies were done on the stranded animals for investigating the cause of stranding. Samples were collected from fresh carcasses and about seven dead pilot whales were systematically examined using a standard necropsy protocol[24,25]. Atmospheric air temperature was 24-33°C on the day of stranding. A standard set of tissue samples were taken, depending on the carcass condition, for conducting a range of standard diagnostic tests including microbiology, histopathology and other diagnostic studies. Tissue samples or swabs of selected tissues, including liver, kidney, spleen and lung were taken aseptically for microbiological studies. A range of tissue samples from the dead animals were collected, preserved in neutral buffered 10% formalin and transported to the laboratory at Mandapam Regional Centre of CMFRI for further analysis. The tissues were embedded in paraffin, sectioned at 2-4 µm and stained with haematoxylin and eosin for histopathological examination by standard protocol[26,27]. Photographs were taken using the camera (Canon G10) fixed in transmitted-light microscope (Carl Zeiss Axiostar Plus) with a magnification of 100X and 400X.

Results and Discussion

Findings based on necropsy and laboratory investigations (Figure 3)

From external observation, all the specimens appeared to be in good condition and showed no

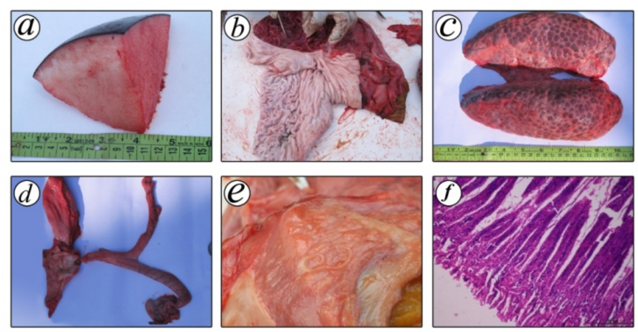

Fig. 3 — *a*, Melon. *b*, GIT examination. *c*, Kidneys. *d*, Reproductive organs. *e*, Nematode worm in mucosa of stomach. *f*, Stomach mucosa: Haemorrhage and necrosis.

Table 3 — Morphometric measurement of a male Short-finned Pilot Whale

Body region	Measuremen (cm)	% of Total body length
Total length	475	100
Tip of upper jaw to center of eye	51	10.7
Tip of upper jaw to apex of melon	23	4.8
Tip of upper jaw to angle of gape	39.5	8.3
Tip of upper jaw to external auditory meatus	56	11.8
Centre of eye to center of blowhole	43	9.1
Tip of upper jaw to blowhole along midline	76	16
Tip of upper jaw to anterior insertion of flipper	71	14.9
Tip of upper jaw to tip of dorsal fin	147	30.9
Tip of upper jaw to midpoint of genital aperture	279.5	58.8
Tip of upper jaw to center of anus	320	67.4
Girth, on a transverse plane intersecting axilla	91.5	19.3
Girth, on a transverse plane intersecting anus	86.5	18.2
Flipper length-anterior insertion of tip	61	12.8
Flipper length-axilla to tip	74	15.6
Flipper width	51	10.7
Dorsal fin height-fin tip to base	56	11.8
Flukes width- tip to tip	30.5	6.4
Distance from nearest point on anterior border of flukes to notch	112	23.6
Teeth- total count (each row- 9; lower jaw-18 & upper jaw-18)	36 number	--

significant traumatic lesions characteristic of by-catch, boat impact or shark attack. There were also no gross lesions except the abrasions over dorsal fin, fluke and flippers. The stomach was free of recently-ingested prey. The fore stomach and the pyloric part of the stomach were empty. There were 2 to 3 visible Anisakis nematode parasites, identified as *Anisakis typica* (Family: Anisakidae; Order: Ascarida),) which were buried deep to the mucosa. Gonadal tissue was grossly normal. The cut section of melon was floating. Tissues from internal organs (heart, lungs, liver, spleen, kidney and reproductive organs) were preserved.

Histopathological findings (Figure 4)

In the liver, moderate haemorrhage and engorged sinusoid with haemolysis of the RBCs was observed. Bile duct hyperplasia with proliferation of fibroblast was observed in the liver parenchyma. Hepatic nucleus was eccentrically placed in the periphery by fatty changes. Hepatic nuclear degeneration was also observed. In spleen, lymphoid follicular hyperplasia was observed in the area of entire white pulp. The red pulp area showed moderate haemolysed RBCs. Hyperplastic nodules showed degeneration of lymphocytes and its nucleus. Depletion of lymphocytes with condensation of nucleus like karyorrhexis and karyolysis was observed. Lymphoid hyperplasia and nodular degeneration with necrosis was also observed. Kidney cortex showed diffused haemorrhage with haemolysis of the RBCs. Sinuses were engorged with haemolysed RBCs. Medulla portion showed fibroblast proliferation with hydropic degeneration of the tubules. The epithelium was distorted in the collecting tubules. Lymphnode (mediastinal and mesentric) cortex area revealed lympho follicular hyperplasia and degeneration. In melon, cornified type of epithelium with loose muscular structure was observed. The loose structural myocytes showed hyaline degeneration, loss of cross striations with mild engorged sinuses.

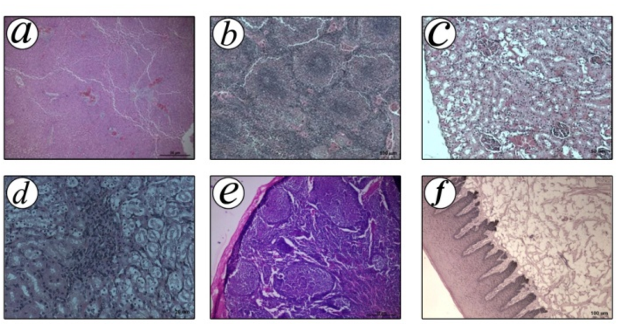

Fig. 4 — *a*, Liver: Moderate haemorrhage and fatty changes. *b,* Spleen: Lymphoid follicular hyperplasia. *c,* Kidney: Haemorrhage and degeneration of tubules. *d,* Kidney: hyaline degeneration and haemolysis. *e,* Lymph node: Cortex lymphpoid hyperplasia. *f,* Melon: Cornified epithelium and l0ose muscle structure.

Microbiological findings

Bacterial isolation was carried out from the swabs collected from heart blood and blow hole. Based on the morphology and some biochemical characteristics, *Bacillus* sp*, Enterococci* species and *Streptococci* species were identified. The SFPW were reported as reservoir and host of morbilli viruses, could potentially transmit the viruses to other resident cetaceans. Morbillivirus suppresses a host's immune system, increasing risk of secondary infection. In the present study, all the short-finned pilot whales were healthy and pathological investigation showed that the animals were not infected with diseases. Based on the necropsy and subsequent findings, it is concluded that the animals showed no obvious signs of health problems.

Causes of mass stranding

Kinship behaviour

Mass stranding events of marine mammals remain an enigma and it was not known for what reason they run themselves aground on dry land; at all events it is said they do so at times and for no obvious reason[28]. So far, 19 cetacean species have been affected by the mass stranding events and the events were very frequent in false killer whales (*Pseudorca crassidens*), long-finned pilot whales (*Globicephala melas*), and short-finned pilot whales (*Globicephala macrorhynchus*)[29,25]. Mass stranding of shot-finned pilot whales (SFPW) in India are not very common and so far only 4 incidences have been reported in the past 160 years. To investigate the cause of recent mass stranding event of Manapad, several factors were analyzed. One hypothesis is that the name pilot whale implies the tendency of the animals to follow a leader and the pod members commit suicide if the leader dies. However, there is no scientific proof that the pod have a clearly defined leader. Another popular hypothesis is that, the pilot whales live in groups and the members are all descendants of a single maternal ancestor or kinship based behaviour. Also it has been documented that a whole group of cetaceans could strand around a sick companion, refusing to leave it until it died due to strong cohesive social bonds[30]. Contrary to this hypothesis, recent findings based on molecular studies clearly showed that a pod is consisted of multiple maternal lineages andfound no correlation between spatial distribution and kinship along the stranding beach. The unrelated groups of pilot whales used to come together possibly to mate or feed[31].

Effects of seismic noise

Another hypothesis is that the pod of short-finned pilot whales enter the shallow region while chasing the prey during high tide period and usually gets stranded when the tide recede[32]. This hypothesis has insufficient evidence to prove. Healthy pilot whales are very sensitiveand theynormally avoid the above cited situation and change course seawards.

To discover oil and natural gas deposits, seismic surveys are being conducted throughout the world. Seismic surveys can raise the background noise levels by 20 dB over 300,000 sq. km. continuously for many days[33]. Odontocete hearing abilities vary from species to species and the hearing ranges from 0.5-160 kHz. The SFPW had greatest sensitivity at lower frequency of 40 kHz and a cut off frequency between 80 and 120 kHz[34]. The common bottlenose dolphins have good hearing from 0.75-140 kHz, with a typical cut off frequency around 120 kHz[35]. Marine mammals were observed to change their surface behavior leading to reduction in foraging efficiency while succumbing to hearing impairment due to seismic noise. Marine mammals also avoid seismic noise by vacating the area before full blown noise was reached. However, the sighting rates of pilot whales, sperm whales, killer whales and mysticetes did not decrease during the seismic survey[36]. In the present case, no seismic surveys were conducted on record during the mass stranding period at Manapad and nearby areas. During the mass stranding event at Manapad, many people hypothesized that underwater earthquake or seaquake might be the cause. On 11.01.2016, earthquake occurred in the Celebes Sea of Philippines at the magnitude of 6.5 on the Richter scale, 420 nautical miles away from the stranding site. However, if the SFPW were affected by this seaquake, they would have stranded in Nicobar or Sri Lanka coast and were not likely to strand off Manapad. There was no seaquake near Manapad. Incidentally when a major seaquake occurred on 26.12.2004 at the magnitude of 9.3 in Richter scale happened on the Sumatra-Andaman stretch, triggering a devastating Tsunami, there is no record of marine mammals getting affected. Therefore the seaquake as a cause also runs into an improbable zone of causality.

Navy sonar activity

Another report suggests that naval surface ships' use of mid-frequency active sonar (MFAS) could trigger mass strandings of beaked whales. Approximately 632 surface ships from 46 countries are currently fitted with a hull-mounted sonar system operating in the medium-frequency range[37]. The beaked whale strandings were significantly correlated with naval activity in the Caribbean and Mediterranean seas, but not off the coasts of southern California and Japan[38]. However, a conclusive MFAS and stranding relationship has not been established[39]. Cutting back to the present case, there was no naval sonar activity in the southeast coast of India during the mass stranding period. Hence, the mass stranding events of Manapad was not induced by navy sonar too. Documents reveal that disease and parasitic infections could have been the cause of single and mass cetacean strandings[40].

Geomagnetic anomaly

Geomagnetic anomaly as a cause was reported in many mass stranding events. Klinowska[42] first observed an association between the live stranding positions and magnetic field levels. He found that live strandings occurred at locations where magnetic minima, or lows in the magnetic fields, intersect the coastline. Animals were prone to make navigational errors in particular geomagnetic configuration, which caused the mass stranding[43,44]. It was observed that in many areas, geomagnetic lines turn and run perpendicular to the shore. Geomagnetic induction anomalies were identified in the southern tip of peninsular India. The phenomenon of low magnetization anomaly, all centered near the southern tip of the India is referred as South India Offshore Conductivity Anomaly (SIOCA)[45]. The Manapad stranding site falls within the area. The geomagnetic lines turn and run perpendicular to the shore. When the pilot whales used these lines to navigate, they could follow to the coast. Another reason for the geomagnetic anomaly could be the dominant tidal period. Night time observatory and CHAMP satellite magnetic measurements exhibit clear peaks at the dominant tidal periods[46]. Solar activity and the effects of lunar cycles also strongly influence the geomagnetic anomaly[47]. Two days before the Manapad mass stranding event was a new moon day and the highest high tide (spring tide) of 1.16m height was observed during the live stranding day 11.01.2016. Therefore, based on the circumstantial evidences and logical reasoning based on exclusion of plausibilities, it is assumed that 'Geomagnetic Anomaly' could be one of the reasons for the mass stranding.

Coastal topography

Coastal bathymetry and abiotic factors play a major role in mass stranding events. Bathymetry was identified as an important factor in several mass stranding studies[48]. Of the 76 mass stranding events recorded in Florida, USA in the interregnum 1977 and 2001, 32 were of SFPW. Subsequent works indicated that both bathymetry and wind-induced water circulation were found to be causing mass stranding[49]. Bays happen to be the significant coastal units were many mass stranding events occur. Out of 66 mass stranding events reported in Australia over a 100-year period, all events except 3 strandings occurred in the bays. Incidentally, many of the bays have a headland at one or both ends[9]. A headland is surrounded by water on three sides whereas a bay is surrounded by land on three sides. Headlands are characterized by high breaking waves, rocky shores, intense erosion, and steep sea cliffs. Bays are typically quiet with sandy beaches. In the Manapad event also, mass stranding was observed in the bay where headlands are present in both the ends. The northern side of bay-headland is called Tiruchendur headland and the southern side of bay is Manapad headland (Figure 2b). These headlands are constituted by marine sedimentary rock. The elevation of Manapad headland is 30m MSL and Tiruchendur headland has 25m MSL. The elevations of these headlands are high at the NE edge of the headland, but decrease along the coast and have their minimum at the SW edge of the headland. The Manapad bay has gentle beach slope with shallow sandy bottom gradients towards east-southeast of Gulf of Mannar (Figure 2e). At Manapad headland, wave-cut features are clearly visible. Pot holes with diameters of 60cm to 160 cm are seen in the nearshore zones of the exposed rocks. The grinding process by the pebbles due to waves result in pot hole formation[50]. Waves refract and bend towards Manapad headland because of the offshore shoal area associated with the headland, and therefore, the wave energy is concentrated on the headland, and thus the wave height is larger than the adjacent embayment. For the record, the largest of the stranded male SFPW (TL 582CM) was found on the Manapad headland (Figure 2d), which was an isolated occurrence compared to the rest. Clua *et al.*[51] compared the multiple mass stranding sites of New Zealand with other sites elsewhere in the world and found that all mass stranding sites had similar coastal topography of gently sloping sandy beaches with an adjacent protruding section of coastline. Chambers and James[52] postulated that live strandings are commonly occurring along the beaches with shallow sandy gradients as a result of reductions in the effectiveness of echolocation where the odontocetes are less familiar. Hence it sounds quite plausible that the Manapad bay topography, which is similar to these structures, would have triggered the SFPW mass stranding. The Karumeni river discharge in the Manapad bay contributes to the fine sediments. There were 6 numbers of SFPW found stranded in the river mouth (Figure 2f) and all of them were male. During December and January, coastal current moves towards southward-southwest direction. Therefore, live stranding first occurred at Alathalai and then progressed towards Karumeni river mouth area in Manapad.

Biosonar dysfunction

Worldwide mass stranding event records show that the manifestation is more in sandy headland-bays with low seabed slope area than other sections of a coastline. Mass stranding of SFPW was caused by sonar termination or biosonar dysfunction. The mechanism involves the relationship between acetacean's acoustic detection sensitivity (dynamic range) and an oceanic acoustic phenomenon known as sonar termination.Sonar termination occurs when a navigational echolocation click projected towards the coast critically attenuates to a point where it is not detectable. Chambers and James[52] model predicted sonar termination to occur at slopes less than 1°. Slopes >5° were highly likely to be detected at a safe distance. Fine sandy sediments generally produce offshore headland-bay slopes less than 0.5° around southern Australia. The combination of (fine) sands and seabed slopes less than 1° is highly favourable to the sonar termination effect producing telling impact[52]. The Manapad stranding site sea floor is flat and highly irregular with gentle slope towards seawards. During the low tide period, the sand bars with intermittent channels are clearly visible (Figure 2e). The slope in the Manapad stranding site was calculated as 0.4° to 2.326°. The tides in this area are semi-diurnal in nature, i.e., occurrence of two high and two low waters every day. The mean tidal range is of the order of 0.3 m to 1.18 m at spring and between 0.5 m to 0.70 m at neap tides. Manapad stranding site seabed is also having the same structures and the sediment grain size measured was fine (0.125-0.25mm).

Conclusion

The SFPW are nocturnal feeders and their major foods are cephalopods, particularly squids. The SFPW distribution and abundance are generally regulated by prey availability. There is strong correlation between SFPW sightings (Figure 1) and squid spawning period at Lakshadweep. Mohamed *et al.*[53] reported that the area around Lakshadweep Islands is a major spawning ground for oceanic squids probably because of higher productivity as compared to the central Arabian Sea basin which is normal foraging area for adults. Dense aggregations (~1,30,000 number/ km^2) of oceanic squid juveniles with dorsal mantle lengths ranging from 3 to 30 mm size were observed in the surface layers during night. The continental slope area of Manapad consists of rich resources of cephalopods, sardine fishes, Indian mackerel and other fishes. To find out the sighting frequency of SFPW in Manapad coast, fishermen interview survey (n = 68) was conducted during the mass stranding event. The results showed that after the stranding in 1973, there was no stranding and there has been no record of sightings of SFPW in the last 43 years. Fishermen, who had witnessed the 1973 mass stranding event, also opined that they have not seen the animal either live or dead afterwards. It has been reported that SFPW normally inhabit off shore and during winter come to inshore shallow region for feeding on squids[3]. It is likely that the SFPW stranded in Manapad moved to the shallow region in search of food when the SST is normally low (26° C) during December and January. Based on these probabilities, the single most predominant cause to have triggered the mass stranding of SFPW in Manapad appears to be biosonar dysfunction. However, various other factors like geomagnetic anomaly, tides, wind derived onshore currents and lunar cycle have played a concomitant role in piloting the movements of SFPW into the shallow bay. After reaching the shallow bay, the animals got disoriented because of not knowing the way to go deep.

Acknowledgements

The authors are thankful to Director, CMFRI for facilities and encouragement.

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