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Understanding Strandings: 25 years of Humpback Whale (Megaptera novaeangliae) Strandings in Queensland, Australia

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ABSTRACT

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Cetacean strandings are well-known phenomena in all parts of the world. In most cases the underlying reasons are unknown. Incidents have been associated with factors including changes in magnetic fields, diseases, unusual weather events, vessel strikes, pollution and fishing. Quantitative analyses over large spatial and time scales can provide insights into stranding hotspots, trends and relationships with physical drivers. Here we collated and combined available information on humpback whale (*Megaptera novaeangliae*) incidents that occurred in Queensland, on the east coast of Australia between 1989 and 2014. This study provides a first overview of incidents for humpback whales for the east coast of Australia over a 25 year period. Incidents included reports of carcasses, vessel strikes, injured animals found stranded, entrapped in shallow water, entangled or floating offshore. The location, timing, age class and types of over 200 incidents were analysed for trends and compared with oceanic and physical processes. The majority of incidents involving calves or juvenile humpback whales occurred during the austral winter (peak in August). The rate of strandings was associated with the position of the East Australian Current, and lagged Southern Oscillation Index (SOI). Our study demonstrates the importance of long-term strandings records to allow for the investigation of trends over spatial and temporal scales relevant to migratory species. A comprehensive strandings program is an important conservation and monitoring tool to better understand long-term trends and to quantify key threats to cetaceans.

ADDITIONAL INDEX WORDS: *Humpback whales, stranding, East Australian Current, SOI.*

INTRODUCTION

Strandings, entanglements and vessel strikes involving cetaceans often receive considerable public attention. The underlying patterns or causes of strandings are, however, not well known (Evans *et al.*, 2005). Stranding records can provide valuable information for investigating trends on location, timing and type of incidents over long periods of time and large spatial scales (Evans *et al.*, 2005; Meager and Limpus, 2014).

Humpback whales, *Megaptera novaeangliae,* are an iconic species of baleen whale that underpin a billion dollar commercial whale watching industry. Humpback whales in the southern hemisphere migrate annually between their summer feeding grounds in Antarctica and winter breeding grounds in the tropics (Dawbin, 1966). The movement along the migratory route is thought to be influenced by physical and biological factors resulting in the majority of the population passing within 10-30 km of the shore (Noad *et al.*, 2008). The Group V humpback whales travel along the east coast of Australia and are a distinct population. Recognised aggregation sites for resting or breeding of this population in Queensland, Australia, include the Gold Coast bay, Hervey Bay, Moreton Bay, the Swain Reefs, Whitsundays, southern Great Barrier Reef, Bell Cay and the Palm Island Group (DEWR, 2007; Meynecke *et al.*, 2013).

Strandings, mortalities and incidents involving humpback whales have been reported and investigated previously in other parts of the world. On the Pacific coast of Columbia most strandings (1986-2000) are calves and occur from August to October (Capella-Alzueta *et al.*, 2001). A similar trend was evident in Western Australia, where most humpback whale strandings occurred during the southern migration (August to October) and 44% of strandings were calves (Groom and Coughran, 2012). In New South Wales, Australia, the largest known cause of incidents was entanglement of cetaceans (134 individuals) with the majority being humpback whales caught in fishing gear (Lloyd and Ross, 2015). The reasons humpback whales strand are diverse, and can be influenced by behaviour and health of whales in addition to extrinsic factors such as the predation, geography of the coastline, proximity to shore, water temperature, wind and ocean currents (Geraci *et al.* 1993; Meager and Limpus, 2014).

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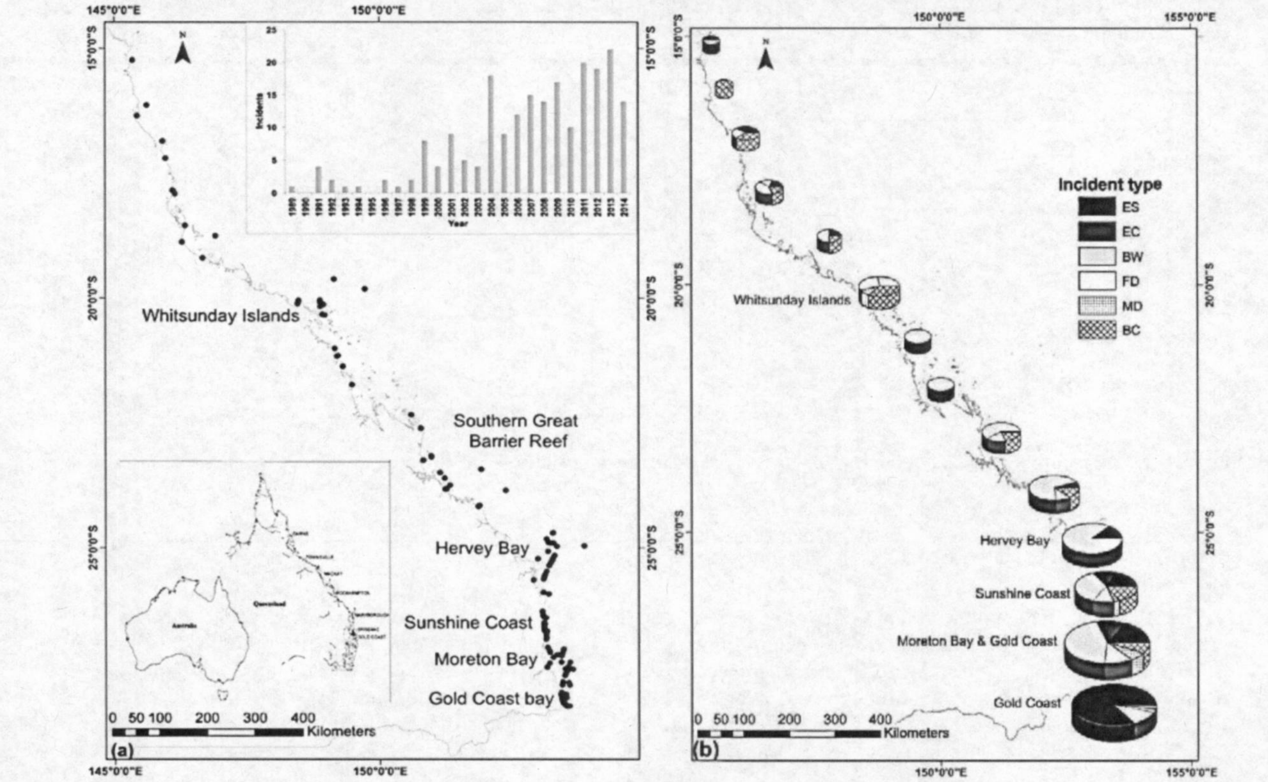

Figure 1. (a) Locations and number of strandings along the coast of Queensland, Australia (1989-2014); (b) incident types based on latitudes ranging from 28°S to 15° S with size of graphs proportional to the number of strandings. ES = entanglement in Queensland shark control program gear; EC = entanglement in commercial fishing gear; BW = washed ashore (dead or alive); FD = floating dead or alive; MD = entanglement in marine debris; BC =vessel interaction.

Humpback whale migration may be influenced by the environment (Ramp *et al.*, 2015), and large-scale oceanographic and climatic factors. Along the east coast of Australia the East Australian Current (EAC) flows in a southward direction as the western boundary current of the South Pacific sub-tropical gyre (Roughan and Middleton, 2002). The EAC strengthens during the austral summer and has weaker flows from May to July in the austral winter (Tranter *et al.*, 1986). Depending on the position of the EAC humpback whales may migrate closer or further to the shore utilising the current (Gaspar *et al.*, 2006). Another large scale climatic factor that may affect the whale population El Niño Southern Oscillation (ENSO) phenomenon, as measured by the Southern Oscillation Index (SOI). El Niño events generally bring warm and dry conditions with above average temperatures and below average rainfall to the Australian continent. It has been speculated that there is link between El Niño events and population dynamics of humpback whales, although the ecological link is unknown and may be a function of a complex relationship between climate and krill availability in the Antarctic foraging grounds (Chaloupka and Osmond, 1999; Murphy *et al.*, 2007).

This study aimed to investigate trends in reported humpback whale stranding incidents in nearshore waters of Queensland, Australia. We also aimed to explore the rates of humpback whale strandings in relation to major climatic (SOI) and the oceanic (EAC) factors.

METHODS

The Queensland east coast, ranging from Tweed Heads (28.1833°S, 153.5500°E) to the tip of Cape York (10.6833°S, 142.5333°E), was the focus of this study (Figure 1). The climate ranges from subtropical in the south-east to tropical in the north of Queensland.

Data were compiled from a number of sources, the Queensland Marine Wildlife Strandings and Mortality Program (StrandNet), the Sea World Rescue Foundation archive and newspaper articles for the time period 1989-2014. StrandNet records are based on information provided from government departments, community groups, businesses, environmental organisations, and the general public and were included from 1996-2014. Sea World Rescue Foundation has been involved in the rescue of marine wildlife for several decades and information from their archive was extracted. For the purpose of this study strandings were defined as reports of carcasses, vessel strikes, injured animals found stranded, entrapped in shallow water, entangled or floating offshore. The final database included information on suspected and confirmed cases giving date, location, type, size, sex, fate, injuries, age and an incident description for 214 humpback whales ranging from 1989-2014.

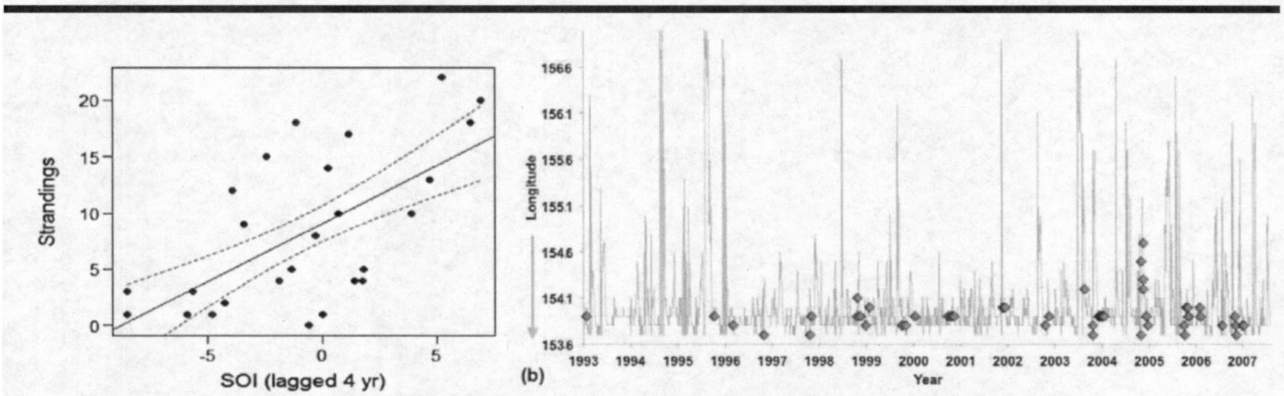

Figure 2. (a) Relationship between average SOI and the annual strandings rate from 1989 to 2014 (± 95% confidence intervals, $\beta = 1.02$, $r^2 = 0.40$, $p = 0.02$, robust regression), (b) position of the EAC (light grey line, arrow indicating direction to coast) over a 14 year period (1993-2007) with 58 stranding events (only beached or entanglement from Fraser Island to Tweed Heads, black diamonds).

The data was categorised into different incident types including beach washed, entanglement in gear from the QSCP gear, entanglement in commercial fishing gear, entanglement in marine debris, vessel collision and floating (dead or alive). The whales were classified in age groups of calves (<8 m in length), juveniles (<10 m in length), sub-adults (<12 m in length and adults (>12 m length) (Meynecke *et al.*, 2013). Data was mapped in ArcGIS (v. 10.1) to identify 'hot spots' of strandings and then summarised for each latitude. The annual summary of strandings was standardised by the estimated population (Franklin, 2014) to account for an 11% increase of population per year (Noad *et al.*, 2011).

Monthly SOI values (based on the difference in sea level pressures between Tahiti and Darwin, Australia) were obtained from the Australian Bureau of Meteorology. The location of the centre of the EAC was based on the CSIRO BLUElink Ocean Reanalysis model for 1992-2008. The longitude position of the EAC was measured daily from the centre of the main jet of the current with a relative high certainty south of Fraser Island (Oke *et al.*, 2008). Only stranding data south of Fraser Island (Hervey Bay) to Tweed Heads was compared with the position of the EAC. Incidents that were likely to have occurred offshore, such as vessel strikes and carcasses floating offshore were not included in this analysis. The relationship between SOI and strandings was examined using linear models. A range of SOI predictors were tested including SOI averaged over the year, SOI averaged over the migration season (May to October), lags of up to 4 years and moving averages of up to 4 years.

RESULTS

The highest number of reported incidents took place in south-east Queensland between 28 and 26°S with 124 incidents or 58% of all reported strandings during the observation period (Figure 1a). The southern Gold Coast bay had the most reported incidents for any of the regions with 73 records or 34%.

Of the 214 reported whales the age class of 54 was unknown or not reported. The majority were either calves or juveniles (55%) and only 34 involved adults (16%) (Table 1). The majority of strandings occurred during the austral winter (June to August, 58% of strandings) and spring (September to October, 40% of strandings). The annual summary of strandings indicated strong variability between years with higher strandings occurring approximately every 2-3 years (e.g. 2004-2007) In spite of this periodic variability, the number of strandings increased over the time period. A weak trend of increasing strandings remained when adjusted for the estimated annual population size. This was because of lower than expected strandings earlier in the study period, with the notable exception of 1991.

More than one third (37%) of the recorded incidents were a result of entanglements involving QSCP gear (27%), fishing gear (8%) or marine debris (2%). Another 87 whales (41%) washed up on beaches (dead or alive), while 23 (11%) whales were reported as floating dead or alive in the waters offshore. A total of 22 cases (10%) were attributed to interactions with vessels. The type of incident varied with location with entanglements being highest in south-east Queensland (Figure 1b).

Almost half of the stranded whales were reported as alive were either released alive, sighted alive but left in situ (91 whales or 43%), while another 89 whales (42%) were found dead, or died from their injuries sustained during the incident. (Table 1). In some cases a whale was euthanized and in other instances whales were able to release themselves.

A linear relationship was evident between the annual number of strandings and SOI, that was strongest for a 4 year moving average ($r^2 = 0.40$ $p = 0.02$, Figure 2a). The number of incidents was generally higher in strong La Niña events than in El Niño events (Figure 2a). Data were insufficient to analyse cause-specific trends.

The average position of the centre of the EAC during the observation period (1992-2008) was at longitude 154.03995°E.

In south-east Queensland, 89% of beach washed strandings and entanglement occurred when the centre of the EAC was closer to the coast than average (1993-2007). Most strandings took place when the centre of the EAC was between longitude 153.7° and 153.9°E (Figure 2b).

DISCUSSION

Our analysis of 25 years of humpback whale strandings records across the subtropical-tropical coastline of Queensland provided insights into spatial 'hotspots', temporal trends and variability associated with large-scale oceanic and climatic environmental factors. Strandings clustered in the regions recognised as resting, socialising or breeding grounds (DEWR, 2007). One key 'hotspot' for strandings was the Gold Coast, a region where the migratory corridor is close to the shore and where humpback whales are known to rest (Meynecke *et al.*, 2013). It is also adjacent to a large metropolitan centre and therefore represents a site where anthropogenic interactions would be expected. Entanglements were the dominant known cause of strandings in the region and 75% of all reported entanglements occurred on the Gold Coast.

The increase of strandings is largely a reflection of the recovering humpback whale population (Noad *et al.*, 2011). However, the increasing trend of humpback whale strandings remains when adjusted for the estimated annual population for the time period 1989-2014, because few strandings occurred in the earlier years of the study period (<1996). Notwithstanding the possibility that the strandings reporting rate has changed over this period, this analysis suggests that other risk factors may have increased. Whether this is due to changes in anthropogenic sources such as vessel activity, fishing gear deployment, noise pollution, marine debris or water quality, or a natural driver is unknown.

Similar to findings elsewhere (Capella-Alzueta *et al.*, 2001; Holyoake *et al.*, 2012; Moura *et al.*, 2013), calves and juveniles dominated strandings with only 15-20% of the strandings involving adults, and the peak strandings rate occurred late in the austral winter (Meager and Sumpton, 2016). Mother and calf pairs are known to prefer to rest in shallow, sandy bays during the southern migration, which makes them more susceptible to anthropogenic impacts and strandings (Franklin *et al.*, 2011; Holyoake *et al.*, 2012; Meynecke *et al.*, 2013).

Individual animals attend the migratory flow at different times depending on sex, age and reproductive state (Dawbin, 1966) and calves traveling in August maybe in a state that makes them more vulnerable to strandings. The highest number of mother and calf pairs are seen travelling late in the southern migration (Paterson *et al.*, 1994). Females in advanced pregnancy are also the last to travel north, and some of the August strandings may be unsuccessful pregnancies. The proximate reasons for the peak of strandings of young humpbacks in August would be an important question for future research

The SOI represents large scale climate variability and showed a lagged, positive relationship with strandings Whether this was because of effects on the population size, the number of whales attending the migratory flow, health or another reason is unclear. Earlier research has noted the potential link between the number of humpback whales migrating along the Queensland coast and ENSO (Chaloupka and Osmond, 1999). Climate and oceanographic dynamics can influence the position and concentration of krill, which may have a direct effect on the timing of the northern migration of humpback whales (Paterson *et al.*, 1994), energy reserves or breeding success (see also Leaper *et al.*, 2006).

Table 1. *Summary of strandings per year (live or dead). M = male; F = female; UnS = unknown sex; ES = entanglement in QSCP; EC = entanglement in fishing gear; BW = washed ashore (dead or alive); FD = floating dead or alive; MD = entanglement in marine debris; BC = vessel interaction; UnA = unknown fate.*

Year	89	91	92	93	94	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Total	1	4	2	1	1	2	1	2	8	4	9	5	4	18	9	12	15	14	17	10	20	18	22	13
M	-	-	-	-	-	-	-	1	1	1	1	1	2	3	1	1	-	1	2	2	2	5	2	1
F	-	-	-	-	1	-	-	-	5	1	2	-	-	1	1	-	3	1	1	1	2	2	3	1
UnS	1	4	2	1	-	2	1	1	2	2	6	4	2	14	7	11	12	12	14	7	16	11	17	11
ES	1	2	3	1	2	1	1	1	-	2	4	2	1	7	5	2	2	1	6	1	1	5	5	7
EC	-	1	-	-	-	-	-	-	-	-	-	-	-	3	-	4	5	-	-	-	-	1	3	-
BW	-	1	-	-	1	2	-	1	8	1	5	3	1	4	3	3	1	5	5	7	14	8	10	5
FD	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	2	4	2	5	1	2	3	2	-
MD	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	1	-	-	2	1	-
BC	-	-	-	-	-	-	-	-	-	-	-	-	1	4	-	1	3	5	-	1	3	1	2	1
Dead	-	-	-	-	-	-	-	-	6	1	7	3	2	4	2	4	5	5	11	6	13	10	7	3
Alive	1	4	2	1	1	1	1	2	2	2	2	1	2	9	7	5	7	4	6	3	5	7	7	9
UnA	-	-	-	-	-	1	-	-	-	1	-	1	-	4	-	3	3	5	-	1	2	1	8	2

The movement of the EAC core current to inshore waters can cause upwelling events and slope water intrusion bringing cooler waters to shore (Roughan and Middleton, 2002). Whales and other marine megafauna are known to use currents for navigation (Gaspar *et al.*, 2006) and prefer cooler temperatures (Dalla Rosa *et al.*, 2012). The encroachment of the EAC towards the coast may therefore result in a migratory corridor closer to the shore, and an increased likelihood of interacting with coastal human activities or stranding upon the shore. Other conditions such as wind and wave conditions, and sea surface temperature may also be useful for an improved prediction of humpback whale strandings, as would biological parameters such as calving rates and condition.

CONCLUSIONS

The increasing number of humpback whales and increasing number of users of the marine environment suggests that anthropogenic sources of strandings such as vessel interactions and entanglements will become more frequent into the future. Climatic and oceanic factors may act to mediate the number of these interactions, and therefore should be further understood. Such trends are best observed and monitored on a national or global scale, and by collaboration across jurisdictions.

Our descriptive approach detecting humpback whales stranding patterns and occurrence provides for the basis of a more in depth analysis to reveal underlying patterns, frequencies and dependencies on environmental factors. Understanding and predicting how the environment influences the vulnerability of humpback whales to natural and anthropogenic threats would support informed strandings management.

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