Sonar termination as a cause of mass cetacean strandings in Geographe Bay, south-western Australia

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ABSTRACT

Geographe Bay, south-western Australia has been host to several past mass live cetacean (whale and dolphin) strandings. It is noticed that the majority of stranded whales tend to be healthy, toothed cetaceans (*Odontoceti*) which employ echolocation as a method of navigation. This paper explores a bioacoustic mechanism known as sonar termination as a major factor in the occurrence of these strandings in Geographe Bay. Sonar termination occurs when a navigational echolocation click projected towards the coast critically attenuates to a point where it is not detectable. The paper proposes two mechanisms contributing to sonar termination: first, the presence of a gently sloping shore and second, the presence of continuously created stagnant micro sized bubbles (microbubbles). By depicting a wedge shaped coastline as a perfect flat reflector the attenuative effect of multiple reflections and resident microbubbles in a coastal water column on a cetacean echolocation signal is calculated, and a limiting distance that a cetacean may be able to detect the presence of a shoreline is determined from these results. A brief review of the most recent mass strandings at Dunsborough (03/04/05, 02/06/05) is presented and the plausibility of the bioacoustic mechanism's role in the strandings is investigated.

INTRODUCTION

Geographe Bay, a 100km wide north-facing embayment situated between Cape Bouvard and Cape Naturaliste on the south-western coast of Australia, has been host to several mass beachings of live cetaceans within the last 15 years. The strandings actively involve the coastal communities of Dunsborough and Busselton in the removal, transportation and re-floatation of the stranded cetaceans and the causes for each stranding event are uncertain. There have been a few explanations postulated for the occurrence of such strandings but so far there has been no direct link to the causation of a mass stranding event. It is, however, noted that the cetaceans stranding at Geographe Bay involve large groups (5 or more) of apparently healthy toothed cetaceans (*Odontoceti*- which is a cetacea suborder that in part comprises of families of dolphins, small toothed and beaked whales) where majority of the stranded herd appear to be free of disease or parasitic infection, and the location of the stranding is over a gently sloping sandy bottomed beach. These findings are similar to other studies of occurrences of mass strandings elsewhere (Geraci 1978, Warneke 1983, Robson 1984, McManus et al. 1984, Brabyn & McLean 1992) and in the absence of disease, parasitic infection or anthropogenic activity the dysfunction of echolocation has been previously suggested as a possible cause of mass strandings at these types of beaches (Dudok van Heel 1962). However, this finding is without sufficient quantitative examination. We present an illustration of a proposed bioacoustic mechanism based on echolocation dysfunction. The mechanism involves the relationship between a cetacean's acoustic detection sensitivity (dynamic range) and an oceanic acoustic phenomenon known as sonar termination. Whilst acknowledging that a mass stranding event is a very complex situation, which involves the consideration of psychoacoustic and social characteristics of a cetacean herd, and the possible use of other senses, our proposed mechanism is very specific to Geographe Bay and may indicate why this coastal region is a recurring mass stranding location.

Sonar termination occurs when an acoustic signal is transmitted from a certain distance offshore towards a gently sloping shore of angle less than a degree and critically attenuates to a point where the reflections are not detectable. The attenuation is caused by the additional path length the signal travels due successive reflections, the reflection loss at each reflection and small micron range sized bubbles (microbubbles) spread throughout the water column. The reflections contain important information about the location of the shoreline. Successful detection of a shoreline from reflections may only occur at a point where the cetacean is at a high risk of stranding or has already stranded. A misdetection of the proximity of a shoreline may also result in confusion and disorientation of the cetacean and result in a navigational error inducing the onset of a mass stranding.

The detrimental effect of microbubbles on ultra-high frequency navy sonar (> 40 kHz) has only been recently examined (Richards & Leighton 2001, Richards & Leighton 2003) and it is proposed that this effect is important when considering the performance of long range, high frequency sonar models (Richards, White & Leighton 2004). Our study further investigates this proposal and will illustrate the importance of the role of microbubbles in a mass cetacean stranding. We present the first calculation of the attenuative effect of microbubbles on long range cetacean echolocation over an idealised gently sloping beach similar to that of Geographe Bay.

Bathymetry and oceanography of Geographe Bay

Geographe Bay is a relatively protected bay with a reported gently sloping bathymetry (2m km^{-1}) characterised by a sandy substrata with overlying submarine sandbars near shore and extensive beds of seagrass in the deeper regions 2-14m (McMahon et al. 1997). A bathymetry plot based on Admiralty Chart 5011 1983 is illustrated in Figure 1. The angle to the shoreline at several approach directions to the stranding locations rarely exceeds 0.5° verifying that this type of beach is one with a very gentle slope.

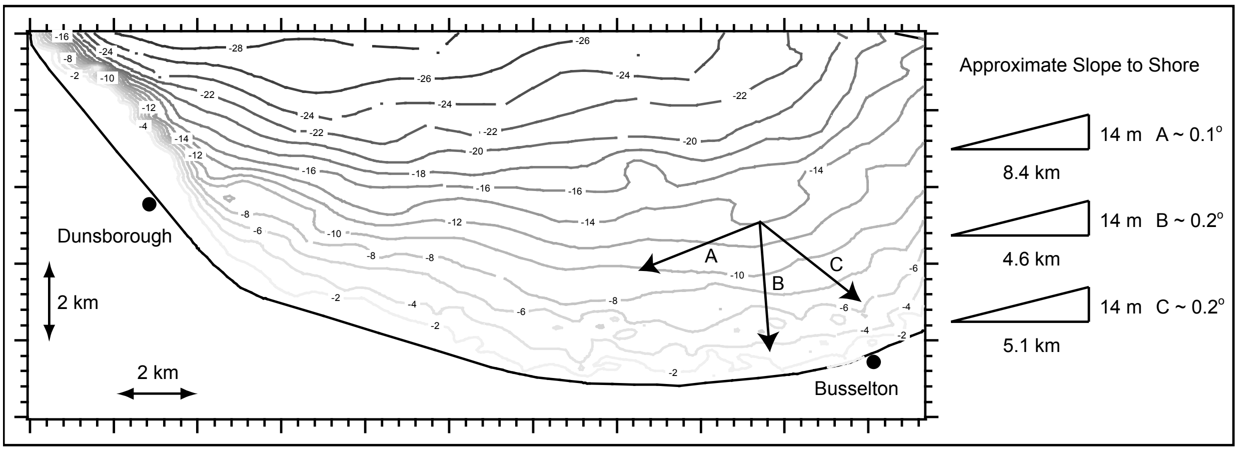

Figure 1: Contour plot of topography of Geographe Bay, Dunsborough to Busselton. Data points have been obtained from Admiralty Chart 5011, 1983 with approximate angles of shore slope illustrated.

The physical oceanography of Geographe Bay is dependent on its proximity to the nearby Leeuwin Current (Fahrner & Pattiaratchi 1995) and will have an effect on variation of the salinity and temperature range throughout the year. The Leeuwin Current is an eastern boundary current of warm, low salinity, low nutrient water that flows at the surface from the northwest cape of Western Australia towards the most south western proximity, Cape Leeuwin and then towards the Great Australian Bight. The position of the current relative to the bay varies seasonally and in the winter months the current flows strongest and is within close proximity to the bay (Creswell 1991). Upwelling is not a feature of the current and nutrient levels within the bay are largely dependent on terrestrial inputs (Lenanton et al. 1991) which sustain a large amount of marine life within the inner bay. The presence of such marine life so close to the coast may result in pelagic cetaceans, probably not familiar with the coastline, being closer to the coast than usual to feed during certain periods. The water column is well mixed with little stratification. Water temperature varies from 21.6 °C in the summer and 14.8 °C in the winter (McMahon et al. 1997) and salinity varies between 33.1 and 37.2‰ (Water Corporation 2003).

Recent mass cetacean strandings at Geographe Bay

There have been four mass stranding events occurring within Geographe Bay since 1995. The first and largest stranding occurred in August 1996 which involved approximately 320 long finned pilot whales (*Globicephala melas*). A small pod of 6 Gray's beaked whales (*Mesoplodon grayi*) stranded in January 2003 and the third and fourth strandings of cetaceans occurred recently in April and June 2005 involving the beaching of 19 long finned pilot whales and 120 false killer whales (*Pseudorca crassidens*) respectively.

The second most recent beaching of a herd of long finned pilot whales occurred at approximately 6am on the 03/04/05. The stranded whales were spread on both the east and west sides of Busselton between Peppermint Beach and Siesta Park (Figure 2). Four of the 19 beached whales were found dead and two died the day after (CALM 2005b). The remaining whales were successfully refloated and herded out to Cape Naturaliste with no re-stranding occurrences (CALM 2005c). Reported weather conditions at a nearby Busselton weather station indicate that the wind close to the time of stranding was from the E/NE at 37 km h^{-1}. Stormy

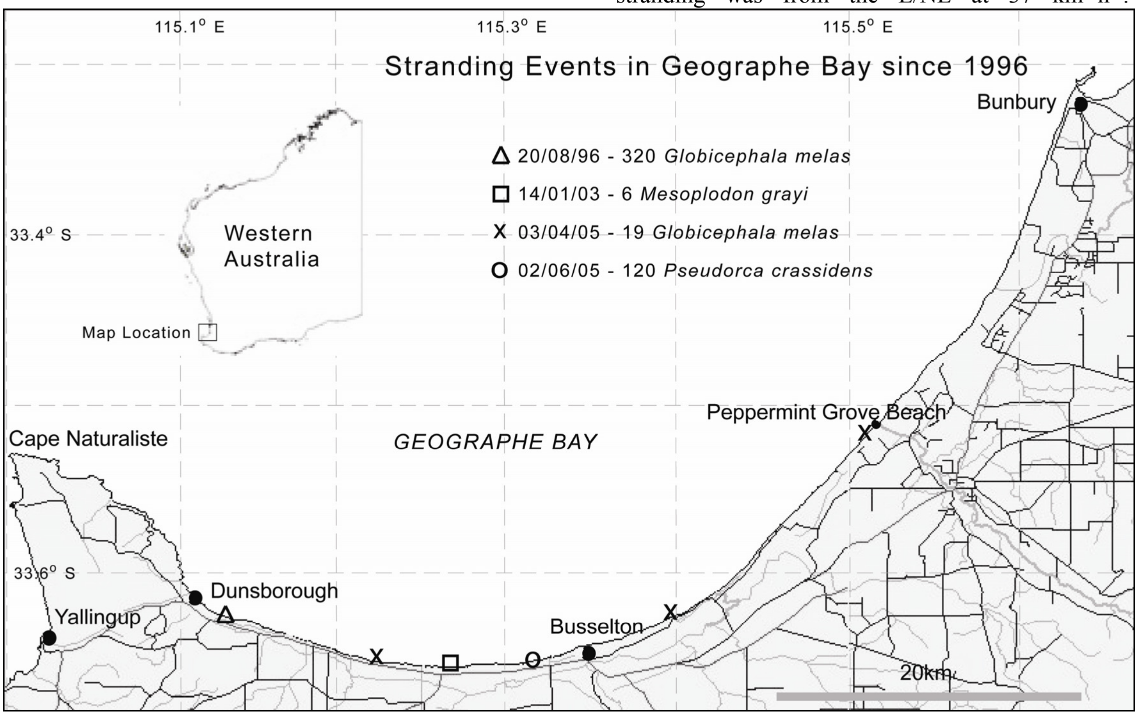

Figure 2: Map of Geographe Bay showing approximate positions of mass cetacean stranding events since 1995.

conditions had also prevailed for 3-4 days prior to the stranding with gusts from the S/SW up to 70 km h^{-1} and a total rainfall measuring 38mm had occurred over the period of 36 hours preceding the stranding event (BOM 2005a). The most recent stranding incident occurred on the morning of 02/06/05 at approximately 8:10am involving 120 false killer whales (*Pseudorca crassidens*) beaching themselves over 600m between Earnshaw Street and the Dolphin Bay boat ramp, West Busselton (Figure 2). There was one recorded fatality amongst the whales and the rest of the herd were successfully returned to the sea with no re-stranding occurrences (CALM 2005a). A post mortem examination of the single fatality revealed a higher than normal parsasitic load in its intestinal tract (*Sick whale may have led to stranding* 2005). The wind direction at the time of the stranding was from the E/NE at 17 km h^{-1}, no rain was observed for the period of three days before the stranding and the wind was continually offshore from the E/NE reaching speeds of 46 km h^{-1} (BOM 2005b).

Cetacean Dynamic Range

It is well established that *Odontoceti* echolocate for both short and long range navigation (Norris 1964). The sensitivity of a cetacean to its echolocation signal can be illustrated by the construction of a bioacoustic dynamic range function; the difference between the cetacean's emission and hearing thresholds. This dynamic range function is a good reference of the cetacean's ability to perceive reflections and noise

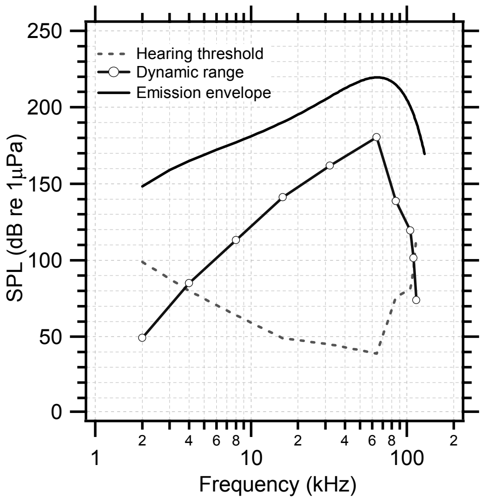

Figure 3: Pseudorca crassidens echolocation characteristics: (i) Emission envelope, (ii) Hearing threshold, (iii) Dynamic range.

features from the coastline and indicates how much an echolocation signal can be attenuated before it falls below the cetacean's hearing threshold and is no longer detectable.

A cetacean's hearing and emission thresholds are frequency dependent and many species of cetaceans have been subject to numerous psychoacoustic studies, to name a few – Johnson 1967, Au et al. 1974. We use the work of Woodings and James (Woodings 1995) for our purposes to illustrate the frequency dependent dynamic range, shown in Figure 3, of a Western Australian stranding species (*Pseudorca crassidens)* collated from several in-situ observations (Thomas et al. 1988, Thomas & Turl 1990). Although this species has a displayed hearing and emission levels ranging from 2 to 120 kHz, the dynamic range function suggests that this species has an optimal echolocation range between 30 and 80 kHz. Signals generated within this bandwidth are able to suffer 150 dB of attenuation before falling below the cetacean's detection sensitivity. The dynamic range is also degraded by the level of oceanic ambient noise. This degradation corresponds to the raising of the hearing threshold, thus reducing the dynamic range. We postpone the role of ambient noise in this study due to the lack of data available for noise levels within this region.

Wedge waveguide termination - Geometrical acoustics of a gently sloping shore

The cross section of a shore can be approximated by a wedge shaped waveguide that traps high frequency signals traversing within it. Termination of a signal in a wedge waveguide is well known in electromagnetic antenna theory where a low angle wedge shaped lossy material is introduced to achieve a reflectionless termination. This concept has also been employed in the design of anechoic acoustic baffles. The oceanic acoustic analogue of this process has received relatively little attention. There has been a past attempt to provide a discrete formula for the turn around loss due to bottom reflections for propagation up a wedge (Weston 1983), similar to this study, but this study does not focus on the low angle slope conditions for termination. Dudok van Heel 1962 attempted to observe sonar termination in a low angle wedge shaped oceanic environment by transmitting basic echo sounder pulses at different coastal sites. The results of the study noted a reduced intensity of the reflections at sites with gently sloping beaches but the results were qualitative and failed to evaluate the sound pressure level of the echoes, or establish a relationship with a cetacean's transmission and hearing threshold. For simplicity as well as consistency we choose to base our calculations on the geometrical acoustic solution proposed by Woodings and James 1995 (Woodings 1995), rather than the Biot-Tolstoy normal coordinate solution for a transient signal traversing in a wedge waveguide (Tolstoy 1973).

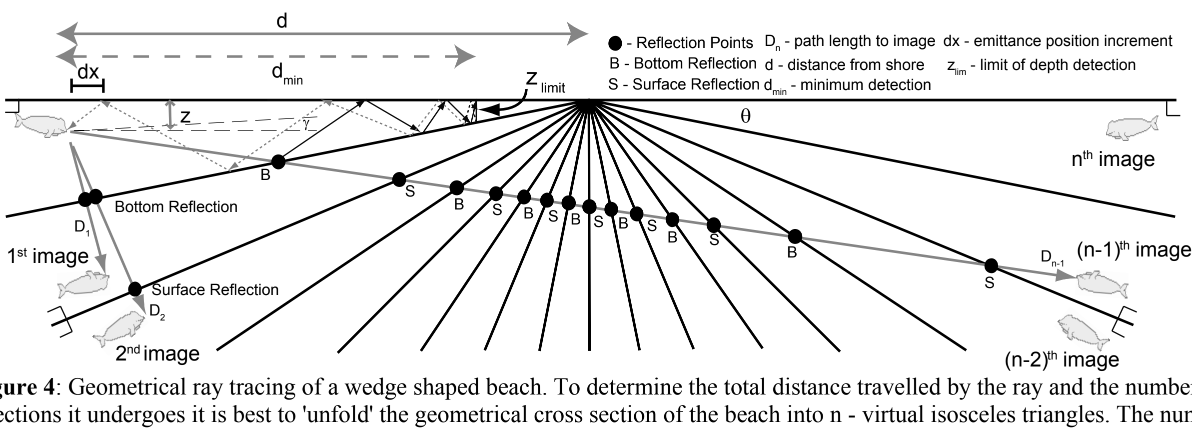

Figure 4: Geometrical ray tracing of a wedge shaped beach. To determine the total distance travelled by the ray and the number of reflections it undergoes it is best to 'unfold' the geometrical cross section of the beach into n - virtual isosceles triangles. The number n depends on the angle of the gently sloping beach.

Consider a cetacean echolocating downwards a distance d offshore with shore angle θ shown in Figure 4. The sea bottom and sea floor are modelled as perfectly flat reflectors. Reflecting the wedge shape around a central apex will reveal a family of solutions of transmission angles that will be successfully received. The number of reflections an echolocation signal suffers for a particular transmission angle from emission to reception is simply the number of times it intersects virtual wedges on the way to the cetacean's virtual image. The distance D_n travelled by the signal from emission to reception is then equivalent to the distance between the cetacean and the cetacean's n^{th} virtual image and is determined by:

$$D_n = 2\sqrt{d^2 + z^2}\,\sin\left(\frac{\beta}{2}\right) \quad \text{eq. 1}$$

$$\beta = 2m\theta \qquad (\text{for } m = n)$$
$$\beta = 2(m+1)\theta - 2\gamma \quad (\text{for } m = n+1)$$

where d is the distance offshore, z the depth, θ the beach declination, m and n the number of surface and bottom reflections and γ the angle to the beach apex from the cetacean.

Sound absorption by microbubbles

The presence of microbubbles throughout the coastal water column contributes directly to sonar termination by viscous and thermal damping of the incident signal energy and also re-radiation of energy by the bubble (Devin Jnr. 1959). It is well accepted that bubbles are continuously created at the water surface usually by rain drop entrainment (Pumphrey & Elmore 1990) and surface waves (Dahl 1994). Other sources of continuous creation of bubbles relevant to Geographe Bay are photosynthesis by marine algae and decaying matter on the seafloor (Medwin 1970, Medwin 1977). Tidal and wave motion mix the microbubbles thoroughly in very shallow waters (less than 3m) resulting in a spatial distribution of bubbles of different sizes from the micron range to a few millimetres in diameter throughout a coastal location. Due to a retardant or neutral buoyancy, these microbubbles can reside within the water column from a few hours to a few days depending on the level of oxygen saturation in the water and bubble surfactant film contaminants such as micro sized particles (Turner 1961, Mulhearn 1981).

The amount of energy absorbed by a microbubble is a maximum at its natural resonant frequency and is approximated by the following equation (Minnaert 1933):

$$f_{res} = \frac{1}{2\pi a}\sqrt{\frac{3_\gamma p_b}{\rho}} \quad \text{eq 2}$$

where a is the bubble radius, p_b is the pressure inside the bubble, γ the specific heats ratio of gases and ρ the density of sea water. A small correctional error occurs in eq. 2 due to the isothermal correction for bubbles of radius greater than two microns (Medwin 1970). We choose to omit this error to the model of resonant oscillation as the equation is sufficient for our demonstration.

The attenuation by a bubble at resonance is parameterised by the extinction cross section σ_e, the ratio of the sum of the extinguished power to the intensity of the incident acoustic wave. At resonance the extinction cross section for microbubbles is larger than its physical geometric cross section indicating a larger interception area of the incident echolocation signal. It is defined by (Clay & Medwin 1977):

$$\sigma_e = \frac{4\pi a^2(\delta / ka)}{[(f_{res} / f_{inc})^2 - 1]^2 + \delta^2} \quad \text{eq. 3}$$

where f_{inc} and k are the frequency and wave number of the incident acoustic wave and δ the damping constant of the bubble. We employ the results of Devin Jnr. 1959 as a reference for the values of the damping constant when evaluating the extinction cross section's role in the proposed mechanism.

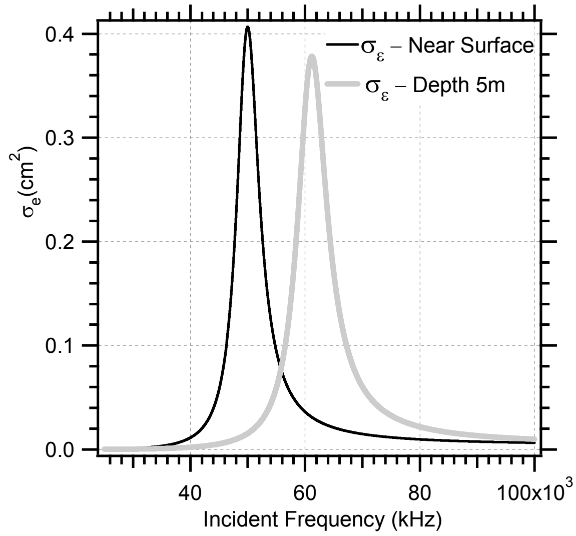

Figure 5: The extinction cross section σ_e for a bubble of radius 65μm at the surface and a depth of 5m.

A complex situation arises when considering an ensemble of bubbles of various radii distributed throughout the water column. The presence of the hydrostatic pressure term p_b in eq. 2 implies that two microbubbles with the same radius created or existing at two different depths will have different oscillational responses. This effect is illustrated in Figure 5 where the extinction cross section is different for two microbubbles of the same radius at different depths. Off resonant losses are also significant for broadband transmission and the evaluation of the total extinction cross section S_e at a particular depth is solved by the integration of all extinction cross sections over the probable density distribution of bubbles (Medwin 1970):

$$S_e(z) = \int_{r=r_{min}}^{r=r_{max}} \sigma(a,z)\,n(a,z)\,da \quad \text{eq. 4}$$

where n(a,z) is the density of bubbles with radii over radius increment da (usually taken as 1μm) at depth z. The radial limits r_{min} and r_{max} are chosen to cover the full range of observed bubble populations. There is a wide variation in reported bubble densities (Wu 1981, Phelps & Leighton 1998) and in the absence of reported observations for very shallow coastal waters we choose to employ the bubble density population estimates used by Weston 1989. Weston quotes the number of bubbles per cubic metre within the spread of radii da at depth z as:

$$n(a,z) = 1.25\times10^{-2} p(a)\, W^3\, e^{\frac{-z}{1.2}} \quad \text{eq. 5}$$

where W is the wind velocity at 10m height and p(a) is the normalised probability density function. We refer you to Weston 1989 for the numbers specifying the probability distribution. Instead, we show our results in Figure 6 of the expected bubbles densities for the radii range 20μm to 0.01m over depth for wind speeds of 20 km h^{-1} and 60 km h^{-1}. The wind speeds are chosen to reflect the meteorological conditions for the stranding events of 02/06/05 and 03/04/05 respectively.

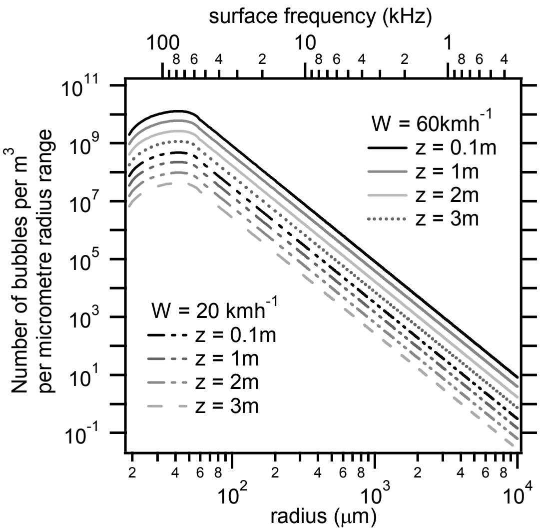

Figure 6: A plot of the bubble size distribution as a function of depth and wind strength to be used in the stranding model. The corresponding surface frequency is provided as a reference.

The attenuation coefficient α_B for bubbles at particular depth is calculated by (Medwin 1970):

$$\alpha_B(z) = 4.34 S_e(z) \qquad \text{eq. 6}$$

Using expected winter temperature and salinity values of 16°C and 35‰ respectively for Geographe Bay the results of the attenuation due to bubbles to be used in a sonar termination model, based on expected bubbles densities (Figure 6), is shown in Figure 7.

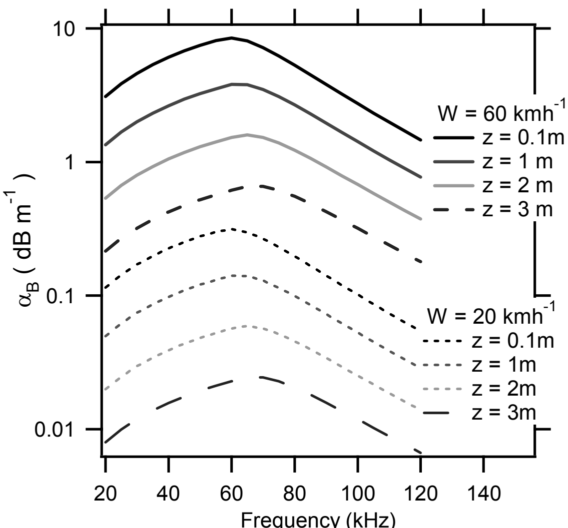

Figure 7: Attenuation due to bubbles α_B (dB m^{-1}) at for two different wind speeds, 20 kmh^{-1} and 60 kmh^{-1} . Calculated from expected coastal bubble densities (Weston 1989)

Sonar termination model

For an ideal wedge shaped coast, the detection condition for a cetacean placed offshore with dynamic range R is:

$$R \geq 20\log D + D\alpha_W + L_S + L_B + L_{BD} \qquad \text{eq. 7}$$

where D is the path length travelled by the echolocation click, α_W the attenuation coefficient due to ionic absorption in seawater, L_S and L_B the losses due to sea surface and sea bottom reflections, taking into account the variation in grazing angle, and L_{BD} the loss due to suspended microbubbles in the water column integrated over the path length. We have followed Weston 1983 in representing the reflection loss coefficient as a sinusoidal function of the grazing angle.

We define the parameter: minimum detection distance - d_{min}, which is the distance at which a cetacean is able to detect the presence of a shoreline. For our purposes the presence of a shoreline is deemed detected when the reflections arriving from within a location of minimum depth z_{lim} of 1m are received (shown in Figure 4). At this depth the cetacean is at great risk of stranding or may have already stranded. For very low slope beaches this location may be a considerable distance from the actual shoreline. The minimum detection distance is calculated by first evaluating the sonar condition (eq.7) for reflections arriving from within the minimum depth for an emission distance d offshore. If the condition is false and reflections arrive from within a minimum depth with a signal level below the cetacean's dynamic range, the presence of the shoreline is not detected, the distance d offshore is incrementally reduced by an amount dx and the sonar equation is re-evaluated. The minimum detection distance is obtained by repeating this process until the sonar condition is satisfied.

The results for the minimum detection distance as a function of frequency for an expected stranding shore slope of 0.5° and a shore slope of 5°, where a mass stranding is not expected, is shown in Figure 8. Our calculations employ the dynamic range function of a *Pseudorca crassidens* (Figure 3) and the expected microbubble population densities for 20 and 60 kmh^{-1} wind speeds (Figure 6). We have chosen to omit the surface loss coefficient L_S in our model as loss in the surface layer is predominantly caused by bubbles which are already accounted for. We have also applied a range of bottom loss coefficient (B) values from 0 to 15 dB per reflection to allow for a range of bottom types and to illustrate the sensitivity of the model to reflection loss.

The detrimental effect of microbubbles can be seen in Figures 8(a) and (b) on the successful detection of a shoreline of depth 1m. The microbubbles are most dense in the 30-60 micron range (Figure 6), which corresponds to surface frequencies within the specified dynamic range of a *Pseudorca crassidens*. The integration of all extinction cross sections results in a combined attenuative effect of microbubbles that is a maximum between 50-70 kHz for depths 0.1-3m (Figure 7). A typical echolocation click from a *Pseudorca crassidens* comprises of frequency components usually between 10-170 kHz, with a peak signal energy centred between 30-45 kHz, and a 3dB bandwidth of 39 kHz (Randall et al. 1992). The results suggest that microbubbles will band limit a large amount of the peak signal energy of an echolocation click and some frequency components may be detected whilst some critical frequency components will be missed for a particular distance offshore. This band limiting is most evident for higher bubble densities regardless of the slope (Figures 8(b), (d)) where a dip in the minimum detection distance is observed within the bandwidth where bubbles are most attenuative. A slight dip can also be observed in the slope of low angle with low bubble density (Figure 8(a)) and can be explained by the fact that the signal path for such a low angle slope will spend more of its time in the upper surface layer where the density of bubbles is greater. The presence of microbubbles in the water column should therefore have a significant effect on the echolocating abilities of a *Pseudorca crassidens*.

The sensitivity to reflection loss for a slope when compared to a 5° slope is self evident in Figures 8(a) and (c). Regardless of the bubble density the introduction of a sea bottom reflection loss at a low angle beach of 0.5° reduces the detection distance to near zero or zero for all frequencies and may sufficiently mask the presence of a shoreline to a cetacean. Figures 8(c) and (d) illustrate that the detection of a 5° slope is more robust to reflection loss than that of 0.5°. This result is expected as the number of reflections for a slope of 0.5° is far greater than that of a 5° slope. These results indicate that detection of a shoreline of a 5° slope will most likely always occur and this may explain the non-occurrence of mass cetacean strandings at shores of large angle.

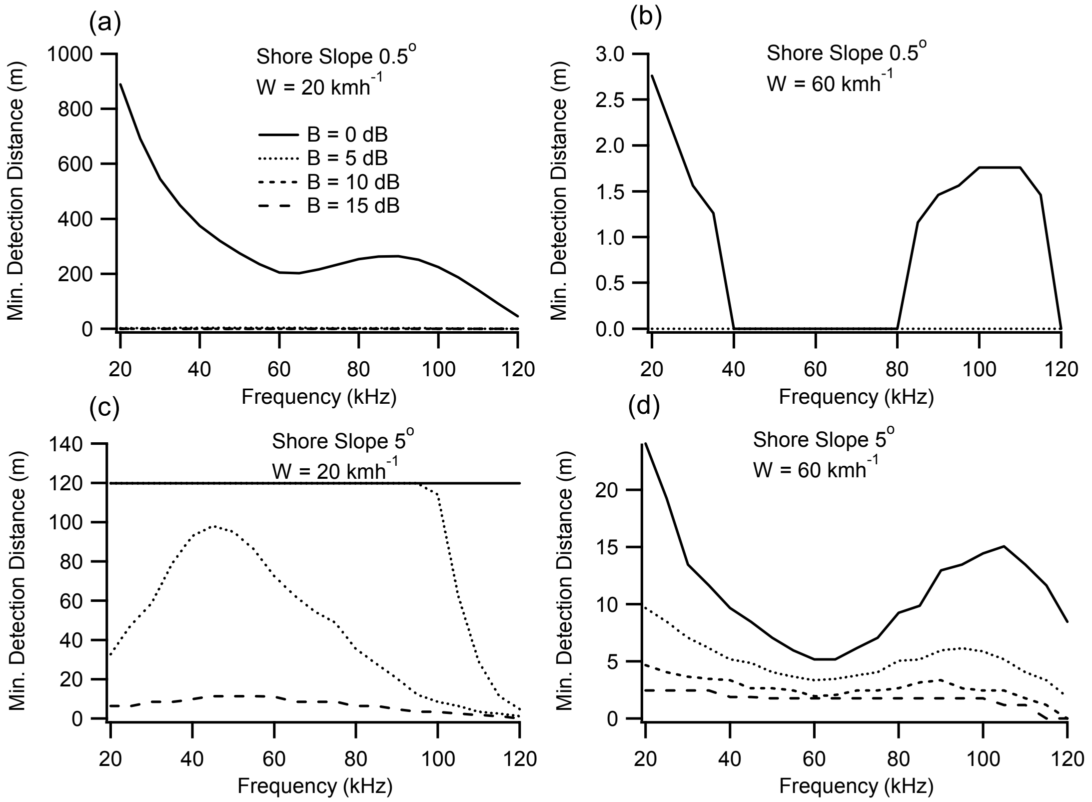

Figure 8: Minimum detection distance of a shore depth of 1m for shore slope angles of 0.5° and 5° for bubble density populations occurring at wind speeds 20 and 60 kmh^{-1}.

Discussion

In modelling the stranding scenario we have approximated the cetacean as a point source with a frequency dependent dynamic range R between 20-120 kHz. The beach has also been modelled as a perfectly flat reflector. A mass stranding event is a complex mechanism and when accurately modelled the social and psychoacoustic characteristics of a cetacean herd and detailed coastal acoustics of a stranding site must also be considered. By omitting such factors we have presented a 'best case' scenario of a stranding event. A stranding site is rarely a perfectly flat reflector. The sea bottom and sea floor are highly irregular with only an *average* gentle slope. Reflection loss and acoustic backscatter vary. The water column at a coastal site is in constant changing flux, and the varying age and health of each particular cetacean within a herd and transient levels of ambient noise will affect the dynamic range function employed in this study. We have also employed observed coastal bubble population densities that have been measured in deeper waters and measurements of near shore bubble populations are further warranted. We believe the addition of such complex parameters into our model will more than likely result in a reduction of the minimum detection distance of the shoreline. It must also be emphasised that our simple model only gives an indication of the detrimental effects of acoustic propagation and long range target detection over gently sloping beaches. In situ measurements for stranding locations are required to account for the previously suggested complexities and substantially verify this phenomenon. The model we have presented may however be sufficient to account for the stranding events of 03/04/05 and 02/06/05. The presence of pelagic cetaceans in Geographe Bay, due to the influence of the oceanography of the region, that are not familiar with the coastline is required for a stranding to take place. Once this condition is satisfied active detection of the coastline is adversely affected by the large reflection loss due to the gently sloping bathymetry. Both stranding events were preceded by sufficient microbubble generating mechanisms and residual microbubbles in the water column further adversely affected cetacean active echolocation. The results of the model in this study illustrate the combined effect of both reflection loss and microbubble attenuation that will most likely mask the presence of a shoreline to a herd of cetaceans or degrade the signal to a point where a navigational error may occur as a consequence. Weather conditions were also calm during both strandings and the absence of swell and coastline noise affect a cetacean's passive detection system by not alerting the cetacean to the presence of a shoreline. All these factors suggest a dire situation for a herd of cetaceans swimming offshore at Geographe Bay and it is likely that such factors played a role in the onset of the strandings of the 03/04/05 and 02/06/05.

Reflection loss and microbubbles alone may be sufficient to explain the occurrence of either stranding event, however, it must be noted that the second stranding event involved an animal with a high parasitic loading. It is possible that the herd may have succumbed to the proposed stranding mechanism in an altruistic attempt to assist a sick and disorientated member of the herd. This sick member may have already stranded as a consequence of being at greater risk of succumbing to the stranding mechanism due to ill health decreasing its dynamic range.

Conclusion

This study aimed to determine if sonar termination was a relevant factor in the cause of the most recent mass cetacean strandings occurring at Geographe Bay, Western Australia on the 03/04/05 and the 02/06/05. By treating the strandings from an entirely bioacoustic perspective a cetacean has been modelled as an acoustically emitting point source with a species specific dynamic range. The shore has been approximated as a wedge waveguide of low angle with perfectly flat reflecting surfaces. The propagation of an acoustic signal, from a point source offshore, from emission to reception has been analysed and an integrated bottom loss that is a function of the grazing angle has been numerically calculated. The attenuative effect of microbubbles on a Western Australian stranding species, *Pseudorca crassidens,* has also been calculated by employing past observational models of wind dependent shallow water coastal bubble densities. It was found that for this particular coastal region microbubbles are most attenuative within the 50-70 kHz bandwidth which corresponds to the optimum dynamic range of this particular cetacean. A minimum detection distance of a shoreline (of a critical depth of 1m) has been derived in a model that combines losses from reflections and microbubbles for a typical Geographe Bay slope of 0.5°, and a slope of 5° where strandings have not been observed to occur. Results of the calculation of the minimum detection distance indicate that detection of a shore of slope 5° is possible at a safe distance from the shoreline when accounting for wind dependent bubble populations at wind speeds of 20 and 60 km h^{-1} and reflection losses up to 15dB per reflection. A shore of slope 0.5° under similar conditions however is sufficiently masked and this can be attributed to the higher number of reflections the signal suffers during transit and the path the signal travels through a coastal population of microbubbles.

While acknowledging there are other factors and mechanisms that may have a role in a stranding, our results suggest that the mass stranding of the 03/04/05 may have occurred due to the combined presence of a high population density of microbubbles after stormy conditions and the large reflection loss associated with the bay. The mass stranding of 02/06/05 may be the result of a similar mechanism combined with the initial stranding of a sick member of the cetacean herd.

The proposed model is only a simplified indication of the effect of sonar termination and its role in mass cetacean strandings. Verification of such a phenomenon experimentally in situ is needed to sufficiently explain this bioacoustic mechanism and is planned to take place in the near future.

Acknowledgements

The authors would like to thank Simon Woodings for his earlier work on this research, David Mell, Doug Cochrane, and Mark Pittavino from the Department of Conservation and Land Management Western Australia for their past and ongoing assistance with this project, Mandar Chitre and Dr. Matthias Hoffmann-Kuhnt from the Acoustic Research Laboratory, National University of Singapore for their ongoing collaboration and Dr. Kate Gregory and Dr. Richard Yin for making various aspects and logistics of this research possible.

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