Sharing the waters: minimising ship collisions with Bryde's whales in the Hauraki Gulf

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Research Progress Report
February 2012

Executive summary

The Hauraki Gulf holds one of the few resident populations of Bryde's whale known in the world and this whale has become one of the iconic animals of the Gulf. There is little known about the Bryde's whales of the Gulf and the only study on population size performed to date estimates around 46 resident and 159 transient whales. Ship strikes have been identified as the main cause of mortality for these long-lived whales in the Gulf. The actual collision rate is unknown, because strikes frequently go unnoticed by the ships' crew, whales may not die immediately or not strand after the collision, and carcasses may not show external signs of impact, which are uncovered only after a full necropsy to reveal broken bones and/or internal haemorrhages. In total, just under half (44%) of all recovered Bryde's whale carcasses have information to determine cause of death, and of these 83% have been attributed to ship strikes. This high rate of ship-related mortality might not be sustainable for the local population, mainly because resident whales in the Gulf are those with a higher probability of collision in the high ship-use area of the inner Gulf. This has raised concern and stimulated an effort to study whale behaviour to determine what makes them vulnerable to collisions. These results will be used to base mitigation measures to reduce the whales' collision risk and ensure a healthy population of whales in the Gulf.

Here we used multi-sensor d-tags attached with suction cups to the back of the whales to investigate subsurface behaviour. Seven tag deployments resulted in nearly 63 hours of detailed movement and acoustic recordings. Whales foraged both at the surface and underwater, performing dives up to 55 m in depth and 9 min long, although the majority were <10 m deep and 2 min long. Tag data and visual observations showed that whales often stayed foraging in a relatively small area for many hours but could also travel at fast speeds and become difficult to locate. Overall the whales spent more than 90% of their time between the surface and a depth of 12 m. This range overlaps with the draught of ships entering Auckland Harbour putting these whales in the collision zone with respect to depth. Furthermore, the whales were less active and closer to the surface at night likely reflecting resting behaviour, making them more vulnerable to ship-strike. The acoustic record showed that whales emit down-sweeps and moans, but their vocalisation rate is low at least during the period of the study, suggesting acoustic warning techniques would likely not be viable.

Bryde's whales are present in the Gulf year-round and their preferred habitat directly overlaps with ships transiting into the Ports of Auckland. Therefore, considering possible courses of action based on international examples, we suggest speed restrictions to shipping as the optimal way to reduce whale mortality from ship-strike in the Gulf. Based on international research, a maximum speed of 10 knots would reduce the risk of whale death from ship-strike to 25%. In addition mandatory reporting of whale sightings would increase awareness of their presence. As international shipping companies are familiar with similar whale protection zones and practices elsewhere, endorsement of speed restrictions by the International Maritime Organisation, in addition to national and local legal frameworks would ensure efficient implementation of these urgently needed whale conservation measures within the Hauraki Gulf.

Contents **Page**

List of figures

Acknowledgements

This research was generously funded by the Auckland Regional Council Coastal Enhancement Fund, University of Auckland Faculty Research Development Fund, Department of Conservation Hauraki Gulf Marine Mammal Fund, Marie Curie Post-Doctoral Fellowship from the 7th European Frame Program (to NAS), Foundation for Research Science and Technology ISAT Grant.

It took a dedicated team of people helping tag whales, collect the data and handle logistics, so many thanks in particular to Brady Doak, Peter Browne, Arthur Cozens, Angela Little, Peter Crabb, Emily Duder, Murray Birch, John Montgomery, Emma Carroll, Liz Collison, Lily Kozmian-Ledward, Liz Hartel, Dan Engelhaupt, Matt Pine, Cat Davis, Brendan Hall, Dave Jenkinson (UoA), Phil Brown, Martin Stanley, Callum Bourke (DOC).

Finally thank you to the Hauraki Forum, in particular Tim Higham for ongoing support, William Goodfellow, Andy Light & Jo Logan from Explore NZ, and to David Wiley (SBNMS – NOAA), Michael Moore (WHOI), Mason Weinrich (Whale Center of New England), Steph Behrens (Zoo Aquarium Assn) and Stuart Hunter (Massey University) for valuable research discussions about the issue of whales and vessel-strike.

Research was conducted under a DOC permit PER/02/2009/01 and University of Auckland Animal Ethics permits AEC 03/2008/R636 & 910 issued to RC.

Cover: Bryde's whale lunge-feeding (Steph Behrens photo) and a dead, ship-struck male Bryde's whale examined on Motutapu Island, February 2007 (Rochelle Constantine photo).

1. Background and research objectives

The Bryde's whale is a 13 – 15 m long species of baleen whale discontinuously distributed throughout the warm-temperate and tropical waters of the Pacific, Indian and Atlantic Oceans. Unlike other whales they do not undertake a polar migration, instead preferring the warmer waters between 40°N and 40°S. There are only a few places where Bryde’s whales are frequently sighted, and the Hauraki Gulf and coastal Northland region holds one of only a few known resident populations in the world.

Currently, there is little known about the whales' habitat use and distribution throughout New Zealand waters and, under the New Zealand Threatened Species Classification System, they are listed as Nationally Critical due to their limited distribution and low population size (Baker et al. 2010). They are regularly sighted year-round in the Hauraki Gulf primarily bordered by Little Barrier and Great Barrier Islands, Coromandel and the mainland, with fewer sightings north of Little Barrier Island; a consistent pattern observed since research began (O’Callaghan & Baker 2002, Thompson et al. 2002, Baker & Madon 2007, Behrens 2009, Wiseman 2011). Bryde’s whales range along the coast with several individuals from the Hauraki Gulf seen near the Bay of Islands, and it is likely that they travel offshore from New Zealand into other waters. The residency patterns of Bryde’s whales in the Hauraki Gulf vary, with some whales sighted frequently over several years and others only seen once. To determine the number of whales using this area, two models were used; one that accounts for the possibilty that the population size can change throughout the study (an open model) and one that assumes no movement in or out of the study area (a closed model). These have different biases but both models help us understand the dynamic nature of the Hauraki Gulf Bryde’s whale population. An open estimate of abundance from 2003-2006 found 46 (CV = 0.08) whales per annum and a closed estimate found 159 (CV = 0.35) whales for the three year period (Wiseman 2008). These estimates covered the region with the most frequent sightings of whales within the Gulf so do not represent the population estimate for the entire New Zealand population; this currently remains unknown. Extensive coastal surveys of northern NZ have highlighted the Hauraki Gulf as the area with a consistently high likelihood of sighting of whales so the estimates represent an important habitat for the species (Baker & Madon 2007, Behrens 2009).

Vessel strike is a significant cause of death to cetaceans around the world with 11 species known to have died due to collisions with vessels (Laist et al. 2001, Douglas et al. 2008, Van Waerebeek et al. 2008). The population-level effects are difficult to quantify as there is often a lack of demographic data on the whales and the occurrence of vessel strikes are either undetected or not reported. It is well recognised that current records of vessel-strike mortality are an underestimate with only 17% of strike reported in some areas (Kraus et al. 2005). The increasing number of reported vessel strikes is attributed to an increase in the number, size and speed of vessels passing through whale habitat and better incident reporting (Laist et al. 2001, Weinrich et al. 2005, Douglas et al. 2008). The growth in some whale populations since the end of large-scale commercial whaling is also a contributing factor in some locations.

Over the past decade it became apparent that Bryde’s whales in the Hauraki Gulf region may be vulnerable to vessel strike (Wiseman et al. 2003), but it wasn’t until 2009 that a comprehensive assessment of the number and possible causes of mortality resulted in the extent of the problem being understood (Behrens 2009). Today it is clear that the majority of dead whales in the region are Bryde’s whales and that vessel-strike is the predominant cause of whale mortality in the Gulf. The first vessel-struck Bryde’s whale was reported in the Gulf in 1996 and up until January 2012, a total of 41 whales have been found dead, with a further three reported dead but their carcasses not recovered. Of the 41 whales, only 18 had sufficient data collected to assign the definite or probable cause of death with 15 (83%) whales where vessel-strike was the most likely cause of death. This follows a pattern seen overseas with vessel-strike assigned as one of the major causes of mortality of several species of large whale (Laist et al. 2001, Panigada et al. 2006, Douglas et al. 2008). An assessment of whale presence, overlaid on a schematic representation of the main areas of ship and other vessel usage, shows that Bryde’s whales favour waters where ships mainly transit to the Ports of Auckland and also ferries travel between Auckland, Great Barrier Island and Coromandel (Figure 1).

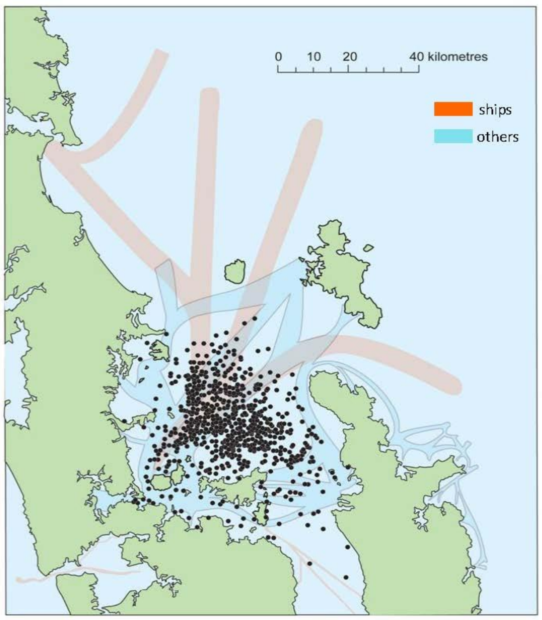

Figure 1. Sightings of Bryde’s whales from 2000-2008 (Explore NZ data) and areas of likely vessel traffic movement (ARC image). Figure modified from Behrens (2009).

With the knowledge that preferred whale habitat overlapped directly with the main shipping routes to Auckland, we initiated a research project with the aim of understanding Bryde’s whale sub-surface behaviour to determine why they are vulnerable to vessel-strike. The d-tag (Johnson & Tyack 2003) is a recoverable instrument, attached by suction-cups, that records short-term high-definition data about the movements and acoustic environment of the whales. To achieve this, the tag has a suite of 3-D motion, time and depth sensors recording at a rate of 50 Hz and two broadband hydrophones sampling at 96 kHz. The hydrophones record sound ranging from the low frequency vocalisations of the whales (tens of hertz) to ultrasounds up to 45 kHz.

Here we report the results of our research using d- tags to address the following three objectives:

1. Quantify behavioural parameters affecting collision risk, such as time spent at collision depth and activity budgets of the whales.
2. Describe daily patterns in whale behaviour that may affect the probability of collision.
3. Investigate the feasibility of passive acoustic detection of Bryde's whales to minimise collision risk (using vocalisation rates) in the context of the acoustic environment of the Hauraki Gulf and the potential for masking from shipping.

We need to know what makes Bryde's whales vulnerable to vessel strike. This knowledge will enable us to provide managers, and recreational and commercial vessel operators guidance about how to minimise whale mortality and protect this vulnerable, resident population of whales in the Hauraki Gulf.

2. Methods

Fieldwork

We conducted surveys from the *RV Hawere*, the Leigh Marine Laboratory (UOA) 17m research vessel, departing from Ti Point on days with sea-states less than Beaufort 3, but ideally Beaufort 1. Observers scanned for whales, dolphins, birds and fish aggregations. When a whale was sighted it was approached slowly and group composition was determined (i.e., calves present or absent) and the behavioural state was assessed. If the group contained no calves and was moving slowly throughout an area a small rigid-hull inflatable boat (RIB) was launched from the *Hawere*. Initially we used a 4.5 m RIB with a 30 hp 2-stroke engine but this was not ideal for tag-deployment as we needed to approach the whales rapidly and as silently as possible as they surfaced. In August 2011 we started using DOCs 5 m RIB *Tangihua*, with a 60 hp 4-stroke engine which was a more appropriate vessel for tagging. On one occasion (22 August 2011) whales were observed very near the coast of Leigh and a tag was deployed from a Leigh Marine Laboratory 4.5 m RIB with a 60 hp 4-stroke engine. Once the tag-boat was deployed, observers onboard the *Hawere* guided it to the whales and provided instructions about whale movements and location which were entered into the computer to try and determine surfacing patterns. When a whale was close enough the tag boat increased speed to match the whales' speed and direction and as the whale surfaced the tag was placed on its back from the end of a 6 m carbon fibre pole (Figure 2). The pressure of the pole movement was sufficient for the four suction-cups to attach to the whale and remain attached for just over 20 hrs.

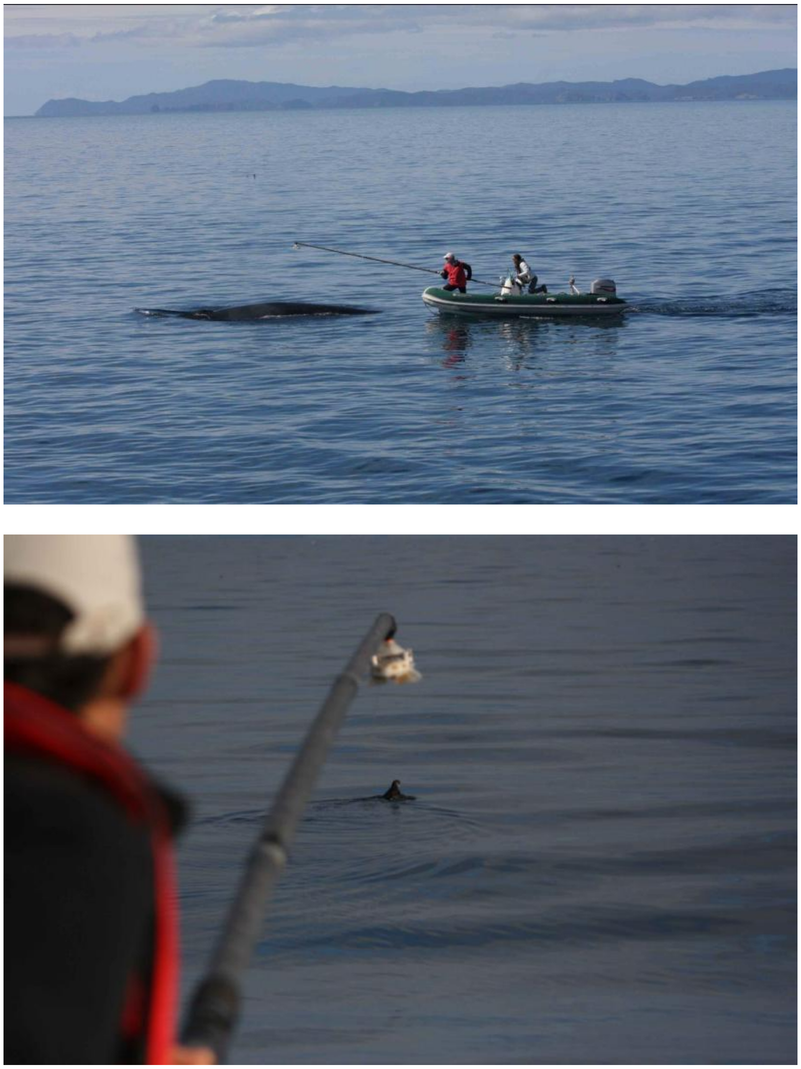

Figure 2. Top: Boat approach to a whale with pole deployed from the front of the vessel. Bottom: The tagging pole with the d-tag attached to the end. R. Constantine & N. Aguilar photos.

Once the tag was successfully deployed, the tag boat returned to the *Hawere* and we collected data on surfacing intervals, respiration rates, surface behaviour (e.g., lunges, chin-slaps, travelling, resting), associations with other cetaceans or birds and proximity to prey aggregations. A photograph was taken of the location of the tag on the whale to allow calibration of the tags' magnetometers and accelerometers (Figure 3), and if the whale had not already been photo-identified by marks on its dorsal fin, it was approached for photo-identification purposes. Typically after a period of a few hours of behavioural observations, we left the whale and the tag release was monitored from a hill on the mainland via VHF transmissions from the tag as the whale surfaced. When the tag detached, it was retrieved by the researchers onboard the *Hawere* and the data were downloaded onto a computer for analysis, the tag was recharged and prepared for the next deployment.

Figure 3. Tag whetu deployed on the right dorsal side of a Bryde's whale, 28th September 2011. R. Constantine photo.

Data analysis

Analyses were conducted using *Matlab* (Mathworks), *Raven* (Cornell Lab of Ornithology) and *R* (The R Foundation for Statistics) software. Sensor data recorded at 50 Hz were decimated to 5 Hz for analysis of depth and whale orientation. A method was developed to extract pitch, roll and heading of the whales, correcting for the position of the tag on the body of the whale (Figure 3). The jerk (acceleration rate) of the whales was calculated with sensor data decimated to 25 Hz. Jerk was used as an indicator of the movement rate of the whales, and high jerk levels interpreted as lunge events. A further indicator of the activity of the whales is the low frequency flow noise of the water over the tag, which increases with speed.

The acoustic recordings were analysed to describe the environmental sounds the whales were exposed to (biological and anthropogenic components) and to determine the frequency and type of whale vocalisations. Full bandwidth recordings and decimated wavs (to 8 and 2 kHz Fs) were inspected by scrolling spectrograms and by listening to sections of interest. In addition, 10 s every 2 min of the 96 kHz wavs were routinely listened to and scored for ship noise presence and other sounds.

3. Results

Summary of survey and tag data

From 9th April 2010 - 28th September 2011 we departed from Ti Point and non-systematically surveyed the Hauraki Gulf until we located Bryde's whales. A total of 66 groups of Bryde's whales were sighted for a cumulative total of 83 individuals including five mother-calf pairs (note that whilst efforts were made to minimise encountering groups more than once, this was not always possible so these counts are cumulative). The average group size was 1.3 whales (SE = 0.07, range 1-3, n = 66) although we often saw a number of whales spread throughout the area where we tagged whales. Seven tags were deployed on six individual whales (tag deployments rua and toru were on the same whale - Table 1) for a total of 62 hrs 36 mins of recordings. Tag deployment time ranged from 12 mins to 20 hrs 14 mins. Three whales had distinctive fins accompanied by photographs of sufficient quality to match to the Bryde's whale catalogue (curated at UOA). Of these three whales, two were already catalogued (Table 1).

Table 1. Summary of tag and whale data.

Date	Tag	Tag start	Tag end	Total time (hh:mm)	Whale ID	1st sighted
1 Aug 2011	tahi	12:57	13:20	0:23	Poor image	-
9 Aug 2011	rua	14:22	14:34	0:12	HG023	May 2003
9-10 Aug 2011	toru	14:51	11:05	20:14	HG023	May 2003
21 Aug 2011	wha	11:18	23:58	12:40	No nicks	-
26-27 Aug 2011	rima	10:54	6:13	19:19	No nicks	-
27 Sep 2011	ono	11:07	14:23	3:16	HG045	Aug 2004
28 Sept 2011	whetu	15:25	21:58	6:33	New	-

Dive profiles

Examples of the dive profiles recorded in the longest tag deployments are shown in Figure 4. Bryde's whales are active animals that concentrate their activity in the upper water layer, most often within one or two body lengths from the surface. Tagged whales were never observed resting by logging at the surface, as is typical in other species, but dove nearly continuously and were routinely engaged in surface foraging.

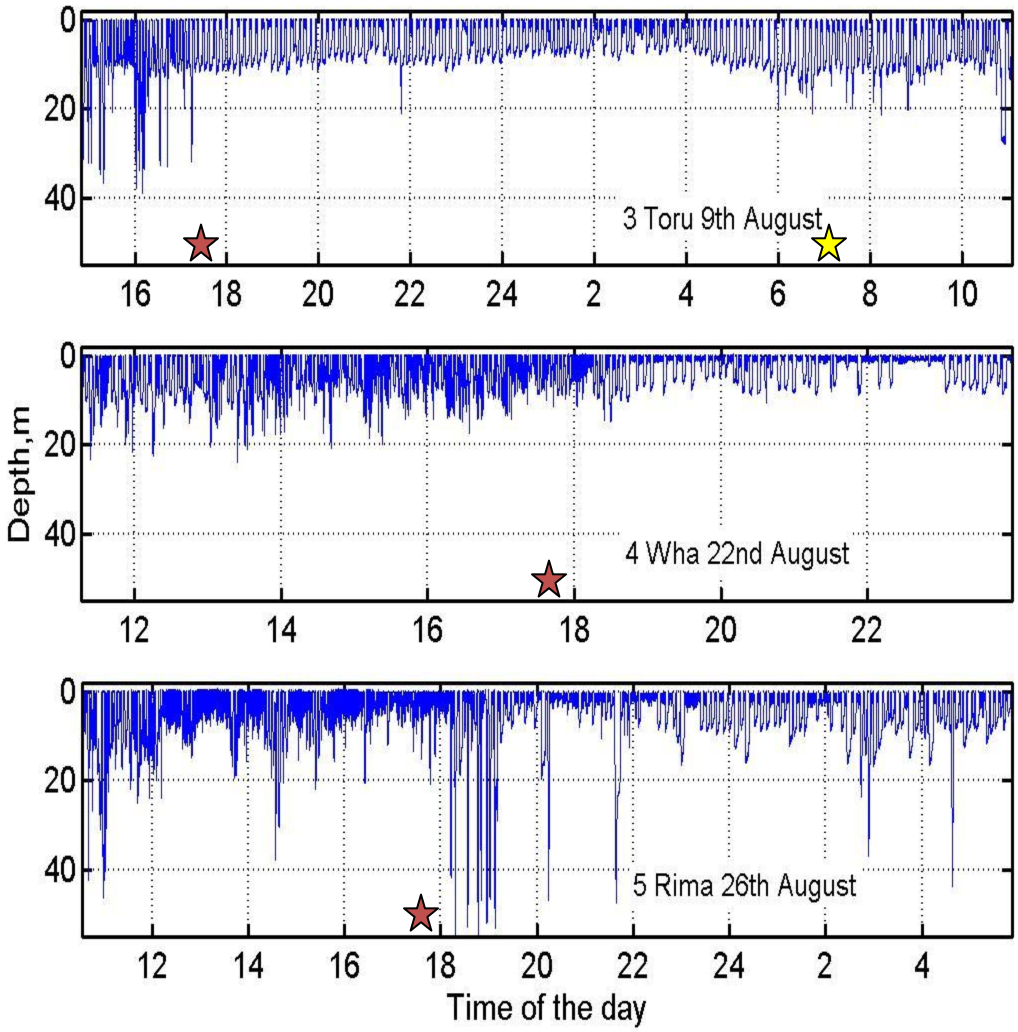

Figure 4. Example dive profiles of three tagged Bryde's whales. Time of sunset is denoted by the red star and sunrise (tag toru only) denoted by the yellow star.

Whales spent most of their time within approximately one adult body length from the surface. Despite being so close to the surface, whales performed a variety of activities, such as breathing, traveling, resting and foraging. To differentiate simple body movements related to breathing from purposeful dives we defined a threshold at 2 m depth. Events when the whales left the surface and reached <2 m depth were considered to be part of their surface respiration bouts, while “dives” were defined as reaching >2 m depth. This shallow threshold was selected because whales often made foraging dives very close to the surface. The majority (83%) of the dives were <10 m depth (Figure 5), with a mean of 6.6 m and a maximum of 55 m.

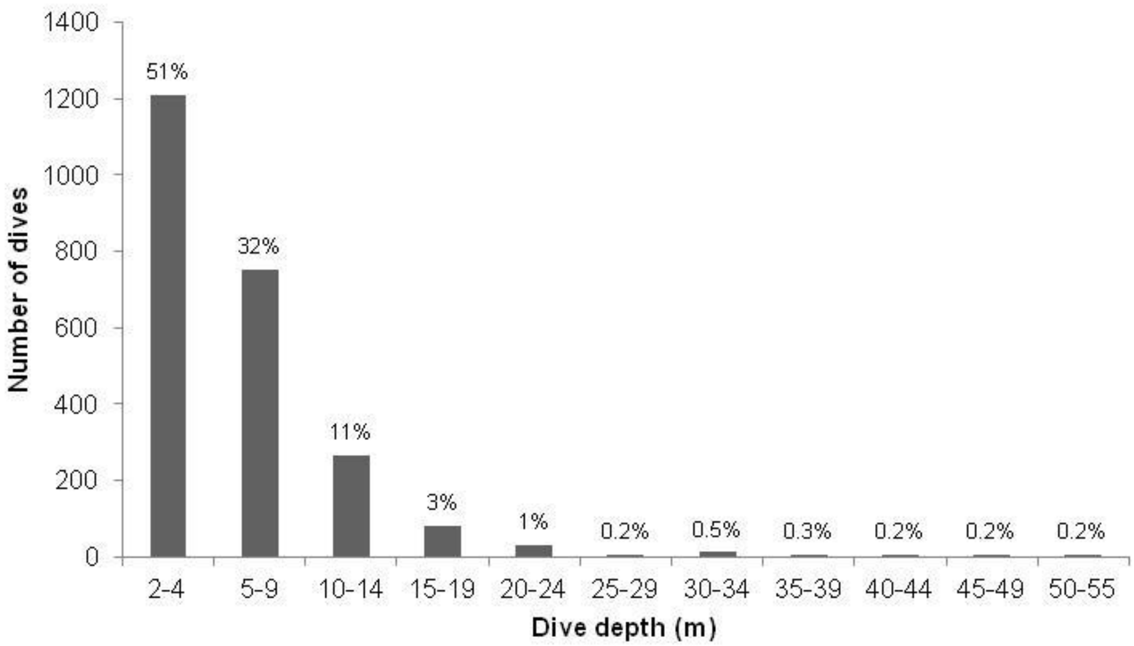

Figure 5. Total number of dives below the surface (2m+ dives) and dive depth for all tag data exceeding one hour duration (n = 5). Percent of total dives shown above the bars.

Dives lasted up to 9 min but were on average much shorter (1 min). There was a tendency for deeper dives to be longer but this does not hold for the deepest dives. These were generally less than 5 min long, while medium depth dives around 20 m deep were the longest of the dataset (Figure 6). The distribution of dive depth was significantly different for each of the four whales where the tag was attached to the whale allowing day and night recordings (Kolmogorov-Smirnov p = 0.00 in all cases). Pooling all data, daytime dives tended to be deeper than nighttime dives, with a significant difference (t = 6.85, p = <0.0001) in dive-depth during the day (average ± S.E. = 7.3 ± 0.14 m) and night (average ± S.E. = 5.5 ± 0.22 m). In contrast, daytime dives tended to be shorter than nighttime dives (average = 1 min and 1.4 min respectively, Figure 6) although the differences were not significant.

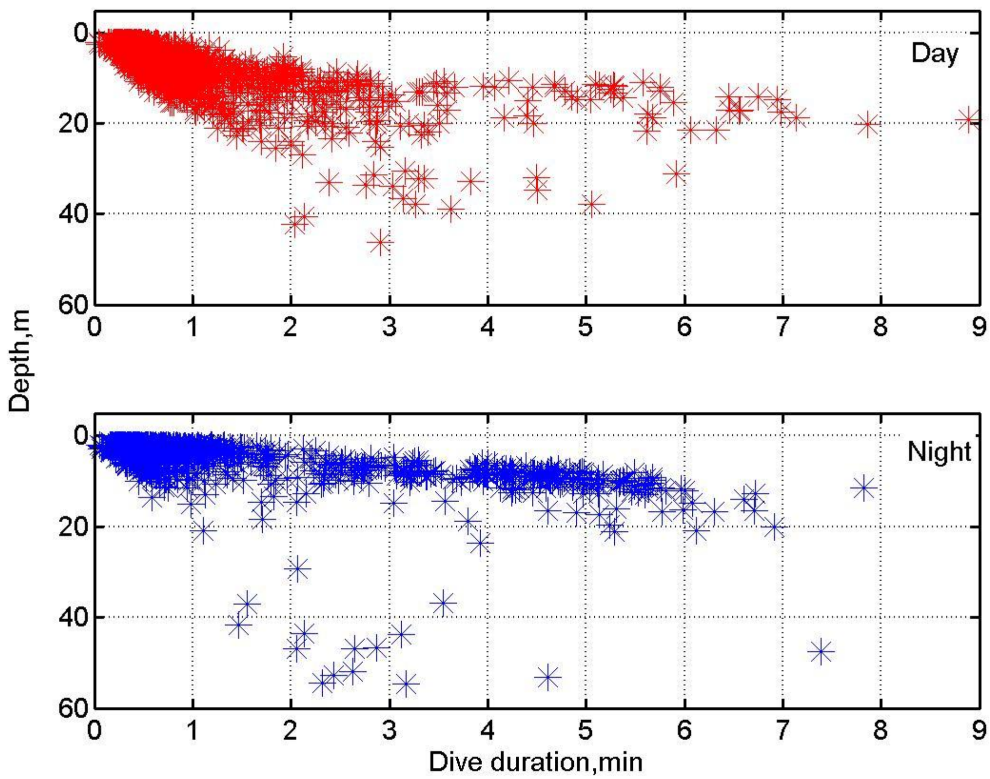

Figure 6. Relation between dive depth and dive duration for dives performed during the day (top, red) and at night (bottom, blue). Day and night periods were defined by official sunset and sunrise times

An important factor affecting collision risk is the time spent by the whales in the collision zone, defined both by the presence of vessels and by the depth of the hull or draught. The Ports of Auckland can accommodate ships with draughts up to 12.5 m with the majority of ships' draughts around 8-9 m in depth. Figure 7 provides a breakdown of the time spent by the whales at different depths during the tag recordings, showing that whales are in the collision depth range for large vessels over 90% of the time.

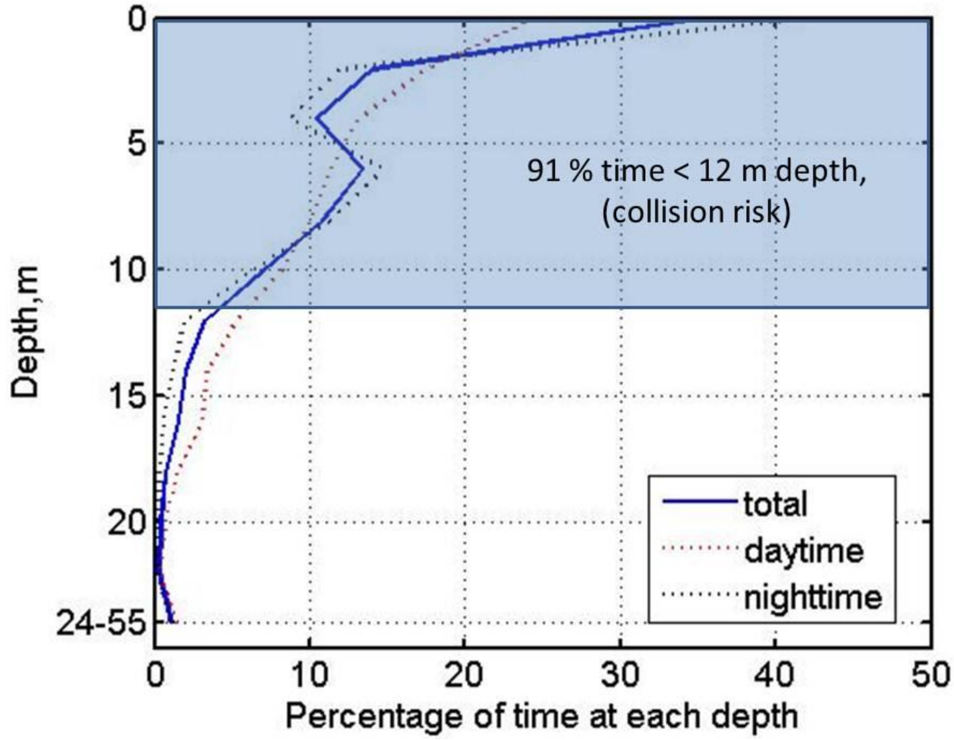

Figure 7. Time budget of the tagged whales at different dive depths, showing that whales spend more than 90% of their time within the collision risk zone

Patterns of behaviour

The whales' behaviour was measured using the depth, movement and acoustic data as indicators of activity. Foraging can take place both underwater and at the surface and distinguishing surfacings to breathe from surface lunges typically associated with foraging behaviour is not possible based solely on depth data. We are currently investigating the use of two further layers of information: i) the 3-axial acceleration of the whales and the cumulative acceleration rate (jerk) and, ii) the low frequency sound level in the tag, related to the flow noise of the water over the tag, which increases with the speed of the whale (Aguilar Soto et al. 2008). The jerk and flow noise indicate independently the occurrence of underwater lunges, which show also as stereotyped movements in the dive profile (Figure 8). Based on this, we are currently using the jerk and the flow noise to identify and describe foraging activity of the whales.

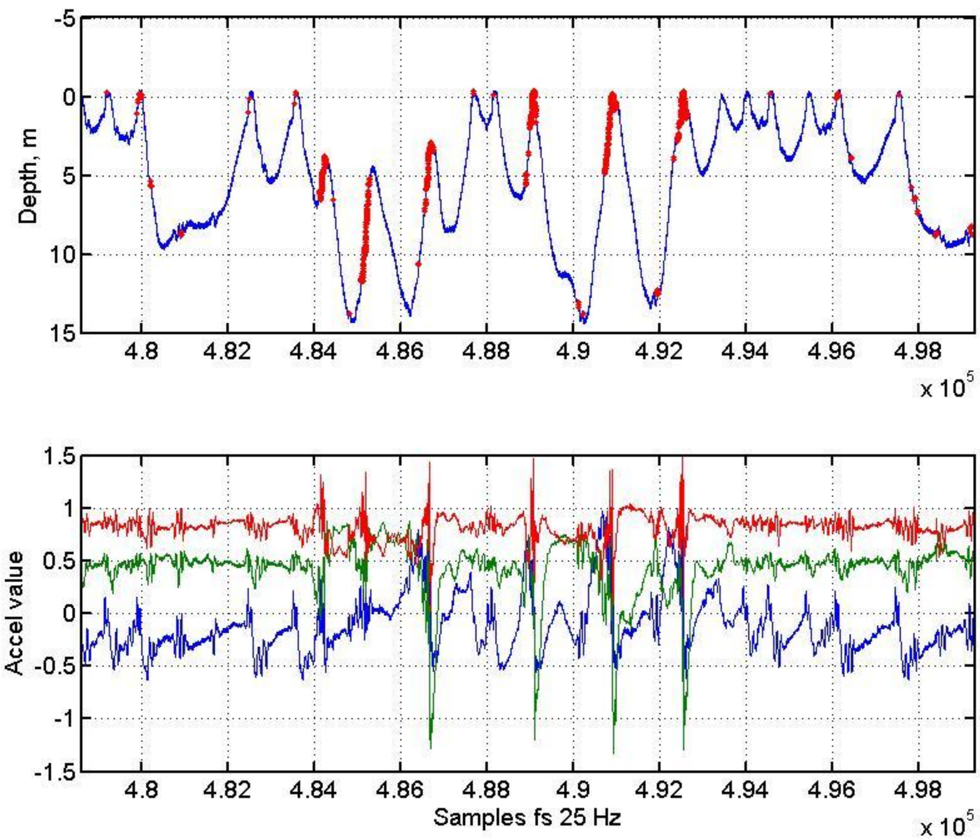

Figure 8. Example of a section of the dive profile of tag wha. The upper panel shows the dive profile in blue and events of high acceleration rate (jerk) in red, interpreted as lunges. The lower panel shows the 3-axis accelerometer values, indicative of the roll, pitch and heading of the whale, with strong peaks (changes in orientation) coinciding with the lunges.

Whales spent most of the day foraging. Flow noise tended to be lower at night, suggesting that the whales were resting more during this period. Resting did not involve logging at the surface as seen in other whales (e.g., sperm whales) but instead they engaged in slow dives to shallow depths well within the collision zone.

The behaviour of the whales differed during the day and night. Although at night there were some lunging dives, including the deepest dive recorded in the data set, in general the whales tended to perform fewer accelerations and reduced their speed, indicated by an overall reduction in the flow noise (t-test $p = 0.00$ for the four whales with day/night recording, comparing both jerk and flow noise data during day and night time). There are two possible but not mutually exclusive explanations for this nighttime pattern of activity: i) the whales are resting; ii) the whales change their foraging method to skimming. Skim-feeding is characterised by slow swimming with mouth agape and has been observed, although rarely, during the day in the Hauraki Gulf (Wiseman 2008). Skim-feeding lacks the sudden changes in acceleration characteristic of lunge-feeding but requires steady fluking and dense prey layers. Further analysis of the data will allow us to quantify the percentage of nighttime that the whales dedicated to their more typical lunge foraging technique, resting and to potential skim-feeding.

Vocalisations and the acoustic environment

Bryde's whale vocalisations have been described previously in the Hauraki Gulf thanks to recordings from a navy sono-buoy permanently moored near Great Barrier Island (McDonald 2006). These studies provided us valuable information on the characteristics of the whale calls vary geographically (Heimlich et al. 2005). The acoustic analysis of the vocalisations of the whales recorded by the tags is still on-going but preliminary results suggest that the whales' vocal activity is low-level, at least during the study period and for the sampled behaviours. Clear down-sweeps (Figure 9) were recorded in two of the seven tag deployments. These sounds were rare and tended to occur in bouts, with an inter-call interval of 400 to 500 s and when the whale was at a very similar depth (13-14 m). Other sounds apparently produced by the whale are less conspicuous than down-sweeps and the analysis of these vocalisations is still on-going.

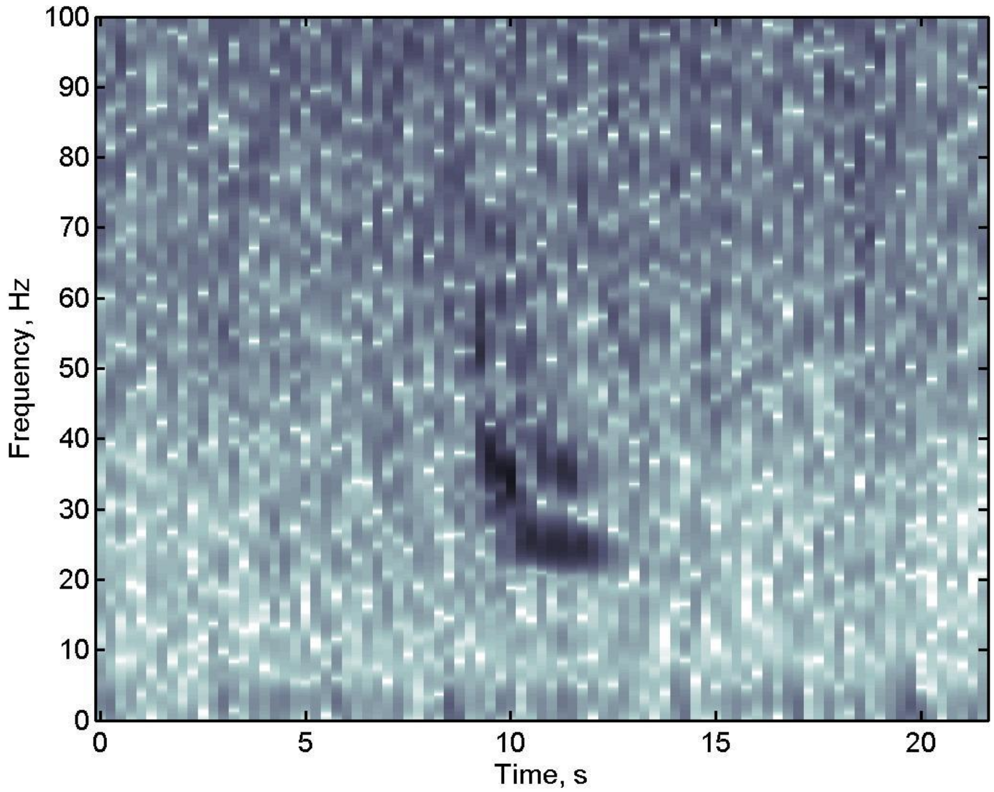

Figure 9. Spectrogram of a down-sweep recorded in tag ono (indicated by the dark pattern around 10 s). This whale produced most of the down-sweeps recorded in the dataset. Spectrogram from wav decimated to 4 kHz bandwith, Hann window size 1000, 50% overlap, 16384 NFFT.

Tag recordings are dominated by flow noise at the low frequencies typical of Bryde's whale vocalisations. However, down-sweeps are readily identifiable and flow noise was low during the night, reducing masking potential during around half of the total recording time. In spite of this, the recording rate of down-sweeps was very low.

The acoustic environment of the whales was variable. Whales tagged very close to shore had a large component of biological sounds characteristic of the reef, such as snapping shrimps and fish. All recordings included acoustic detections of dolphin clicks and whistles (most likely from common dolphins) and of vessel noise. All whales were tagged in the northern area of the inner Gulf (offshore between Flat Rock to Leigh and towards little and Great Barrier Islands) and most stayed in the area for the duration of the tag recording. One tag, however, was recovered near Tiritiri Matangi, and this tag included several events with elevated ship noise indicative of closer vessel passages and long episodes of clearly audible vessel noise. The overall vessel-noise budget of each tag recording is being analysed as indicative of the exposure to vessels in the different areas visited by the tagged whales. Figure 10 shows an example of the difference in background levels recorded by the tag under normal conditions and during a vessel passage.

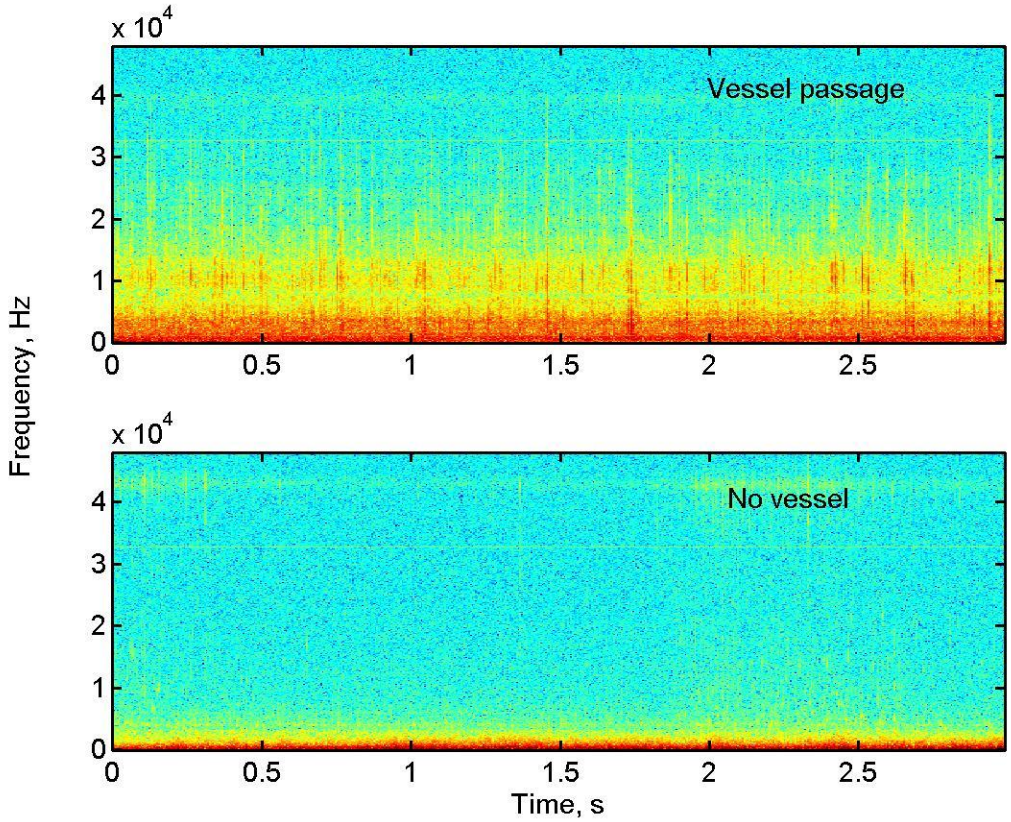

Figure 10. Spectrogram of a section of the tag recordings with ship noise and without, for the same whale and at the same depth (6 m). Low frequency recordings in the tag are dominated by the flow noise of the water over the tag which is shown as a thin red line of higher sound level. During the passage of the vessel noise, noise increases at low frequencies and up to the ultrasonic region.

4. Conclusions

We mostly found solitary Bryde's whales and they spent the majority of their time near the surface. The d-tag data show that Bryde's whales spend 91% of their time at depths where the risk of collision with a large vessel, i.e. draughts of up to 12 m, is most likely to occur.

The lack of large, surface-active aggregations of whales makes them difficult to observe when they come to the surface to breathe, and subsequently this makes them vulnerable to vessel-strike. From boat-based observations of surface behaviour we recorded whales chin-slapping followed by a side-lunge which forms part of their foraging behaviour. Tagged whales were observed mainly foraging on krill and plankton but fish foraging was also observed. Preliminary examination of the d-tag data suggests no differences in sub-surface behaviour when foraging on these two different prey types. When below the surface during daylight hours they were engaged in highly active behaviours for considerable periods of time, most likely foraging, and at night they were nearer the sea surface and less active, indicative of resting behaviour or possibly, although less likely, skim-feeding at the surface. Resting nearer the surface during the night makes them even more vulnerable to vessel-strike as it removes any likelihood that the vessel could see the animals and, where possible, manoeuvre to avoid them. In addition, the whales may be less aware of their surroundings when resting which could result in delayed responses to potential threats.

As the primary area where Bryde's whales are sighted overlaps with the region where ships and other large vessels transit to Auckland Harbour (Figure 1), the probability of collision is high, especially for whales frequently sighted in the Gulf. Two of the tagged whales (HG023 & HG045) have been sighted in the Hauraki Gulf since 2003 and 2004 respectively and form part of a semi-resident population of whales. It is possible that these whales are less-responsive to the sound of vessels transiting through the Gulf as they are familiar with the background noise in the area.

The d-tags recorded ambient noise received by the whale as well as whale vocalisations. When the whales passed close to shore there was considerable environmental noise from snapping shrimp and fishes, and most whales were accompanied by dolphins during the tagging period. Background noise from ships was recorded with elevated noise indicative of closer approaches by ships. Surprisingly the whales made very few vocalisations during the study period despite our confidence in recording these low-frequency sounds had they occurred. Off the northeast U.S. coast whale calls are being used as a form of passive-acoustic detection for ship-strike mitigation but this may not be feasible for the Hauraki Gulf as call rates are too low. McDonald (2006) reported relatively few Bryde's whale calls so it is possible that the whales in this region do not rely on vocal communication as much as other species where noise has been shown to mask communication or change vocalisation types (e.g. Parks et al. 2010).

In summary, the results presented here clearly show that Bryde's whales are typically found alone and spend most of their time in the possible strike zone for large ships and other vessels. They are very active during the day where they spend considerable periods of time foraging but at night, they are found closer to the surface and moving slowly, most likely an indication of resting behaviour, possibly making them even more vulnerable to strike. As there is background anthropogenic noise, as well as biological noise, whales in the Hauraki Gulf may be accustomed to these sounds and may not perceive them as threats. We will continue to analyse the rest of the d-tag data to better understand Bryde's whale behaviour in the Hauraki Gulf. In addition, we have recently received the AIS (Automatic Identification System) ship tracking data for the past four years of ship use throughout the Hauraki Gulf. We will use these data to create a map of ship speed, direction and identity to gain a clearer picture of ship movements and to compare this to how the whales use the Gulf.

5. Minimising the risk of vessel-strike

With the year-round presence of Bryde's whales in the Hauraki Gulf, and their preference for habitat that overlaps with the main route whereby ships and other large vessels transit to Auckland, suggests the primary solution to minimise the risk of vessel-strike mortality is for speed restrictions to be implemented.

Vanderlaan & Taggart (2007) found that the probability of a collision between a large whale and a vessel resulting in lethal injury (P_{lethal}) to the whale is 0.79 where 1 equals 100% chance of mortality when a vessel is traveling between 8.6 and 15 knots. Above 15 knots P_{lethal} asymptotically approaches 1. P_{lethal} does not drop below 0.5 until speeds are below 11.8 knots (Figure 11). The lethality increased most dramatically between 10 and 14 knots (from around 35 - 40% at 10 knots, to 60 - 80% at 14 knots). The data used in Vanderlaan & Taggart's (2007) study were limited in that they did not factor in variables such as differences in size and mass for whale species or vessels and as a result the confidence intervals are large. However, they do clearly demonstrate that collisions at higher speeds are more likely to be fatal. Silber et al. (2010) found that increased speeds changed the hydrodynamic flow around vessels rendering them more likely to pull whales towards the vessels increasing the likelihood of collision and exacerbating the effect of the impact. In the Hauraki Gulf large vessels frequently travel in excess of 20 knots through the whales' preferred habitat.

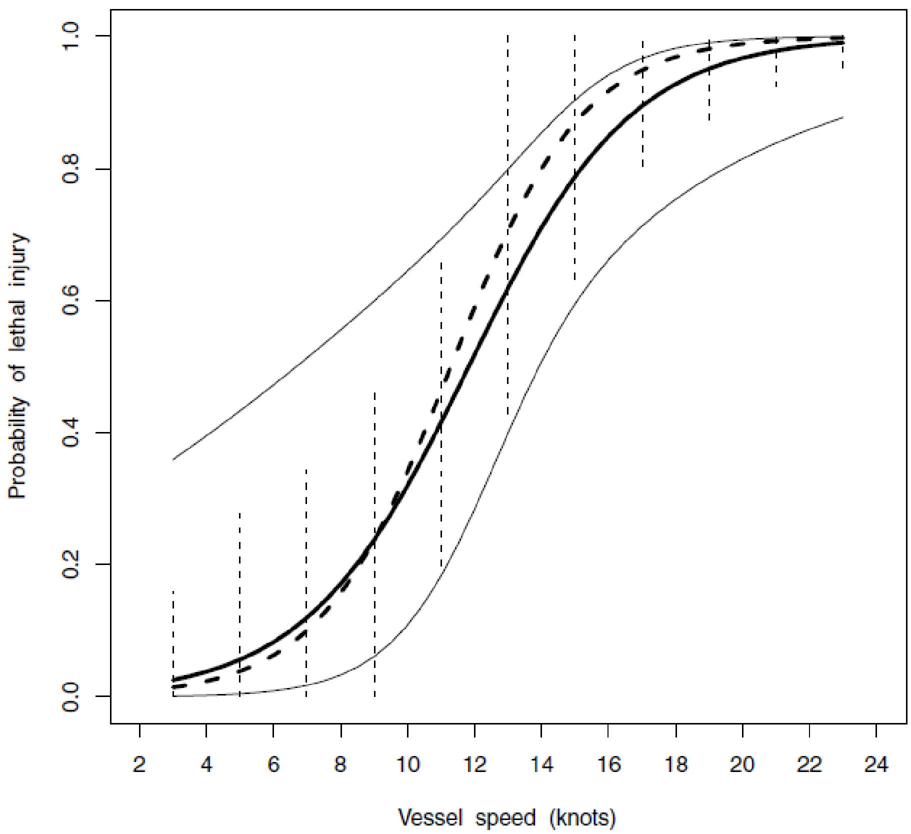

Figure 11. Probability of a lethal injury resulting from a vessel strike to a large whale as a function of vessel speed based on the simple logistic regression (solid heavy line) and 95% CI (solid thin lines) and the logistic fitted to the bootstrapped predicted probability distributions (heavy dashed line) and 95% CI for each distribution (vertical dashed line) (edited from Vanderlaan & Taggart 2007).

Using these criteria, we suggest 10 knots maximum for ships transiting through the Hauraki Gulf. This would hopefully reduce the probability of a lethal injury from vessel strike to around 25%, although it must be acknowledged that the exact data for Bryde's whale vulnerability to vessel-strike mortality has not been quantified. The boundaries of this speed restriction zone should incorporate most of the Hauraki Gulf Marine Park as this region consistently has the greatest density of sightings in the coastal Auckland to Northland area (Baker & Madon 2007, Behrens 2009).

Currently, vessel strikes account for 83% of known Bryde's whale mortalities in the Hauraki Gulf, considerably higher than the 53% reported for North Atlantic right whales (Campbell-Malone et al. 2008) where a variety of measures have been put in place to protect whales. Knowlton & Brown (2007) suggested ways to reduce the risks of vessels striking whales including changing vessel routes, vessel speed restrictions, use of technology to detect whales and educating mariners about the presence of whales. The use of areas to be avoided (ATBA), amendments to traffic separation schemes (TSS) and ship reporting systems for notifications of whale presence have been effective for the seasonal occurrence of North Atlantic right whales off the northeastern U.S. and

Canadian Atlantic waters (Ward-Geiger et al. 2005, Vanderlaan et al. 2008). In some cases (e.g. the Roseway Basin area on the Scotian Shelf) the ATBAs were voluntary but were found to be most effective when internationally sanctioned by the International Maritime Organisation (IMO) as both international and national shipping companies were more likely to comply (Vanderlaan & Taggart 2009). We suggest that IMO sanctioning the suggested speed restriction will increase its success as many of the international shipping companies visiting the Ports of Auckland are familiar with whale conservation measures in other waters e.g., the Mediterranean and northwestern Atlantic seaboard.

Characterisation of the ship traffic can be undertaken to model the efficacy of speed restrictions and compliance, when put in place (Ward-Geiger et al. 2005, Wiley et al. 2011). The use of AIS data to model ship movements, speeds and identity, then overlaying this information on whale habitat use means we can effectively measure the future success of speed restrictions. Also the recent adoption of veterinary pathologist led forensic necropsies of whale carcasses means we have been able to determine cause of death more effectively in the past five years. These necropsies should be standard protocol (e.g. Moore et al. 2004, Campbell-Malone et al. 2008).

As Bryde's whales spend the majority of their time just below the surface of the water, increasing the number of people on watch on the bridge is not an effective strategy to minimise ship-strike, particularly at nighttime when they are even closer to the surface. Even so, we suggest maintaining watch and reporting whale presence to other ships in the Gulf to heighten awareness; this has been effective elsewhere. The use of underwater alarms has proven to be ineffective on other species, in fact increasing North Atlantic right whales' risk of strike (Nowacek et al. 2004), and will only increase the levels of anthropogenic noise that are already detectable in the Hauraki Gulf. There is little evidence that whales avoid approaching vessels and may either be tolerant of them or habituated to the low-frequency sounds that can be heard over considerable distances before the vessels pose a threat. Therefore, we contend that speed restrictions are the best option to protect Bryde's whales in the Hauraki Gulf and with two whales dying in the past five months as a result of vessel strike, it is a timely reminder that we should act rapidly to implement these conservation measures.

6. References

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