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Seasonal occurrence and distribution of Bryde's whales in the Hauraki Gulf, New Zealand

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ABSTRACT

The Hauraki Gulf is a large, shallow embayment located north of Auckland City (36°51′S, 174°46′E), New Zealand. Bryde's whales (*Balaenoptera edeni)* are the most frequently observed balaenopterid in these waters. To assess the use of the Hauraki Gulf for this species, we examined the occurrence and distribution in relation to environmental parameters. Data were collected from a platform of opportunity during 674 daily surveys between March 2003 and February 2006. A total of 760 observations of Bryde's whales were recorded throughout the study period during 371 surveys. The number of Bryde's whales sighted/day was highest in winter, coinciding with the coolest median sea-surface temperature (14.6°C). Bryde's whales were recorded throughout the Hauraki Gulf in water depths ranging from 12.1–59.8 m (mean = 42.3, SD = 5.1). Cow–calf pairs were most frequently observed during the austral autumn in water depths of 29.9–53.9 m (mean = 40.8, SD = 5.2). Data from this study suggest Bryde's whales in the Hauraki Gulf exhibit a mix of both "inshore" and "offshore" characteristics from the Bryde's whales examined off the coast of South Africa.

Key words: Bryde's whale, *Balaenoptera edeni*, Hauraki Gulf, New Zealand, seasonal occurrence, distribution, survey, calving, sea-surface temperature, depth.

Based on complete mitochondrial DNA sequences, Sasaki *et al*. (2006) recognized two sister species of Bryde's whales: *Balaenoptera brydei* and *B. edeni*, with the latter including small-type, more coastal Bryde's whales from Japan, Hong Kong, and Australia. Their samples and samples in previous analyses of small-type whales, all originated from eastern and southeastern Asia. These authors did not include the forms of Bryde's whales that occur in other regions, *e.g.*, in the Pacific off Peru (Valdivia *et al*. 1981), in the Atlantic off Brazil (Best 1977) and in the western Indian Ocean off South Africa (Best 1977). Recent genetic analysis using mtDNA from the "inshore" and "offshore" forms from South Africa confirms the offshore form is *B. brydei*, and establishes that the inshore form is more closely related to *B. brydei* than to *B. edeni* (Penry 2010). These different forms do vary considerably in their habitat use and ecology (refer to Table 1 for a detailed comparison between the South African inshore and offshore forms, as described by Best (1967, 1977) and the Bryde's whales from New Zealand (Wiseman 2008). Recent genetic analysis on the Bryde's whales in the Hauraki Gulf suggests they are *B. brydei* (Wiseman 2008). However, pending resolution of the uncertainty within and between species

Table 1. Distinguishing characteristics of the New Zealand Bryde's whales from Wiseman (2008) and the South African inshore and offshore forms of Bryde's whales adapted from Best (1967 and 1977) and Best *et al*. (1984).

Characteristic	New Zealand Bryde's whales	South African inshore form	South African offshore form
Source	From Wiseman (2008)	Adapted from Best (1967 and 1977) and Best *et al*. (1984)	Adapted from Best (1967 and 1977) and Best *et al*. (1984)
Distribution	<33 km (ca 17 mi) off the coast	<37 km (ca 20 mi) off the coast	>92 km (ca 50 mi) off the coast
Maximum depths reported	~60 m	~200 m	~400 m
Food	Pilchards, euphausiids	Anchovies, pilchards, maasbankers	Euphausiids, myctophids, Lestidium
Sea surface temperature when peak in whale abundance (and season)	12–18°C (winter)	12–13°C (winter)	18–19°C (summer)
Breeding season	Principally in the summer/autumn ($n = 77$)	Unrestricted	Principally autumn

of this genus, we follow the Society of Marine Mammal's committee on taxonomy, who state that *B. edeni* applies to all Bryde's whales.

Unlike most other large balaenopterids, Bryde's whales do not undertake long-distance migrations between low latitude breeding areas and higher latitude feeding areas (Kato 2002). This trait is shared with confamilial species such as blue whales (*B. musculus*) in the eastern tropical Pacific (Reilly and Thayer 1990) and fin whales (*B. physalus*) in the Sea of Cortez (Leatherwood *et al*. 1988). Instead, limited shifts in distribution toward and away from the equator in winter and summer respectively have been observed for the offshore form in South Africa (Best 1977) and Bryde's whales in the Peruvian Sea (Valdivia *et al*. 1981). While the absence of any strict breeding seasonality is evident in some populations, peaks in birth rate have been demonstrated in Northern Hemisphere waters during winter (IWC 1998) and during late summer in the Southern Hemisphere (Best 2001).

Bryde's whale distribution has previously been correlated with SST (Omura and Nemoto 1955), with the species exhibiting an apparent preference for waters above 14°C (Tershy 1992). However, actual distribution is more likely to be related to prey abundance. In New Zealand waters, Bryde's whale movements likely reflect movements of pelagic fish schools (Gaskin 1977). Preliminary fecal analysis from Bryde's whales in the Hauraki Gulf identified both krill and fish as prey items, with fish being particularly important in the diet (Wiseman 2008).

The Hauraki Gulf (Fig. 1) is a large (~65 km wide) relatively shallow (<60 m water depth) embayment located on the northeastern coast of the North Island

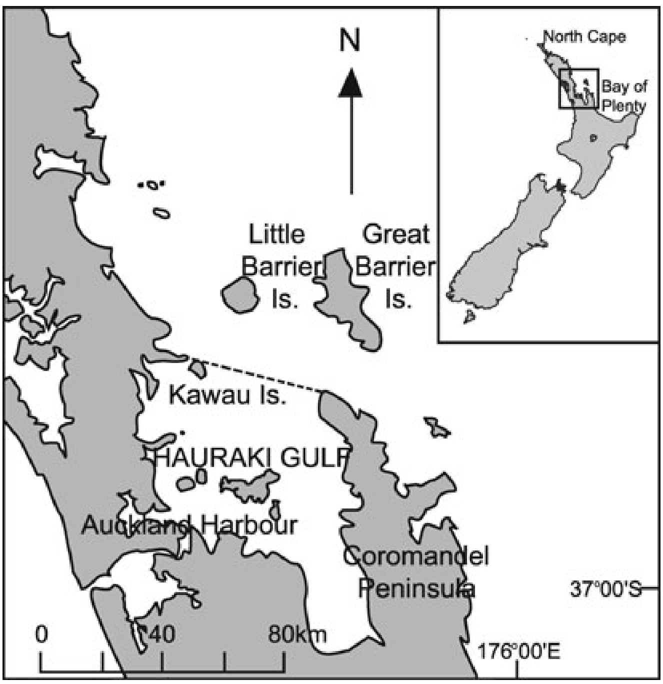

Figure 1. The Hauraki Gulf, northeastern coast of New Zealand. The area south of the dotted line represents the inner Hauraki Gulf and the extent of the area surveyed by *Dolphin Explorer*.

(Manighetti and Carter 1999). This coastal sea can be divided into two areas based on the sheltered waters and influence of the East Auckland Current in the inner, compared with the Outer Hauraki Gulf. The Inner Hauraki Gulf includes the area south of Kawau Island, while outer gulf includes the waters around Little and Great Barrier Islands (Fig. 1). Adjacent to Auckland City (36°51′S, 174°46′E), the Hauraki Gulf experiences high levels of both private and commercial vessel activity (Stockin *et al*. 2008*a, b*). Gaskin (1968) was the first to note Bryde's whales year-round in this region, with his findings substantiated by two later short-term studies (O'Callaghan and Baker 2002, Thompson *et al*. 2002), in addition to more recent aerial survey data (Baker and Madon 2007, Behrens 2009). All latter studies document the presence of Bryde's whale cow–calf pairs, primarily distributed throughout the inner central waters of Hauraki Gulf (O'Callaghan and Baker 2002, Thompson *et al*. 2002, Baker and Madon 2007, Behrens 2009).

Here we assess the seasonal occurrence and distribution of Bryde's whale in the Hauraki Gulf in relation to environmental variables. To examine the potential use of these coastal waters as a nursery area, we also investigate the seasonal occurrence of cow–calf pairs. This information is critical since exposure to heavy vessel traffic can result in long-term disturbance, and impact on health, reproduction or longevity (Reeves *et al*. 2003). Globally, Bryde's whales are among the least studied baleen whales (Kato 2002) and are listed as *Data Deficient* by the IUCN (Reeves *et al*. 2009). The identified (Lloyd 2004, Suisted and Neale 2004, Stockin *et al*. 2008*b*, Wiseman 2008, Behrens 2009) and potential unknown threats to Bryde's whales, in conjunction with a potentially small population size of 159 (97–337 95% CI, Wiseman 2008) have resulted in the New Zealand threat classification *Nationally critical* (Hitchmough *et al.* 2007).

Methods and Materials

Data Collection

Data were collected from a 19.9 m catamaran commercial whale watch vessel (*Dolphin Explorer*). Daily surveys were conducted between March 2003 and February 2006, with data collected during all months over the 3 years. Each survey lasting *ca*. 5 h followed a survey route primarily determined by the prevailing weather conditions. Due to the ability to detect multiple independent groups of cetaceans in the Hauraki Gulf during any single survey (Stockin *et al*. 2008*c*), the vessel was not constrained by having to return to the previous day's sightings of whales. Data were collected at speeds of *ca.* 14 kn and during Beaufort sea states of three or less.

During each survey, at least two trained observers continuously scanned to the horizon east to west with the naked eye and binoculars (8 × 42 magnification) in search of marine mammals. In addition to species cues (blow and body/dorsal contour), aggregations of associated species, including Australasian gannets (*Morus serrator*), common dolphins (*Delphinus* sp.), or both were used to locate Bryde's whales. These species are known to associate during feeding both in the Hauraki Gulf (Wiseman 2008, Stockin *et al*. 2009) and elsewhere (Breese and Tershy 1993, Neumann and Orams 2003).

Data were systematically recorded when the vessel was within 200 m of the whale(s). Date, time and duration of encounter, GPS location (from onboard GPS), water depth (±0.1 m), and SST (±0.1°C) were recorded at the start of each independent encounter. To avoid the difficulty in determining the number of whales present within each encounter, we use only presence/absence data within the following analyses.

Data Analysis

Validation of species ID—Species were confirmed through direct observation of three characteristic rostral ridges (Leatherwood and Reeves 1983). In the field, whales for which rostral ridges were not observed were considered "like Bryde's" whales if: (1) the position and shape of their dorsal fin was approximately two-thirds back along the body and notably falcate (Martin 1990), (2) during surfacing, the head and blow appeared before the dorsal fin (Martin 1990), and (3) an arching of the tail stock was observed prior to diving without tail flukes being shown (Reeves *et al*. 2002). All the "like Bryde's" whales that were biopsied in this region as part of a larger study were later confirmed *via* molecular analyses as Bryde's whales (Wiseman 2008). As such, all "like Brydes" in the present study were pooled with confirmed Bryde's whales for the purpose of analysis. To avoid pseudo-replication and correlation, only data from the first whale observation of each independent survey were used in analyses presented here.

Seasonal occurrence—Observations were categorized by austral season, defined as spring (September–November), summer (December–February), autumn (March–May), and winter (June–August). A monthly index of Bryde's whale occurrence (Trip Encounter Rate or TER), was calculated as the number of trips per month for which whales were observed, expressed as a proportion of the total number of trips undertaken that month. This index took into account the potential for negative correlation between the time spent viewing a whale and the time left available for other encounters and used only the data either from the first survey or whale encounter each day.

Seasonal geographic distribution—Routes were recorded using a GPS from July 2004 to February 2006 (when the GPS was available), to provide information on vessel tracks taken in order to locate Bryde's whales. These tracks were overlaid on a map of the study area divided into 100 equal sized grid squares (see Fig. 3), each approximately 7.2 × 7.2 km in size. Leaper *et al*. (1997) suggested that the search area should be divided equally in order to reduce bias, therefore, allowing broad scale temporal and geographical trends to be examined. With an average eye level height of 4 m (aboard *Dolphin Explorer)*, the distance to the horizon was 7 km; a distance that whales would be detected with binoculars should they be present. Tracks from the GPS were used to calculate the percentage of the total effort in each grid square surveyed, and data for the TER in each grid square and total numbers of observations of Bryde's whales within each grid square were also depicted.

Occurrence of calf encounters—A whale was judged to be a calf if it was equal to, or less than, half the size of an accompanying adult (Corkeron *et al*. 1994). The length of the adult was estimated using the 19.9 m observation vessel as calibration. In addition, calves were continually and very closely associated with an adult, with the majority of surfacings within 10 m, but up to approximately 100 m. The presence of calves was recorded during each survey, with a cow–calf pair only counted once during a single encounter.

Statistical analysis—All data were initially tested for normality and equal variance using Kolmogorov–Smirnov and Bartlett's and Levene's tests, respectively. A two-way ANOVA was used to determine the effect of season and year on TER, and a Pearson's correlation coefficient was used to correlate median SST and TER. The nonparametric Kruskal–Wallis test was used to determine the effect of season on water depth and the numbers of calves observed each season and year. A two-tailed Kolmogorov–Smirnov test was used for the SST and depths of whales observed with and without calves. Where significant differences were detected, *post hoc* comparisons using Tukey HSD were performed to identify the source of variance. Statistical significance was set *a priori* at $\alpha = 0.05$.

Results

Total number of trips—From March 2003 to February 2006, 674 daily surveys were conducted, during which 760 observations of Bryde's whales occurred over 371 d (Table 2).

Species identity—Of the 760 whales observed, 316 of these were initially termed "like Bryde's." Only two further mysticete sightings occurred during the course of the study; a solitary humpback whale (*Megaptera novaeangliae*) and a single dwarf minke whale (*B. acutorostrata* subsp.).

Seasonal occurrence and distribution—Between March 2003 and February 2006, the mean TER ranged from 0.41 in summer to 0.76 in winter (Table 2, Fig. 2). TER differed significantly between seasons ($F = 7.569$, df = 3, $P = 0.001$), although not between years ($F = 0.366$, df = 2, $P = 0.366$). TER was significantly higher in winter than either spring or summer and was significantly lower in summer than autumn.

Between July 2004 and February 2006, data obtained from 187 trips revealed all grid squares were visited (Fig. 3a), with a concentration of tracks evident throughout the central and south western region. Bryde's whales were most frequently encountered in the central and south western inner Hauraki Gulf (Fig. 3b), which given the approximate width of the Hauraki Gulf (*ca.* 65 km), resulted in all encounters being within 33 km of the coastline. The locations of the first whale sighted each day showed that the whales were most concentrated in the central and south western grid squares (Fig. 3c), although TER remained low owing to the relatively high effort throughout this region (Fig. 3d).

Environmental variables—Over the entire study, the median SST ranged from 14.6°C ($n = 153$, range = 12.6–17.6, SD = 1.5) in winter to 19.4°C ($n = 101$, range = 14.2–21.6, SD = 1.7) in summer (Fig. 2). A significant negative correlation was identified as TER ($r = -0.754$, df = 12, $P = 0.005$) increased as the median SST decreased (Fig. 4).

Bryde's whales were observed at a mean water depth of 42.3 m ($n = 520$, range 12.1–59.8, SD = 5.1) and exhibited no difference in depth by season ($H = 1.378$, df = 3, $P = 0.711$).

Occurrence of cow–calf pairs—Bryde's whale calves were observed throughout the year (Table 2). The presence of calves between 2003 and 2006 appeared lowest during spring and highest during autumn, with significantly higher observations of calves during autumn than either spring or winter ($H = 12.198$, df = 3, $P = 0.007$). No difference in calf presence was detected between years ($H = 3.533$, df = 2, $P = 0.171$).

The likelihood of births in the austral summer/early autumn was suggested by two calves which were first observed in January and March. A total body length of

Table 2. The number (#) of daily surveys in the Hauraki Gulf, the total number of observations of Bryde's whales, number of daily surveys when one or more whales were sighted, trip encounter rate (TER), and number of calves between March 2003 to February 2006.

		Daily surveys each year				Total				
Season	Month	2003	2004	2005	2006	# daily surveys	# observations of whales	# daily surveys 1 + whales sighted	TER	# calves
Summer	December		23	14	21	58	37	16	0.28	1
	January		24	24	23	71	84	37	0.52	12
	February		12	24	25	61	51	25	0.41	4
Autumn	March	17	23	26		66	47	31	0.47	15
	April	25	17	23		65	72	33	0.51	8
	May	19	15	15		49	94	39	0.80	13
Winter	June	20	17	14		51	97	42	0.82	8
	July	20	16	19		55	81	43	0.78	4
	August	18	11	22		51	60	35	0.69	4
Spring	September	15	12	14		41	30	19	0.46	3
	October	21	12	16		49	60	29	0.59	1
	November	18	20	19		57	47	22	0.39	5
	Total	173	202	230	69	674	760	371	(mean 0.56)	78

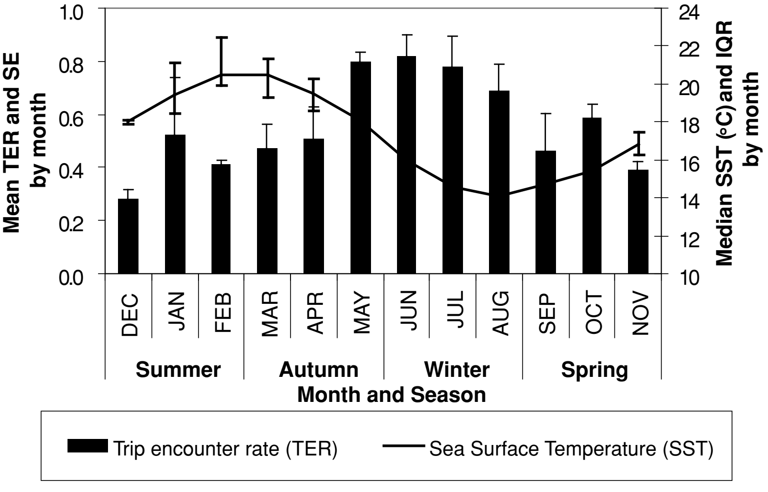

Figure 2. Monthly mean trip encounter rate (TER) with standard error (SE) and median sea-surface temperatures (SST in °C) with upper and lower interquartile ranges (IQR) across years, when Bryde's whales were observed in the Hauraki Gulf between March 2003 and February 2006. "TER" is an index of the number of whale encounters while taking into account the overall number of trips taken.

ca. 4 m was recorded for each of these individuals. Presumed cow–calf pairs were observed at a mean SST of 18.1°C (range = 12.2–23.5°C, SD = 2.8) and mean water depth of 40.8 m (range = 29.9–53.9 m, SD = 5.2). This is significantly warmer (mean = 17.3°C; Z two-tailed = 1.468, df = 520, $P = 0.027$) and shallower (mean = 42.3 m; Z two-tailed = 1.407, df = 519, $P = 0.038$) than Bryde's whales without calves.

Discussion

Bias in Data Collected Aboard "Platforms of Opportunity" or Whale Watch Vessels

The use of whale watch vessels can provide a cost-effective "platform of opportunity" to assess cetacean distribution and abundance (Evans and Hammond 2004), particularly when environmental data can be collected along with sightings and photo-ID data (Wall *et al.* 2006). Nonetheless, platforms of opportunity, including the vessel used in the present study, are not without limitations. For example, we acknowledge that *Dolphin Explorer's* route was a potential source of bias in the present study. However, search patterns were occasionally based on sightings of a number of species, not just Bryde's whales and therefore, the number of trips where prior information was used to search for Bryde's whales was very small. Furthermore, sightings of common dolphins in the Hauraki Gulf reported by Stockin *et al.* (2008*c*) revealed similar occurrence and distribution trends from data collected aboard *Dolphin Explorer* and an independent research platform using a random search methodology. Data presented here were spatially stratified using a particular size of grid square to minimize this search bias, as defined in Leaper *et al.* (1997). Finally, encounter rate was chosen as an index of abundance in relation to the route taken; thereby relative abundance

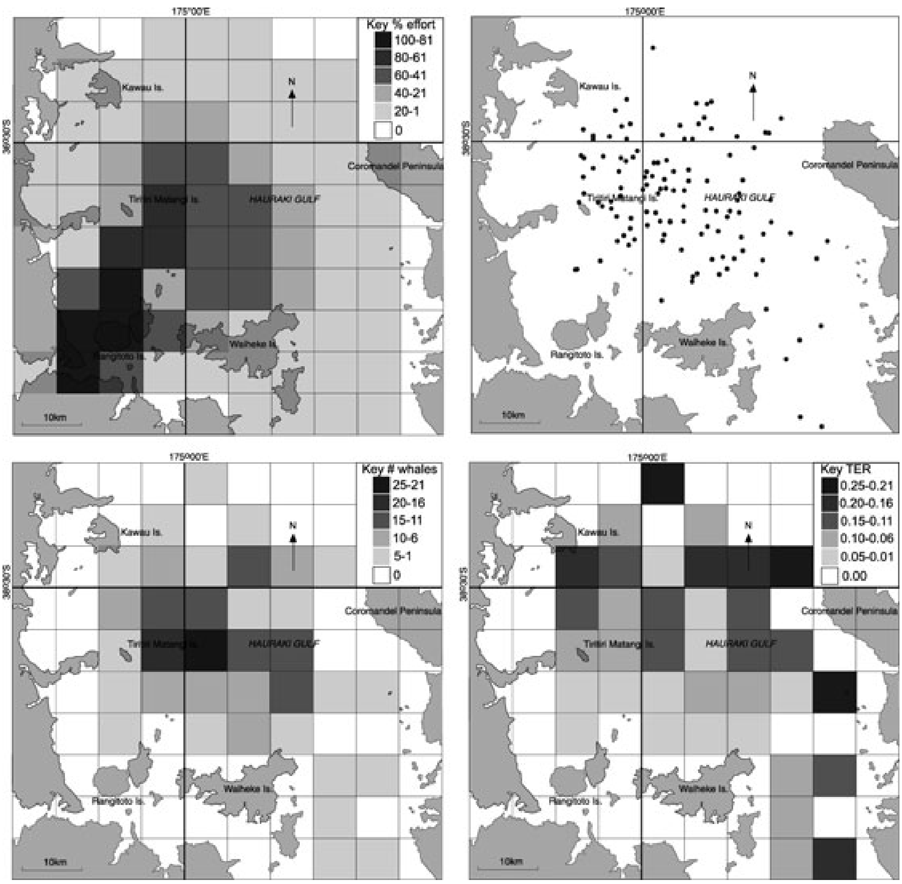

Figure 3. Maps depicting (a) percentage of the number of surveys per grid square; (b) location of the first observation of a Bryde's whale during each survey; (c) number of Bryde's whale observations per grid square, and (d) trip encounter rate (TER) for Bryde's whales in the Hauraki Gulf between July 2004 and February 2006. "TER" is an index of the number of whale encounters whilst taking into account the overall number of trips taken.

between grid squares would be comparable. As such, concerns surrounding bias in the search methodology used in the present study are minimized.

Seasonal Occurrence and Geographic Distribution

Bryde's whales were observed in all months, within the inner Hauraki Gulf. This concurs with earlier findings (O'Callaghan and Baker 2002, Thompson *et al.* 2002) and supports recent aerial survey data suggesting distribution is more concentrated within the inner central gulf waters compared with the outer gulf (Baker and Madon 2007, Behrens 2009). While the year-round occurrence of Bryde's whales within the present study is similar to that recorded off Kochi, southwest Japan (Kato *et al.* 1996), and for the inshore forms off Baja California (Tershy 1992) and the west coast

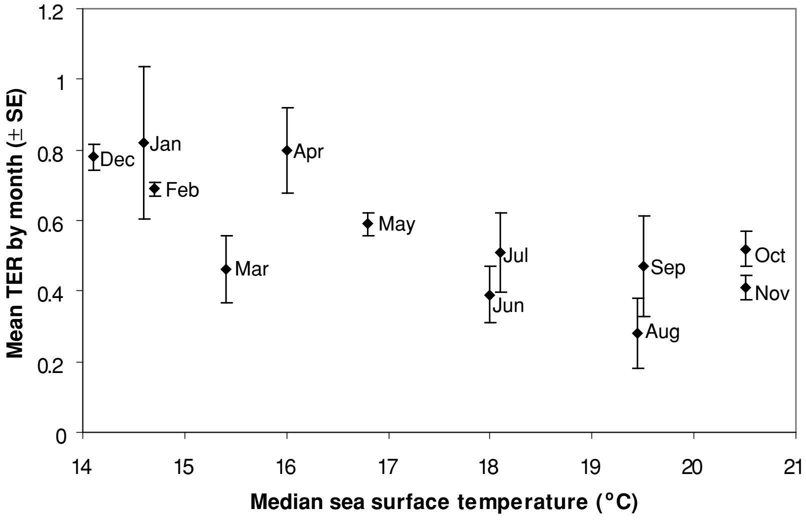

Figure 4. Correlation of trip encounter rate (TER) with standard error (SE) and median sea-surface temperature (SST in °C) when Bryde's whales were observed in the Hauraki Gulf between March 2003 and February 2006.

of South Africa (Best 1967), some differences are apparent. For example, TER of Bryde's whales in the Hauraki Gulf peaked during the austral winter. In contrast, Bryde's whale numbers peaked during the warmer months of the boreal spring off Kochi in southwest Japan (Kato *et al*. 1996), the boreal summer and autumn months for the inshore form off Baja California (Tershy 1992), and during the summer months for the South African offshore form (Best 2001). The exception was the inshore form of Bryde's whales which were more abundant during the austral winter months off South Africa (Best 2001).

The disparity between the seasonal occurrence data presented here and that reported in the literature may be a consequence of timing differences within the migration for these populations. Unlike other species of Balaenoptera, Bryde's whales are not known to undertake long-distance migrations (Kato 2002). However, limited north–south migrations have been observed for the South African offshore form (Best 1960), although this contrasts with inshore Bryde's whales in South Africa, which appear to lack any strong movement patterns (Best 1977). This has implications on the timing of breeding and feeding of these forms off South Africa (refer to Table 1 for a further description). Clapham (2000) suggested the South African inshore Bryde's whale stock may have freed itself from the constraints of migration by remaining in low latitudes and exploiting the year-round prey availability. Following this hypothesis, it may not be necessary for Bryde's whales in the Hauraki Gulf to migrate since certain identified individuals were observed feeding throughout the year (Wiseman 2008). Continuous feeding is possible due to the year round availability of fish (Kendrick and Francis 2002) and zooplankton (Jillett 1971) within these productive waters. The East Auckland Current is the primary reason for this high productivity (Booth and Sondergaard 1989, Chang *et al*. 2003), and explains the extensive marine biodiversity within this region (Kendrick and Francis 2002). Previously, authors have suggested that Bryde's whale abundance is strongly related to upwelling systems which result in higher rates of primary productivity, as demonstrated off Chile (Gallardo *et al*. 1983), eastern tropical Pacific (Ballance *et al*. 2006) and for the inshore form off South Africa (Best 1960). Within the Hauraki Gulf, the upwelling of cooler nutrient-rich water aid plankton production in the inner Gulf (Sharples and Greig 1998). These upwelling conditions provide an ideal environment for the fish that form a large part of the diet of Bryde's whales in the Hauraki Gulf (Wiseman 2008). Stockin *et al*. (2009) observed increased feeding by common dolphins during the winter months in the Hauraki Gulf and attributed this finding to the upwellings that were more frequent during this time. As such, this may also explain the higher occurrence of Bryde's whales during winter within this region.

Environmental Variables

Bryde's whales in the Hauraki Gulf were observed in shallower (mean = 42.3 m, SD = 5.1, range 12.1–59.8 m) waters than has previously been reported elsewhere for this species. Bryde's whales off the coast of Brazil were observed at depths of 15 m but the range extended to 122 m (Siciliano *et al*. 2004). In the Gulf of Mexico, Bryde's whales were observed in water depths between 199 and 302 m (Maze-Foley and Mullin 2006). Similarly, the South African inshore and offshore Bryde's whales were reported in waters of 200 and 400 m, respectively (Best *et al*. 1984).

Bryde's whales in the present study were also observed in cooler waters (mean = 17.3, SD = 2.6, range = 12–24.5°C) than typical for this species. Most authors report Bryde's whales in water exceeding 16°C (Omura 1959, Privalikhin and Berzin 1978). In the North Pacific, 92% of the Bryde's whales observed were in waters exceeding 18°C (Ohsumi 1977). In comparison, the results presented here indicate that 50% of Bryde's whale sightings occurred in water of 16°C or less. Only the inshore form has been observed in water temperatures similar to those reported here (*ca.* 14°C) for those observed off Baja California (Tershy 1992) and from South African waters (Best 1967).

Occurrence of Cow–Calf Pairs

Baker and Madon (2007) reported a late winter to early spring calving season in New Zealand waters, observing calves with estimated lengths between 4 and 6 m in the Hauraki Gulf. The present study observed calves in the Hauraki Gulf throughout the year, peaking during the austral summer/autumn. This is consistent with Best (1977) for the offshore form in South Africa. Two newborn calves (4–4.5 m) were observed late summer/early autumn which concurs with Best (1977) and Kato (2002) who suggest total body length at birth is approximately 4 m. This evidence suggests that parturition may occur within these waters, if not within close proximity to the study site.

In the present study, cow–calf pairs were observed in significantly warmer and shallower waters compared with whales without calves. Similarly, Behrens (2009) also observed cow–calf pairs in shallower waters than other whales. Such oceanographic features are considered favorable for humpback cow–calves (Corkeron and Connor 1999). Similarly, calm waters and shallow sloping aspects have also been described as favorable environmental conditions for southern right (*Eubalaena australis*) cow–calf pairs off South Africa (Elwen and Best 2004). Such environmental conditions appear conducive to reduced energy consumption and a lower risk of injury (Elwen and Best 2004). However, unlike humpback whales, Bryde's whale cows are assumed to be feeding in this region.

In conclusion, the year-round occurrence of Bryde's whales throughout the Hauraki Gulf is likely a consequence of a combination of factors including favorable inshore conditions that support sheltered, yet productive waters. The distance from the coast, depths, SST range and breeding season of the Bryde's whales reported in the present study spans that of both the inshore and offshore South African forms, further confirming the variation evident within the species. Appreciations of such differences are critical when managing different forms and populations. Within New Zealand the presence of Bryde's whales, particularly within Hauraki Gulf waters, results in this species being locally vulnerable to a range of human impacts including tourism (Suisted and Neale 2004), ship strike (Stockin *et al*. 2008*b*, Wiseman 2008, Behrens 2009) and entanglement in fishing gear (Lloyd 2004). For these reasons, the occurrence and inshore distribution of Bryde's whales within busy Auckland waters has important conservation implications for this species.

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