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INTERNATIONAL WHALING COMMISSION

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ABSTRACT

A short field project was conducted in January and February 2014 to test the hypothesis that the South Taranaki Bight (STB), New Zealand is a blue whale (*Balaenoptera musculus*) foraging ground for krill, specifically the euphausiid *Nyctiphanes australis*. Over five days of field effort we observed 50 blue whales, documented foraging behavior, confirmed blue whale prey, observed defecation, documented similar isotopic values across individuals sampled, and linked blue whale occurrence with frontal margins exhibiting relatively high biological productivity. These observations and data strongly support the hypothesis that the STB is a blue whale foraging ground. Genetic analysis determined New Zealand blue whales to be most genetically similar to Australian 'pygmy' blue whales, yet we also identified a new haplotype and found no photo-identification matches to 174 individual Australian blue whales assessed (compared to 1 in 44 individual New Zealand whales assessed). These results suggest that New Zealand pygmy blue whales may comprise a unique population. There are multiple anthropogenic activities in the STB, including oil and gas exploration and extraction, potential seabed mining, vessel traffic, and commercial fishing. Given the proximity of blue whales in this region to industrial activity with associated direct (e.g., vessel strike, toxicity from oil spills, hearing damage from seismic operations) and indirect (e.g., lost foraging opportunities, acoustic masking) threats, there is imminent need for effective regulation. Management efficacy of these anthropogenic activities in the STB depends on robust, well-directed science to avoid direct, indirect, and cumulative impacts on blue whales. Therefore, continued data collection and analyses are needed to determine the significance and extent of this foraging ground to fill critical data gaps and inform management decisions. Otherwise, industrial activities will persist and increase undeterred in the STB.

KEYWORDS: BLUE WHALES, FEEDING GROUNDS, NEW ZEALAND, PHOTO-ID, EUPHAUSIIDS, FEEDING

INTRODUCTION

In 2013, a blue whale (*Balaenoptera musculus*) foraging ground was hypothesized to exist within the South Taranaki Bight (STB) situated between the North and South islands of New Zealand (Torres 2013). Blue whales in New Zealand are currently recognized as a 'migrant' species, and despite active industrial activity in the STB from oil and gas, seabed mining, and vessel traffic, no impact mitigation is in place, other than marine mammal observers on seismic survey vessels. To test the hypothesis of a blue whale foraging ground in New Zealand and collect data on a potentially new population of blue whales, a brief field season was conducted in January/February 2014.

A wind-driven cold-water upwelling systems at Kahurangi Point lies just to the southwest of the STB and generates productive plumes that spin off into the bight (Shirtcliffe *et al.* 1990). Previous studies documented high densities of *Nyctiphanes australis* in this area associated with the plumes (Bradford & Chapman 1988; Bradford-Grieve *et al.* 1993). Blue whales in other foraging grounds in the southern hemisphere feed primarily of *N. australis* (Gill 2002). Therefore, it was suggested that blue whales in the STB also feed on dense patches of *N. australis* that aggregate in response to elevated productivity in upwelling plumes (Torres 2013).

Outside of Antarctica, the distribution and ecology of blue whales in the Indian and Pacific Ocean region of the Southern Hemisphere is not well understood (Branch *et al.* 2007; Double *et al.* 2014). Since 2002, five new blue whale foraging grounds have been reported in the mid-latitudes of this region (the Bonney upwelling, Australia: Gill 2002; the Perth Canyon, Australia: Rennie *et al.* 2009; off the Crozet islands: Samaran *et al.* 2010; in New Zealand (this study): Torres 2013; south of Sri Lanka: de Vos *et al.* 2014). Furthermore, little is known about the migration between these areas and breeding grounds, except recent tracking work linking blue whales feeding off western Australian with wintering habitat in Indonesia (Double et al. 2014). Additionally, genetic information for these populations is limited, including their identity as Antarctic (*B. m. intermedia*) or pygmy blue whales (*B. m. brevicauda*). These recent discoveries demonstrate our significant knowledge gaps about their ecology in the region - a factor that limits our ability to protect these populations from growing anthropogenic activities.

Our work presented here provides needed baseline population and ecological data on the blue whales that occur in New Zealand waters. We hope that these results raise awareness of blue whales in waters surrounding New Zealand, lead to a more thorough examination of their ecology in the region, and ultimately help generate effective management solutions to protect blue whales in the region.

METHODS

Field Methods: With limited prior knowledge of blue whale distribution in the STB (~55,835 km2, median depth ~100 m), satellite imagery analysis was performed to determine the spatial and temporal patterns of chlorophyll a (chl-a) in the region (Figs. 1 & 2). These patterns of variable productivity are assumed to reflect the likely distribution patterns of *N. australis* and therefore of blue whales as a function of trophic transfer. Chl-a concentration in the STB was found to be seasonally and spatially structured. Upwelling events off Kahurangi Point during spring and summer months (Nov. - Feb.) generate nutrient rich plumes that migrate into the STB causing increased productivity near site 2 (red box, Fig. 1). Therefore, survey effort in January and February 2014 was concentrated in site 2, an area of predicted high primary productivity, to maximize blue whale encounter rates.

Field work consisted of survey effort for blue whales, oceanographic sampling, collection of hydroacoustic backscatter data on prey availability, behavioral observations of whales, and collection of photo-identification data, and whale skin and krill samples. A 14 m jet propelled catamaran, equipped with oceanographic sampling capabilities and a flying bridge for observational work, was used as the research platform in the STB between 21 January and 4 February 2014. Prior to each survey day, daily images of sea surface temperature (SST) and chl-a were assessed to locate areas of upwelled water and high surface productivity.

Survey effort was conducted on days with suitable weather conditions (Beaufort Sea State < 4). Profiles of water column depth, temperature, salinity and fluorometry were recorded using a Sea-Bird microCAT (SBE 911plus) Conductivity, Temperature and Depth (CTD) sensor that was lowered at a rate of 1 m/s until approximately 10 m off the bottom. CTD casts were performed at the start and end of survey, approximately every hour while on survey, and at all blue whale sightings. Survey effort was conducted at 8 knots, with one observer posted on the port and starboard sides of the flying bridge. Additional observers surveyed the entire area. Hydro-acoustic backscatter data were recorded while on survey using a Simrad EK60 echosounder (Simrad ES120-7DD splitbeam transducer, 120kHz transceiver, 250 W, 1.024 ms pulse length, 0.5 s ping rate) deployed 1.26 m below the research vessel. At all blue whale sightings, survey effort was stopped, the transducer raised from the water (to increase vessel maneuverability), date, time, and location recorded, and the animal(s) were approached for behavioral observation and further data collection. Immediately after each blue whale sighting, hydroacoustic data were collected to assess prey availability in the region.

Photo-identification captured images of the left and right sides of each blue whale whenever possible. After a reasonable amount of effort spent on photography, biopsy was initiated, with simultaneous photography effort to identify sampled whales. Skin biopsy samples were collected using a lightweight biopsy dart fired from a Paxarms biopsy projector (Krützen et al. 2002; New Zealand Department of Conservation permits Rnw/HO/2009/03; AEC225; AEC266). All samples were stored in 70% ethanol at -20°C. Samples of sufficient size were divided for genetic and stable isotope analyses.

A fine-mesh (500μm) dip net attached to a long pole was used to collect fecal and krill samples from surface waters opportunistically when material was observed. Sample material was placed in a sterilized plastic jar filled with formalin (krill) or ethanol (fecal matter), then frozen. Additionally, approximately 25 krill were placed in an Eppendorf vial with ethanol for stable isotope analysis.

Photo-identification analysis: Photographs of blue whales were reviewed and grouped by individual within each sighting. Using unique pigmentation patterns on the sides of each animal, and dorsal fin shape, the number of individuals documented during the field effort was determined. Using standard methods (Sears *et al.* 1990), images

of STB whales were matched to 12 other catalogs from the New Zealand, Australian and Antarctic regions including 859 images of 269 individual blue whales (Table 1).

Habitat and prey mapping: Interpolated surfaces of maximum fluorescence and surface temperature data captured during CTD casts were constructed using spline methods (regularized, weight 0.2, 4-point approximation, 100 m cell size) in ArcGIS v10.2 (Esri, Redlands, CA, USA). Hydroacoustic backscatter data were integrated over 100 m horizontal segments, and two vertical bins to describe the availability of surface (from the surface exclusion zone to 50 m) and deep (from 50 m to the seafloor or 100 m in deeper areas) prey. The surface exclusion zone was manually determined for each bin based on transducer ringdown depth and the vertical extent of surface noise. We assumed most acoustic backscatter corresponded to krill, yet recognize other biota may occasionally influence the signal. Therefore, we refer to backscatter data as an index of biological productivity. Given the highly patchy nature of prey (particularly krill), daily spline interpolations of mean integrated Nautical Area Scattering Coefficient (NASC; m^2/nmi^2) were created within 100 m buffers of tracklines.

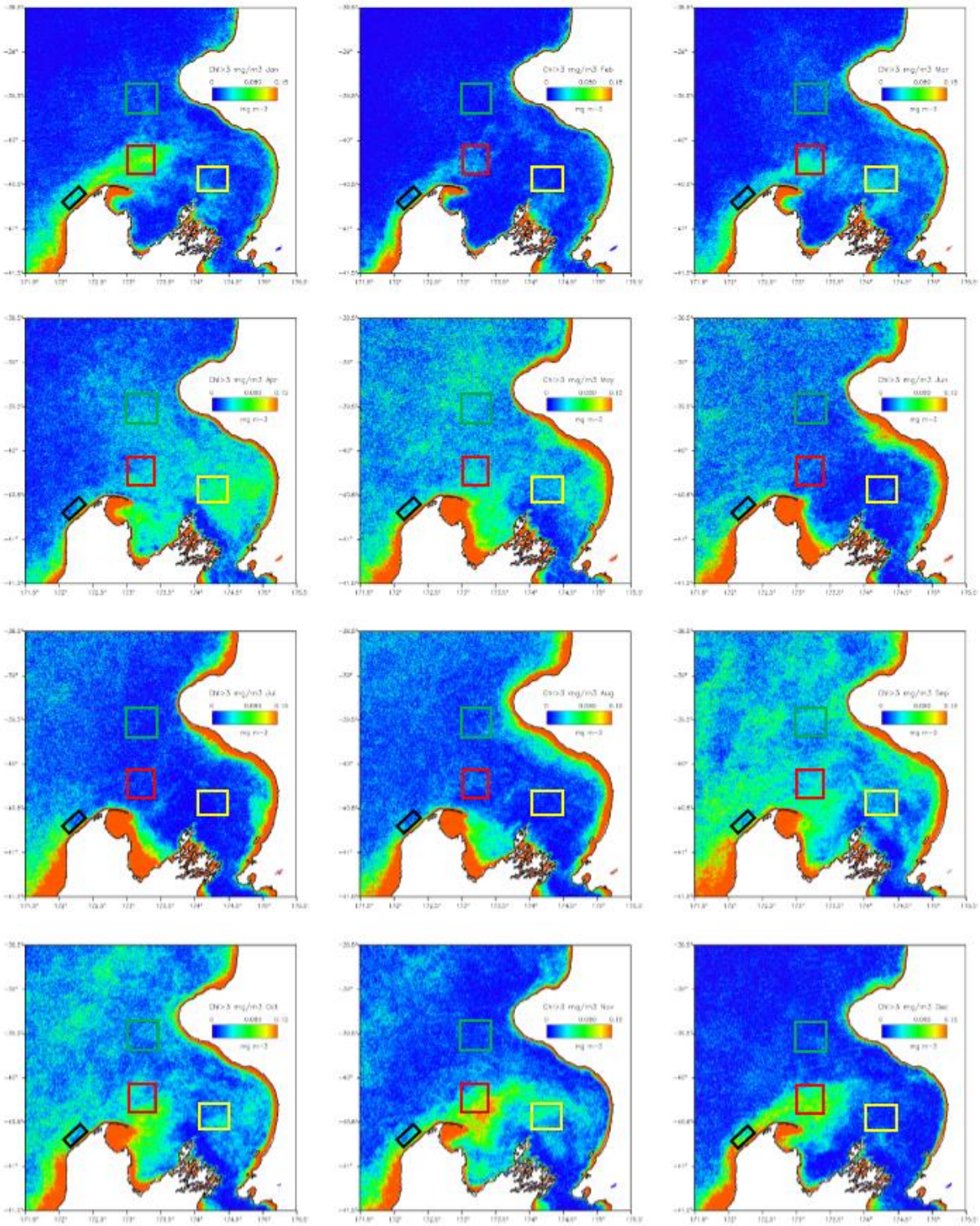

Figure 1. Mean monthly chlorophyll-*a* concentration (mg/m^3) in the South Taranaki Bight (STB) over an 11 year period from July 2002 to November 2013, at 500 X 500 m resolution. Boxes represent the four sites where chl-*a* was quantitatively analyzed (see Fig. 2): black = site 1; red = site 2; green = site 3; yellow = site 4. Satellite data generated from NASA Moderate Resolution Imaging Spectrometer (MODIS Aqua), corrected for co-occurring sediment (Garver & Siegel 1997), regionally validated (Pinkerton *et al*. 2013), and processed using SeaDAS v6.5.7 with the NIR-SWIR switching atmospheric correction (Wang & Shi 2007).

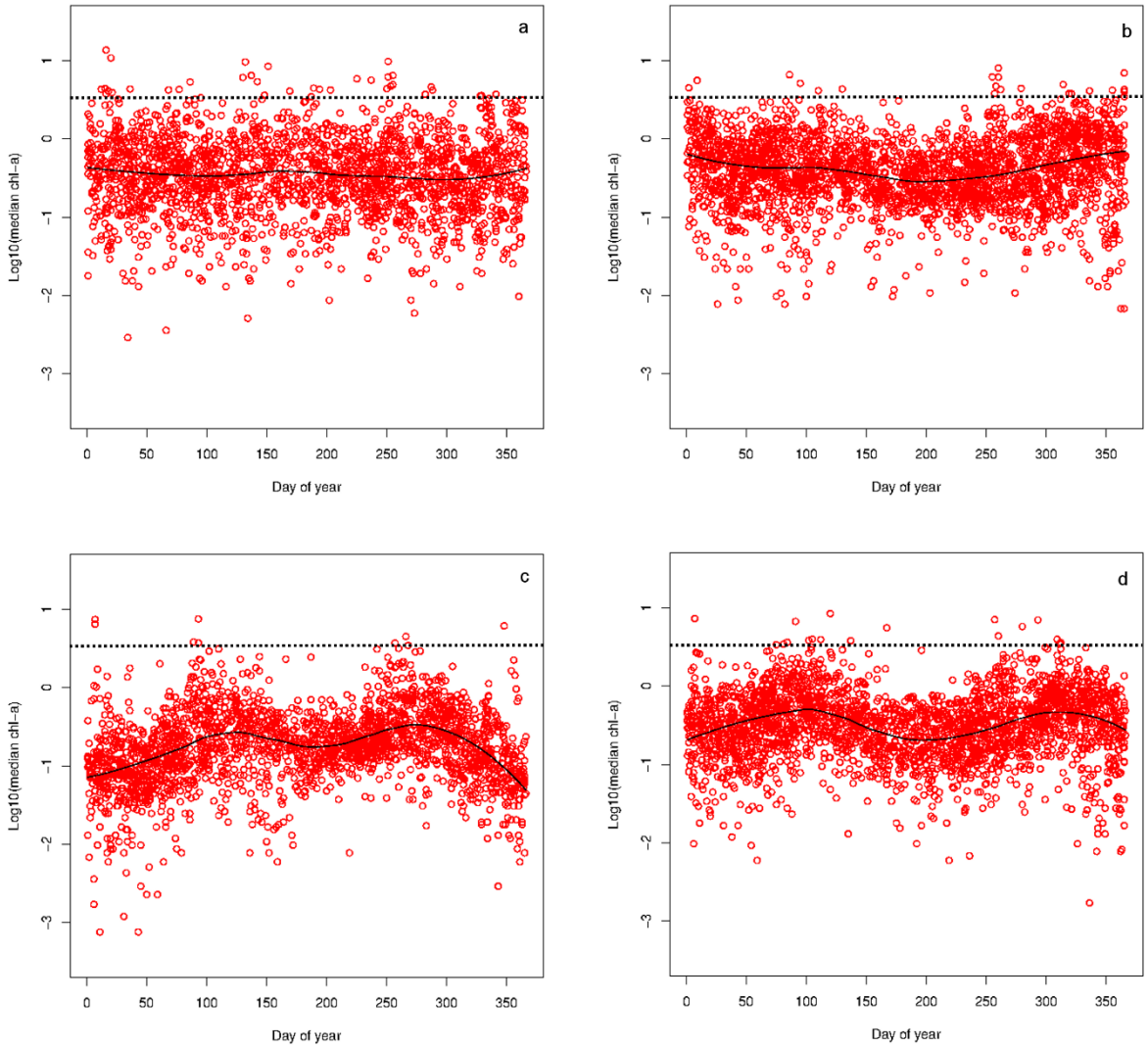

Figure 2. Seasonal cycles of chl-*a* concentration in the STB for (a) Site 1, (b) Site 2, (c) Site 3, (d) Site 4, which reflect the black, red, green and yellow boxes in Figure 1, respectively. Using monthly climatologies of MODIS imagery over 11- years (see Fig. 1) a Loess function was fitted between the Day of Year and $\log_{10}$(median chl-a). Points above the dashed line indicated a "bloom": chl-*a* > 3 mg/m^3.

Table 1. Contributors and details of blue whale photo-identification catalogs matched to blue whales photographed in the South Taranaki Bight between 21 January and 4 February 2014. For each catalog and side of the whale (flank), the number and quality of photos used are given. Picture quality: L=Low, M=Medium, H=High, for the best pictures; No dorsal fin=complementary pictures used for comparison without the dorsal fin in the picture; Not useful=very bad quality pictures, with no distinctive marks, unused.

			Left flank						Right flank					
Collaborator, region, time period	**Total no. photos**	**Total no. individuals**	**No. best photos used**	**L**	**M**	**H**	**No dorsal fin**	**Not useful**	**No. best photos used**	**L**	**M**	**H**	**No dorsal fin**	**Not useful**
Australian Marine Mammal Centre, Bonney Upwelling 2012, south Australia	59	36	26	2	14	7	2	1	25	4	17	4	0	0
Australian Marine Mammal Centre, Antarctic region south of New Zealand, 2013	85	51	39	0	33	6	0	0	46	1	38	7	0	0
Australian Marine Mammal Centre, South Island New Zealand, 2013	21	14	11	0	9	2	0	0	10	5	5	0	0	0
Australian Marine Mammal Centre, East Coast Australia, 2014	3	2	1	0	0	1	0	0	2	0	1	1	0	1
The Blue Whale Study, Bonney Upwelling 1998-2011, south Australia	210	136	104	26	61	11	2	4	106	29	55	12	2	8

Cawthron Institute, South Taranaki Bight, New Zealand, 2013	26	1	1	1	0	0	0	0	0	0	0	0	0	0
Todd Energy seismic survey, South Taranaki Bight, New Zealand, 2013	377	5	2	1	1	0	0	0	3	2	1	0	0	0
Encounter Kaikoura, Kaikoura, New Zealand, 2013	4	2	1	1	0	0	0	0	2	0	1	0	1	0
Whale Watch Kaikoura, Kaikoura, New Zealand, 2012 and 2013	20	3	1	0	1	0	0	0	2	0	0	2	0	0
Kaikoura Ocean Research Institute, Kaikoura, New Zealand, 2012 and 2014	11	2	2	1	0	1	0	0	1	0	1	0	0	0
University of Auckland, Hauraki Gulf, New Zealand, 2010	8	2	2	0	0	2	0	0	0	0	0	0	0	0
Department of Conservation, NZ; Cook Strait Survey	35	15	10	2	7	1	0	0	8	1	6	0	0	1
Total	**859**	**269**	**200**	34	126	31	4	5	**205**	42	125	26	3	10
%				17	63	15.5	2	2.5		20.5	61	12.7	1.5	4.9

Genetic analysis: Tissue samples collected in the STB were analyzed along with 15 previously collected (1994-2014) blue whale samples held at the New Zealand Cetacean Tissue Archive (NZCeTA): 12 from beachcast animals around New Zealand, and skin samples collected from two live animals in Cook Strait and one in the Hauraki Gulf (Fig. 3).

Total genomic DNA was extracted from skin tissue following standard proteinase K digestion and phenol/chloroform methods (Sambrook *et al.* 1989), modified for small samples (Baker *et al.* 1994). Molecular sex identification, amplification and sequencing of the mitochondrial DNA (mtDNA) control region (600bp) and microsatellite genotyping followed Sremba et al. (2012).

Control region sequences were edited to a 410bp consensus region (Sequencher v4.6). Individual haplotypes were aligned with previously published blue whale haplotypes downloaded from GenBank (LeDuc *et al.* 2007; Sremba et al. 2012; Torres-Florez *et al.* 2014; Attard *et al.* 2015). New haplotypes were confirmed by reverse sequencing from a new PCR product following Morin et al. (2010). Microsatellite alleles were analyzed using Genemapper v4.0 (Applied Biosystems) with peaks visually inspected. Replicate samples of individual whales were identified using CERVUS v3.0.3. Mismatches of up to three loci were allowed to prevent false exclusion due to allelic dropout and other genotyping errors (Waits *et al.* 2001). Electropherograms from mismatching loci were reviewed and corrected or repeated.

ARLEQUIN v3.5.1.2 (Excoffier & Lischer 2010) was used to test for mtDNA haplotype differentiation between STB and NZCeTA samples, and among the combined New Zealand samples, and the Southern Ocean (n=183, Sremba *et al.* 2012), Chilean coast (n=113, Torres-Florez et al. 2014), and Australian (n=89, LeDuc *et al.* 2007 and Attard *et al.* 2015) populations.

Stable isotope analysis: Ethanol was evaporated from skin biopsies under a stream of nitrogen gas prior to freeze-drying. The skin was then sub-sampled and weighed into tin boats for stable isotope analysis. The composite krill sample was freeze-dried, ground into a fine homogenized powder, and sub-sampled. Stable isotope analyses were carried out on a DeltaPlus (Thermo-Fisher Scientific, Bremen, Germany) continuous flow, isotope ratio mass spectrometer linked to an NA-1500 elemental analyzer (Fisons Instruments, Rodano, Italy). For details of analytical set-up refer to Morrison et al. (2014). Repeat analysis of National Institute of Standards and Technology and laboratory standards had a precision of better than 0.2‰ and 0.1‰ for $\delta^{15}N$ and $\delta^{13}C$ values, respectively. Carbon isotope data were corrected for lipid content following the equation in Fry (2002).

RESULTS

Observations: Weather conditions allowed five days of survey effort during the research period. In total, 19.9 hrs of survey effort were conducted, covering 314 km (Fig. 4). Ten sightings of blue whales were made (Table 2) with an estimated 50 blue whales observed, including one cow/calf pair (calf's estimated age 6 mo.). Behavior, including three instances of feeding, was consistent with that routinely observed in the established Bonney upwelling (Australia) blue whale foraging ground where *N. australis* is also prey (Gill *et al.* 2011, P.G. pers obs.). Krill surface swarms were observed at three sightings. The mean distance of blue whale sightings to an oil drilling or processing platform was 29.6 km (min: 11.9 km).

Ten skin biopsy samples were collected and genetically analyzed, while only eight samples had enough tissue to also allow stable isotope analysis. One krill sample was confirmed as *N. australis* (Janet Bradford-Grieve, NIWA, pers. comm.). Defecation was observed three times.

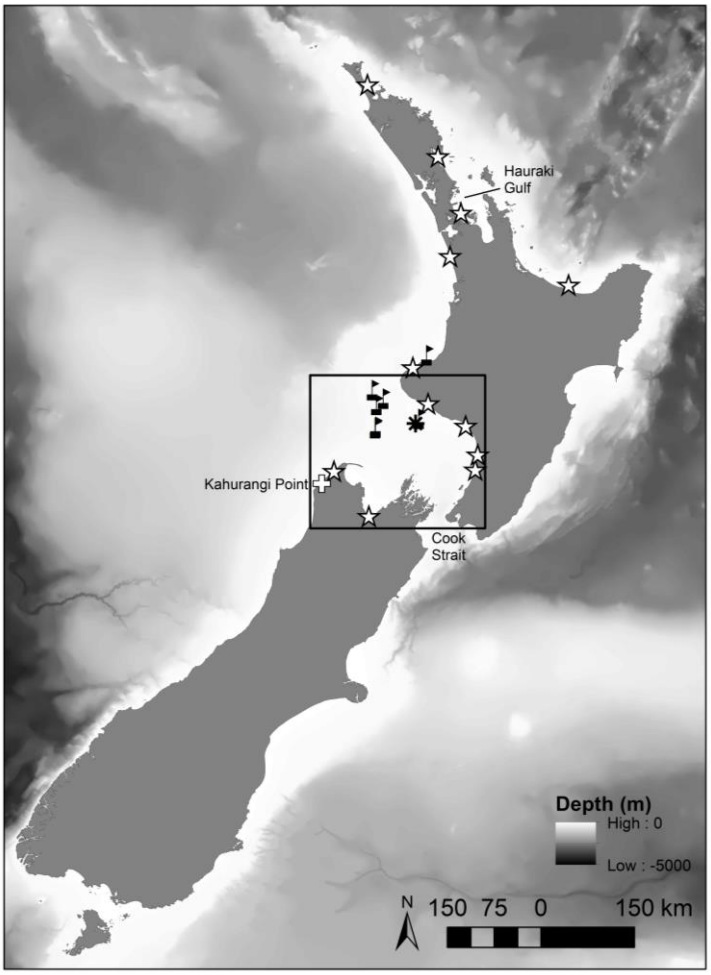

Figure 3. Location of the South Taranaki Bight (STB; black box) within New Zealand. Locations of the Kahurangi Point upwelling (white cross), blue whale beachcast samples (white stars), offshore drilling platforms (black flags), and area of proposed seabed mining (black asterisk) also displayed.

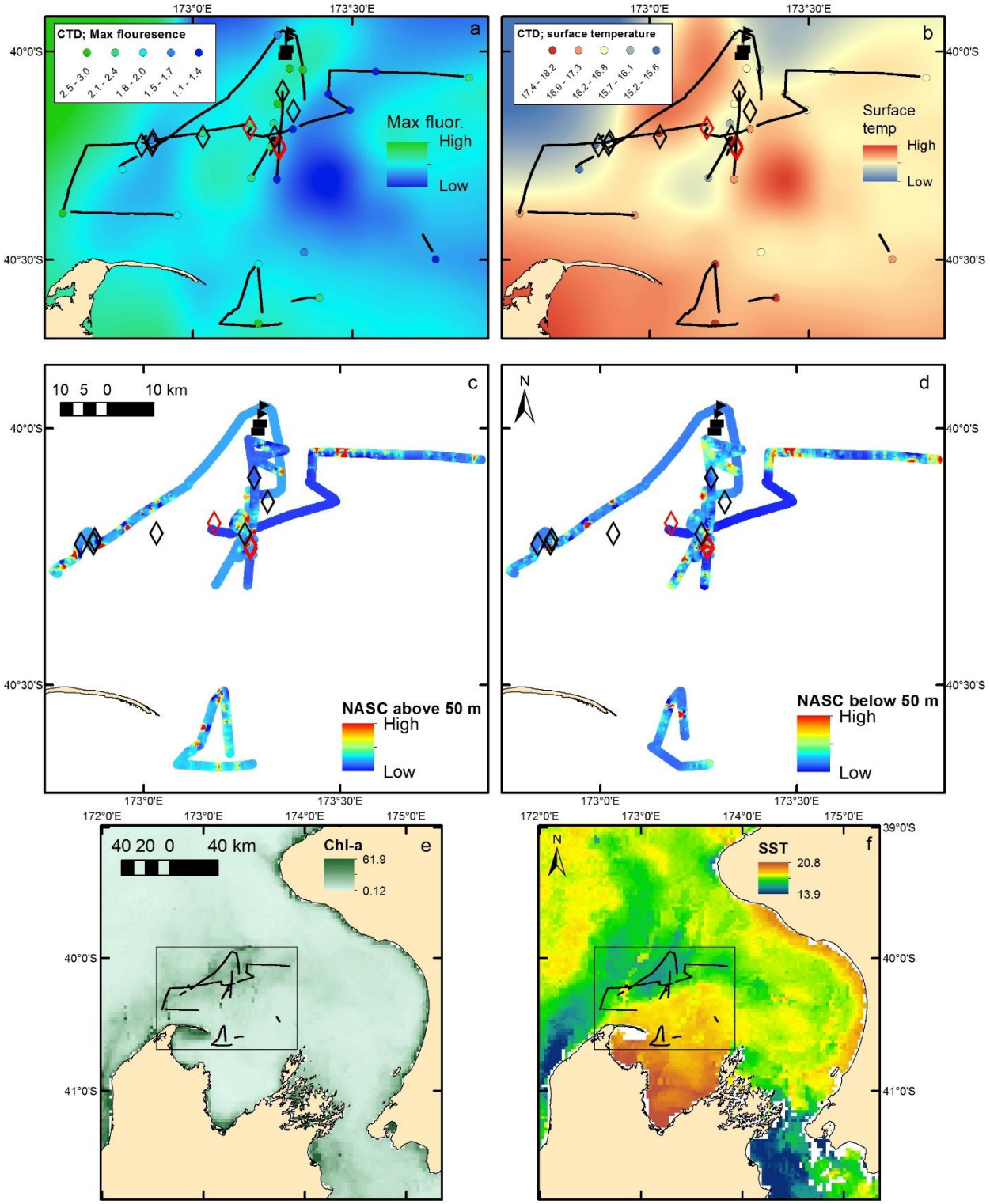

Figure 4. Blue whale survey effort in the South Taranaki Bight (STB) with associated sighting, habitat and biological productivity information. Blue whale sightings marked by diamonds (red = foraging; black = non-foraging) and drilling platforms denoted by black flags. CTD locations, color coded by raw values, displayed with survey effort (black lines) over interpolated surfaces of maximum florescence (a) and surface temperature (b). Interpolated acoustic backscatter data in the upper 50 m (c) and below 50 m (d) derived from integrated values of Nautical Area Scattering Coefficient (NASC; m^2/nmi^2) within 100 m buffer zones of the trackline when the echosounder was operational. Eight-day composites satellite images of chlorophyll *a* (mg/m^3) (e) and sea surface temperature (^{0} C) (f) during the field work in the STB (centered on 28 January 2014, 4 km resolution, Moderate Resolution Imaging Spectroradiometer (MODIS)), with survey tracklines overlaid (thick black lines) and the extent of figures a and b denoted by the black box.

Table 2: Blue whale sightings and ancillary data recorded during survey effort in the South Taranaki Bight (21 Jan – 4 Feb 2014).

Date	Time	Latitude	Longitude	Depth (m)	Surface temp (C)	Total number observed	Number of calves observed	Behavior	On/off survey	Photos collected	Biopsy sample collected	Associated fauna	Krill observed
25-Jan-14	14:14	-40.0960	173.2821	100	15.8	5	0	Unknown	On	Y	Y (1 sample)	N	N
28-Jan-14	08:17	-40.2258	172.8408	109	15.3	3	0	Unknown	On	Y	N	N	N
28-Jan-14	09:39	-40.2165	172.8757	109	15.2	2	1	Unknown	On	Y	N	N	N
28-Jan-14	10:38	-40.2237	172.8728	107	15.1	3	0	Unknown	Off	Y	Y (1 sample)	N	N
28-Jan-14	17:29	-40.1432	173.3165	93	16.4	12	0	Unknown	On	Y	Y (4 samples)	N	N
29-Jan-14	09:03	-40.2337	173.2730	87	15.8	1	0	Feeding	On	Y	N	N	Y
29-Jan-14	10:28	-40.2270	173.2718	85	16.2	5	0	Feeding	On	Y	Y (1 sample)	N	Y
29-Jan-14	12:18	-40.2054	173.2578	88	15.8	16	0	Unknown	On	Y	Y (2 samples)	Sei or Bryde's whale	Y
3-Feb-14	14:18	-40.1847	173.1801	91	17.1	2	0	Feeding	On	Y	N	Gannet feeding	N
3-Feb-14	16:14	-40.2046	173.0331	96	18	1	0	Unknown	On*	Y	Y (1 sample)	N	N

Photo-identification: A total of 22 individual blue whales were photo-identified in the STB, representing 44% of the estimated 50 whales observed. Only one photo-identification match was made between the 22 individual blue whales observed in the STB and 859 images from 12 other catalogs. This match was the cow in the cow/calf pair observed on 28-Jan-2014 in the STB, previously observed on 8-Nov-2010 in the Hauraki Gulf, northeast New Zealand, when it was also observed with a calf.

Genetics: All ten STB biopsy samples amplified between 11 and 15 microsatellite loci and were retained as part of the quality controlled dataset. Matching of these genotypes identified one animal sampled twice during the STB surveys (confirmed by photo-id). It was assumed that the 12 beachcast whales represented individuals. Of the nine STB individuals, seven were male and two were female. Conversely, of the 15 NZCeTA individuals, nine were female and three were male (three failed to amplify). Neither dataset was significantly different from a 1:1 sex ratio ($p = 0.090$ and $p = 0.073$, respectively) using a one-tailed binomial test.

Control region haplotypes were sequenced from all but one of the beachcast samples (Table 2). Five haplotypes were identified, four previously described by LeDuc et al. (2007) and one previously undescribed (referred to here as BmuNZ18). For both the STB and NZCeTA samples the majority of the individuals were haplotype 'd' (66% STB; 69% NZCeTA; Table 3). There was no significant difference in mtDNA haplotype frequencies between the two collections ($FST = 0.00$, $p = 0.63$). Comparison of the haplotype frequencies from the combined New Zealand collection to the Southern Ocean and Chilean collections showed highly significant differences for both FST and ΦST, but there was no significant difference between the New Zealand collection and the Australian pygmy form (Table 4).

Stable isotopes: Very little intra-individual variation was observed in the nitrogen and carbon stable isotope values of the blue whale samples, except for one individual (BMU_14_STB_05; Table 4). This result suggests that these whales forage on similar prey, in similar regions. However, the nitrogen isotope value of the composite krill sample was lower than expected for blue whale diet based on reported trophic enrichment factors (TEFs; ~1‰ and 2.1 to 2.8‰ for $\delta^{13}C$ and $\delta^{15}N$ values, respectively; Borrell *et al.* 2012; Browning *et al.* 2014). The higher TEFs between whales and krill relative to literature estimates suggests that whales (a) consumed additional higher-trophic level prey than krill, or (b) foraged on krill with higher $\delta^{13}C$ and $\delta^{15}N$ values in another region where the isotopic baseline was higher. However, caution is necessary when interpreting these comparative predator-prey isotope results due to a prey composite sample size of one, the uncertain applicability of this TEF to blue whales, uncertain turnover rates of blue whale skin, and slight effects of ethanol preservation on biopsy samples (Lesage *et al.* 2010).

Distribution relative to habitat and prey: Twenty-five CTD casts were performed and 21.05 hrs of hydroacoustic backscatter data were recorded. Comparison of blue whale sightings to interpolated surfaces of maximum fluorescence and surface temperature indicated that whales were encountered most frequently near boundaries between relatively high and low fluorescence and temperature, which co-varied spatially (Fig. 4a, b). This spatial association between blue whales and fronts has been documented in other foraging habitats (Croll *et al.* 2005; Gill et al. 2011). Acoustic detection of relative biological productivity was patchy and blue whale encounters were generally in areas of increased NASC, especially below 50 m (Fig. 4c, d). Furthermore, the highest NASC values occurred at two sightings where foraging behavior was documented. Overview satellite imagery of the entire STB region (Fig. 4e, f) showed that survey effort targeted an area of cold water intrusion with increased chlorophyll *a* from a recent upwelling event.

Table 3. Number of blue whale individuals by mitochondrial DNA haplotype for each dataset and the combined New Zealand dataset (STB = South Taranaki Bight samples; NZCeTA = other New Zealand samples). One beachcast sample from the NZCeTA collection failed. Haplotype codes follow Leduc et al. (2007) except where noted in the text.

	STB	NZCeTA	Total
haplotype d	6	10	16
haplotype e		2	2
haplotype ii	2	1	3
haplotype mm		1	1
BmuNZ18	1		1
Total	9	14	23

Table 4: Results of pairwise comparisons of mitochondrial DNA haplotype (FST) and nucleotide (ΦST) diversity between New Zealand and three other southern hemisphere blue whale populations: Southern Ocean, Chile coast and Australia (LeDuc et al. 2007 and Attard et al. 2015 (n=89)). Mitochondrial DNA information from 23 New Zealand individuals was used for these comparisons.

	Sample size	# haps	# haps shared with NZ	FST	P value	ΦST	P value
Southern Ocean	183	52	1	0.205	< 0.001	0.302	< 0.001
Chile coast	113	19	1	0.250	< 0.001	0.340	< 0.001
Australia	89	10	4	0.006	0.247	0.006	0.257

Table 5. The $\delta^{15}N$ and $\delta^{13}C$ values of blue whales and a composite krill sample collected in the South Taranaki Bight between 21 January and 4 February 2014.

		Lipid-corr	
Blue whale	$\delta^{15}N$	$\delta^{13}C^{\dagger}$	C/N ‡
BMU14_STB_01	11.2	-19.7	5.4
BMU14_STB_02	10.7	-19.1	4.7
BMU14_STB_03	11.0	-19.8	4.2
BMU14_STB_05	11.3	-18.7	4.5
BMU14_STB_06	11.1	-19.1	4.8
BMU14_STB_07	11.4±0.6*	-19.9	Na
BMU14_STB_09	10.6	-20.0	4.6
BMU14_STB_10	11.3±0.4*	-19.3±0.2*	4.8
BMU average ± STDEV	11.1 ± 0.4	-19.4 ± 0.4	4.7 ± 0.3
Composite krill	7.9	-21.5	4.7
Trophic Enrichment Factor	3.2	2.1	

*Samples run in duplicate

†Lipid corrected $\delta^{13}C$ values based on Fry (2002) equations.

‡ Atomic C/N values

DISCUSSION

Our study confirms that the STB is a blue whale foraging ground. During this survey, we observed 50 blue whales, documented foraging behavior, confirmed blue whale prey as *N. australis*, observed defecation (evidence of feeding within the last 24 hr), documented similar isotopic values across individuals sampled, and linked blue whale occurrence with frontal margins exhibiting relatively high biological productivity. Genetic analysis determined New Zealand blue whales to be most genetically similar to Australian 'pygmy' blue whales, yet we also identified a new haplotype and found no photo-identification matches to 174 individual Australian blue whales assessed (compared to 1 in 44 individual New Zealand whales assessed). The lack of mtDNA differentiation between Australian and New Zealand blue whales, with no photographic matches, may result from (1) historic genetic connectivity without divergence over recent time scales, or (2) ongoing genetic connection on breeding grounds with separate feeding grounds. These results suggest that New Zealand pygmy blue whales may comprise a unique population.

Given the proximity of blue whales in the STB to industrial activity with associated direct (e.g., vessel strike, toxicity from oil spills, hearing damage from seismic operations) and indirect (e.g., lost foraging opportunities, acoustic masking) threats, there is imminent need for effective regulation. Offshore industrial activity in New Zealand is growing, especially in the STB where permit applications for seabed mining, seismic survey, and additional oil rigs have all been submitted this year. Many of the blue whale sightings made during this field project were in the vicinity of the Maari Wellhead Platform (minimum distance = 11.9km; Fig. 5). Significant vessel traffic and commercial fishing effort also occur in the STB. These current and future anthropogenic activities in the STB must be carefully considered and managed to avoid direct, indirect and cumulative impacts on blue whales. The efficacy of this management process is dependent on robust and well-directed science.

Figure 5. Blue whale surfacing in front of the Maari Wellhead Platform and floating production, storage, and offloading unit (FPSO).

FUTURE RESEARCH

It is important to note that the STB is a large area (approximately 55,835km^2) and only 314 km of trackline were surveyed during this field project. Furthermore, only five days of survey effort during summer months were conducted. For these reasons, results presented here must be considered a snap-shot of blue whale distribution and ecological patterns in the STB. More extensive survey and research effort is needed to more fully understand blue whale ecology in the STB.

Co-funding through industry and NGO partnerships is currently being sought to support a comprehensive research project to collect the data imminently needed to guide management efforts of this space-use conflict between blue whales and industrial activity in the STB. The primary objectives of this research project include the following:

- Determine the spatial and temporal distribution of blue whales in the region and describe how habitat varies relative to whale distribution in order to improve predictability of blue whales.
- Quantify the significance of the STB foraging ground by addressing how often individuals re-occur in STB, how long are individuals resident in the STB, and where else these whales feed.
- Estimate the abundance of blue whales that use the STB and what proportion of New Zealand blue whales feed in the area.
- Describe the population connectivity and trend of this blue whale population to better understand the population's reproductive capacity and if the population is stable, increasing, or decreasing.

The primary methods to be used to gather the necessary data include the following:

- Deployment of an acoustic hydrophone array in the STB to collect continuous blue whale calls over multiple years. These data will provide information on blue whale relative distribution, abundance, behavior, and response to anthropogenic noise.
- Boat-based survey work in the STB during a two-month field season in two consecutive years will collect individual-based photo-id, genetic and stable isotope data, and habitat and prey data. These data will provide information on how often and how long individuals occur in the STB, blue whale habitat use patterns and diet, the population's genetic connectivity, and abundance estimates based on photo-id and genetic mark-recapture methods. During this period, we will also deploy satellite tags to record the large-scale distribution patterns of individual whales outside the STB.

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REFERENCES

Attard, C.R., Beheregaray, L.B., Jenner, K.C.S., Gill, P.C., Jenner, M.-N.M., Morrice, M.G., Teske, P.R. and Möller, L.M. 2015. Low genetic diversity in pygmy blue whales is due to climate-induced diversification rather than anthropogenic impacts. *Biol. Letters* 11:20141037.

Baker, C.S., Slade, R., Bannister, J.L. and Abernethy, R. 1994. Hierarchical structure of mitochondrial DNA gene flow among humpback whales *Megaptera novaeangliae*, world-wide. *Mol. Ecol.* 3:313-327.

Borrell, A., Abad-Oliva, N., Gómez-Campos, E., Giménez, J. and Aguilar, A. 2012. Discrimination of stable isotopes in fin whale tissues and application to diet assessment in cetaceans. *Rapid Commun. Mass. Sp.* 26:1596-1602.

Bradford-Grieve, J.M., Murdoch, R.C. and Chapman, B.E. 1993. Composition of macrozooplankton assemblages associated with the formation and decay of pulses within an upwelling plume in greater Cook Strait, New Zealand. *N. Z. J. Mar. Freshw. Res.* 27:1-22.

Bradford, J.M. and Chapman, B. 1988. *Nyctiphanes australis* (Euphausiacea) and an upwelling plume in western Cook Strait, New Zealand. *N. Z. J. Mar. Freshw. Res.* 22:237-247.

Branch, T.A., Stafford, K.M., Palacios, D.M., Allison, C., Bannister, J.L., Burton, C.L.K., Cabrera, E., Carlson, C.A., Galletti Vernazzani, B., Gill, P.C., Hucke-Gaete, R., Jenner, K.C.S., Jenner, M.N.M., Matsuoka, K., Mikhalev, Y.A., Miyashita, T., Morrice, M.G., Nishiwaki, S., Sturrock, V.J., Tormosov, D., Anderson, R.C., Baker, A.N., Best, P.B., Borsa, P., Brownell Jr, R.L., Childerhouse, S., Findlay, K.P.,

Gerrodette, T., Ilangakoon, A.D., Joergensen, M., Kahn, B., Ljungblad, D.K., Maughan, B., McCauley, R.D., McKay, S., Norris, T.F., Oman Whale and Dolphin Research Group, Rankin, S., Samaran, F., Thiele, D., Van Waerebeek, K. and Warneke, R.M. 2007. Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean. *Mammal Review* 37:116-175.

Browning, N.E., Dold, C., Jack, I.-F. and Worthy, G.A. 2014. Isotope turnover rates and diet–tissue discrimination in skin of ex situ bottlenose dolphins (*Tursiops truncatus*). *J. Exp. Biol.* 217:214-221.

Croll, D.A., Marinovic, B., Benson, S., Chavez, F.P., Black, N., Ternullo, R. and Tershy, B.R. 2005. From wind to whales: trophic links in a coastal upwelling system. *Mar. Ecol. Prog. Ser.* 289:117-130.

de Vos, A., Pattiaratchi, C. and Harcourt, R. 2014. Inter-Annual Variability in Blue Whale Distribution off Southern Sri Lanka between 2011 and 2012. *Journal of Marine Science and Engineering* 2:534-550.

Double, M.C., Andrews-Goff, V., Jenner, K.C.S., Jenner, M.-N., Laverick, S.M., Branch, T.A. and Gales, N.J. 2014. Migratory movements of pygmy blue whales (*Balaenoptera musculus brevicauda*) between Australia and Indonesia as revealed by satellite telemetry. *PloS one* 9:e93578.

Excoffier, L. and Lischer, H.E.L. 2010. Arlequin suite ver 3.5: a new series of programs to perform population genetics analyses under Linux and Windows. *Mol. Ecol. Resour.* 10:564-567.

Fry, B. 2002. Stable isotopic indicators of habitat use by Mississippi River fish. *J. N. Am. Benthol. Soc.* 21:676-685.

Garver, S.A. and Siegel, D.A. 1997. Inherent optical property inversion of ocean color spectra and its biogeochemical interpretation .1. Time series from the Sargasso Sea. *J. Geophys. Res. C.* 102:18607-18625.

Gill, P., Morrice, M., Page, B., Pirzl, R., Levings, A. and Coyne, M. 2011. Blue whale habitat selection and within-season distribution in a regional upwelling system off southern Australia. *Mar. Ecol. Prog. Ser.* 421:243-263.

Gill, P.C. 2002. A blue whale (*Balaenoptera musculus*) feeding ground in a southern Australian coastal upwelling zone. *J. Cet. Res. Mang.* 4:179-184.

LeDuc, R.G., Dizon, A.E., Goto, M., Pastene, L.A., Kato, H., Nishiwaki, S., Leduc, C.A. and Brownell, J.R.L. 2007. Patterns of genetic variation in Southern hemisphere blue whales and the use of assignment test to detect mixing on the feeding grounds. *J. Cet. Res. Mang.* 9:73-80.

Lesage, V., Morin, Y., Rioux, È., Pomerleau, C., Ferguson, S.H. and Pelletier, É. 2010. Stable isotopes and trace elements as indicators of diet and habitat use in cetaceans: predicting errors related to preservation, lipid extraction, and lipid normalization. *Mar. Ecol. Prog. Ser.* 419:249-265.

Morin, P.A., Martien, K.K., Archer, F.I., Cipriano, F., Steel, D., Jackson, J. and Taylor, B.L. 2010. Applied conservation genetics and the need for quality control and reporting of genetic data used in fisheries and wildlife management. *J. Hered.* 101:1-10.

Morrison, K.W., Bury, S.J. and Thompson, D.R. 2014. Higher trophic level prey does not represent a higher quality diet in a threatened seabird: implications for relating population dynamics to diet shifts inferred from stable isotopes. *Mar. Biol.* 161:2243-2255.

Pinkerton, M.H., Schwarz, J., Gall, M. and Beaumont, J. 2013. Satellite ocean-colour remote sensing of the South Taranaki Bight from 2002 to 2012. NIWA report for TransTasman Resrources Ltd. NIWA, October 2013 (unpublished). 75. [Available from

Rennie, S., Hanson, C.E., McCauley, R.D., Pattiaratchi, C., Burton, C., Bannister, J., Jenner, C. and Jenner, M.N. 2009. Physical properties and processes in the Perth Canyon, Western Australia: Links to water column production and seasonal pygmy blue whale abundance. *J Mar Syst* 77:21-44.

Samaran, F., Adam, O. and Guinet, C. 2010. Discovery of a mid-latitude sympatric area for two Southern Hemisphere blue whale subspecies. *Endang Species Res* 12:157-165.

Sambrook, J., Fritsch, E.F. and Maniatis, T. (1989) Molecular cloning: a laboratory manual 2nd ed. Cold Spring Harbor Laboratory Press, Cold Sprink Harbor, New York

Sears, R., Williamson, J.M., Wenzel, F.W., Berube, M., Gendron, D. and Jones, P. (1990) Photographic identification of the blue whale (*Balaenoptera musculus*) in the Gulf of St. Lawrence, Canada (SC/A88/ID23)

Shirtcliffe, T.G.L., Moore, M.I., Cole, A.G., Viner, A.B., Baldwin, R. and Chapman, B. 1990. Dynamics of the Cape Farewell upwelling plume, New Zealand. *N. Z. J. Mar. Freshw. Res.* 24:555-568.

Sremba, A.L., Hancock-Hanser, B., Branch, T.A., LeDuc, R.L. and Baker, C.S. 2012. Circumpolar diversity and geographic differentiation of mtDNA in the critically endangered Antarctic blue whale (*Balaenoptera musculus intermedia*). *PLoS ONE* 7:e32579.

Torres-Florez, J., Hucke-Gaete, R., LeDuc, R., Lang, A., Taylor, B., Pimper, L., Bedriñana-Romano, L., Rosenbaum, H. and Figueroa, C. 2014. Blue whale population structure along the eastern South Pacific Ocean: evidence of more than one population. *Mol. Ecol.* 23:5998-6010.

Torres, L.G. 2013. Evidence for an unrecognised blue whale foraging ground in New Zealand. *N. Z. J. Mar. Freshw. Res.* 47:235-248.

Waits, L.P., Luikart, G. and Taberlet, P. 2001. Estimating the probability of identity among genotypes in natural populations: cautions and guidelines. *Mol. Ecol.* 10:249-256.

Wang, M. and Shi, W. 2007. The NIR-SWIR combined atmospheric correction approach for MODIS ocean color data processing. *Opt. Express* 15:15722-15733.