

New Zealand blue whales: Recent findings and research progress

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ABSTRACT

Since 2012, we have investigated a newly documented group of blue whales (*Balaenoptera musculus* sp.) in the New Zealand region. Field research has focused on multi-disciplinary data collection regarding the ecology of blue whales occurring in the South Taranaki Bight (STB) region of New Zealand (40.15 S, 173.30 W). The STB region incurs significant anthropogenic activities from oil and gas exploration and extraction, fishing activities, vessel traffic, and would also be affected by proposed seabed mining. Therefore, an improved understanding of the population and ecological parameters of blue whales occurring in the STB and throughout New Zealand waters is essential to develop appropriate and effective conservation management plans that mitigate impacts at individual and population levels. Vessel-based field research in the STB was conducted during January and February of 2014, 2016, and 2017. Data collection focused on visual surveys to assess blue whale distribution patterns with concurrent oceanographic and prey (krill) sampling, blue whale behavioral observations, photo-identification, tissue biopsy and fecal sample collection, and health assessment through photogrammetric Unmanned Aerial System (UAS; drone) operations. Additionally, a five-unit hydrophone array was deployed in the STB region in January 2016, which will remain in place for two years to record blue whale vocalizations and ambient noise levels. Data analyses to date has revealed the following significant findings: blue whales occur regularly in the STB to forage on krill; the population consists of a minimum of 140 photo-identified individuals; blue whales occur in the STB region almost year-round as described by vocalization detections at the five hydrophones of the New Zealand blue whale call; these whales are most genetically similar to Australian ‘pygmy’ blue whales (*B. m. brevicauda*), with one unique mtDNA haplotype identified and very low haplotype diversity; blue whales shift habitat use patterns across the STB region relative to oceanographic patterns, as demonstrated by a markedly different distribution pattern in 2016 during an El Niño event; individual blue whales re-occur within the STB and New Zealand waters inter-annually, including one individual seen three times over a six-year period; blue whales likely also use the STB region as a nursing and breeding area as indicated by behavioral observations and regular acoustic detection of the New Zealand blue whale call. Many lines of evidence now lead us to hypothesize that these whales form a New Zealand population of blue whales that are either resident or semi-resident in New Zealand waters. Continued data collection and analysis is necessary to fill pressing knowledge gaps regarding the ecology of this blue whale population in order to inform environmental management decisions.

KEYWORDS: BLUE WHALES, NEW ZEALAND, PHOTO-ID, ECOLOGY, BEHAVIOR, FORAGING GROUND, ACOUSTICS, GENETICS, ANTHROPOGENIC IMPACTS, STABLE ISOTOPE VALUES, CONSERVATION, POPULATION PARAMETERS

INTRODUCTION

A hypothesis was put forward by Torres (2013) that the South Taranaki Bight (STB) region of New Zealand (Fig. 1) is an important foraging ground for blue whales (*Balaenoptera musculus* sp.). This hypothesis was based on (1) opportunistic and marine mammal observer (on seismic surveys) sightings of blue whales in the STB, (2) historical sightings of blue whales in the STB from Soviet and Japanese whaling records, (3) stranding records of blue whales around New Zealand, and (4) oceanographic studies in the STB documenting regional upwelling events that cause high productivity (Shirtcliffe et al. 1990) and lead to large aggregations of krill (*Nyctiphanes australis*), a known blue whale prey item in the Australasian region (Gill 2002).

The STB region is of particular interest as it is New Zealand's most industrial marine region. There are active oil and gas extraction platforms, and ongoing seismic survey efforts to explore for more oil and gas reserves. Busy vessel traffic frequents the STB with multiple major ports in the region and the neighboring major shipping channel of the Cook Strait. Additionally, the STB is the site of a proposed contentious seabed mine, whereby Trans-Tasman Resources Ltd. is proposing to extract 50 million tons of iron sands from the seafloor each year over a 35-year period (<http://www.epa.govt.nz/EEZ/whats-going-on/current-applications/ttr-2016/Pages/default.aspx>). Hearings for the permit application case are currently ongoing, and the New Zealand Environmental Protection Authority Decision Making Committee is anticipated to make their decision by the end of June 2017. Throughout the permit application hearings, data presented here in this report have been requested to aid in the decision-making process. Understanding distribution and residency patterns, population connectivity, habitat use, and health of this little-studied blue whale population is critical for the evaluation of the potential impacts they may face from the aforementioned industrial activities.

In order to fill knowledge gaps regarding blue whales in the STB, we initiated a dedicated research program in 2013 that consists of a multi-disciplinary approach to enhance our ecological and biological understanding of these whales and their habitat. Since this time we have compiled various data streams regarding blue whale ecology in the STB and New Zealand waters that have developed our knowledge and potential for conservation management of this newly documented blue whale population.

METHODS

Field efforts: Data collection took place in January and February of 2014, 2016, and 2017 in the STB region (Fig. 1). Field work consisted of survey effort for blue whales, oceanographic sampling, collection of hydroacoustic backscatter data on prey availability, behavioral observations of whales, collection of photo-identification data, skin and blubber biopsy sampling, unmanned aerial system (UAS, a.k.a. "drone") flights over whales for photogrammetric data collection, and opportunistic collection of blue whale fecal samples and krill. A 14m jet-propelled catamaran, equipped with oceanographic sampling capabilities and a flying bridge for observational work, was used as the research platform for the 2014 and 2016 field seasons. In 2017, a 19.2 m vessel equipped with the same survey and oceanographic sampling capabilities was used as the platform for field work. Prior to each survey day, daily images of sea surface temperature (SST) and chlorophyll-*a* (chl-*a*) were assessed to locate areas of upwelled water and high surface productivity, and survey effort was directed toward those areas or to areas previously unsurveyed.

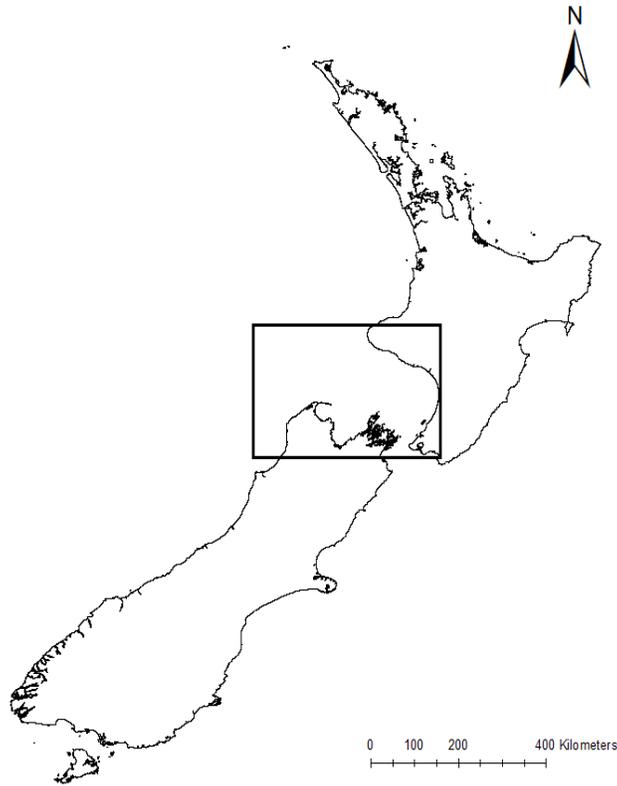


Figure 1. A map of New Zealand, with the South Taranaki Bight (STB) region delineated by the black box.

Survey effort was conducted on days with suitable weather conditions (Beaufort Sea State < 5). Profiles of water column depth, temperature, salinity and fluorescence 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. Hydroacoustic 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 in 2014 and 2016, and 1.45 m below the vessel in 2017. 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 in 2014 and 2016, hydroacoustic data were collected to assess prey availability in the region. In 2017, a RHIB tender was utilized to collect photo-identification and biopsy data, allowing the main research vessel to collect hydroacoustic data during the sighting.

Photo-identification images of the left and right sides of each blue whale were captured whenever possible. After effort was spent on photography, biopsy effort was initiated, with simultaneous photography effort to identify sampled whales. Skin and blubber biopsy samples were collected using a lightweight biopsy dart (cutting head 7 X 19 mm) fired from a Paxarms biopsy projector (Krützen et al. 2002; New Zealand Department of Conservation permits Rnw/HO/2009/03; AEC225; AEC266). Samples of sufficient size were divided for genetic, hormone, and stable isotope analyses. All samples were either frozen at -20°C or stored in 90% ethanol, dependent on biological analysis. When conditions permitted, the UAS was launched from the aft deck and navigated over the whale at least 30 m above the surface of the water. Once behavioral observations and satisfactory images for photogrammetry were obtained, the UAS was retrieved. A fine-mesh (300 µm) dip net attached to a long pole was used to collect fecal and krill samples from surface waters opportunistically when material was observed. Sample materials were placed in sterilized plastic jars and frozen.

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 compared to 13 other sources of photo-identification from New Zealand waters, as well as three catalogs from Australian waters and one from Antarctic waters (Table 1).

Table 1. Sources of photo-identification data from within New Zealand waters and from Australian and Antarctic regions.

Contributor	Years	Region	Number of IDs
Australian Marine Mammal Centre (Double et al. 2013)	2013	South Island	14
Cawthron Institute	2013	South Taranaki Bight	2
Chris Tessaglia-Hymes, Cornell University	2017	South Taranaki Bight	3
Department of Conservation, Cook Strait Survey	2004, 2008, 2011, 2013, 2014	Cook Strait	13
Eric De Boer, Department of Conservation Westport Office	2015	Westport	4
Olive Andrews, Silversea Expeditions	2015	Westport, Raoul Island	5
Petroleum Geo-Services Seismic Survey	2016	South Taranaki Bight	2
Don Neale, Department of Conservation Technical Advisor	2015	Westport	1
Theresa Kirchner, Oregon State University	2013	Kaikoura	1
Todd Energy Survey	2013	South Taranaki Bight	3
University of Auckland	2010	Hauraki Gulf	2
Whale Watch Kaikoura	2010, 2012, 2013, 2014, 2016	Kaikoura	13
Wings Over Whales	2016	Kaikoura	1
Australian Marine Mammal Centre	2012	Bonney Upwelling, South Australia	56
Blue Whale Study, Inc.	1998-2000, 2003-2011	Bonney Upwelling, South Australia	139
Brian Miller, Australian Antarctic Division	2014	East Coast of Australia	2
Australian Marine Mammal Centre (Double et al. 2013)	2013	Antarctica	65

Genetics: Tissue (n = 19) and fecal samples (n = 7) collected in the STB during 2014 and 2016 were analyzed along with 14 individuals identified from beachcast or biopsy samples held at the New Zealand Cetacean Tissue Archive (NZCeTA) (described in Torres et al. 2015).

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). Fecal samples were first filtered through a 0.4 µm Cyclopore polycarbonate track etched membrane filter (GE Healthcare Life Sciences). The filter was transferred to a 2 ml tube and frozen in 800 µl of Longmire’s buffer (Longmire et al. 1997) until extraction. Total genomic DNA was extracted from the filtered samples using the phenol/chloroform method described above for skin samples with an extended mixing period during the first PCI step to ensure the filter had completely dissolved. Initial attempts to amplify DNA from fecal samples failed, suggesting the presence of PCR inhibitors. Affected DNA was cleaned with a OneStep™ PCR inhibitor removal kit (Zymo Research), in some cases two applications were necessary to remove all inhibitors.

All samples were used for a standard DNA profile, including molecular sex identification, amplification and sequencing of the mitochondrial DNA (mtDNA) control region, and microsatellite genotyping followed Sremba et

al. (2012). Control region sequences were edited to a 410 bp 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). 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 calculate haplotype diversity and to test for mtDNA haplotype differentiation between STB and NZCeTA samples, and among the combined New Zealand samples, and three other populations of blue whales: the Southern Ocean (n=183, Sremba et al. 2012), the Southeast Pacific including the Chilean coast (n=113, Torres-Florez et al. 2014), and Australia (n=28, LeDuc et al. 2007; n=89, Attard et al. 2015) populations. We note that LeDuc et al. (2007) refers to the ‘Indian Ocean’ population, including samples collected from the southern and western coasts of Australia, the southwest Indian Ocean near Madagascar and from near the Maldives. Here we use only the samples from the southern and western coasts of Australia. We also note that Australian samples from LeDuc et al. (2007) are reportedly included in the total of n = 89 samples in Attard et al. (2015). The significance of differences in haplotype diversity between the New Zealand dataset and the other blue whale populations were tested using a permutation procedure available in R, *Genetic_diversity_diffs* v1.0.4 (Alexander et al. 2016).

Acoustics: Low-frequency acoustic data, including blue whale vocalizations, were collected using Marine Autonomous Recording Units (MARUs) (Calupca et al. 2000). Distances between surveyed sites ranged between 52.34 km and 192.47 km. Data have been collected continuously over the course of two deployments at each surveyed site: Deployment 01 (January 22nd 2016 - July 1st 2016) and Deployment 02 (July 10th 2016 – December 30th 2016). MARU recordings cover the 10 Hz to 800 Hz frequency range (2 kHz sampling rate).

Data were examined for the acoustic occurrence of the New Zealand blue whale call type (McDonald et al. 2006) (Fig. 2) using Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, USA). Data were visually reviewed in 15-minute spectrograms, with a 10-250 Hz frequency bandwidth, a 512-point Hann window, and 50% overlap. Nearly 300 days of recordings (MARU 1: n = 298; MARU 2: n = 299; MARU 3: n = 299; MARU 4: n = 295; MARU 5: n = 302) were browsed in entirety, and the daily acoustic presence/absence of the New Zealand blue whale call type was annotated for each MARU location.

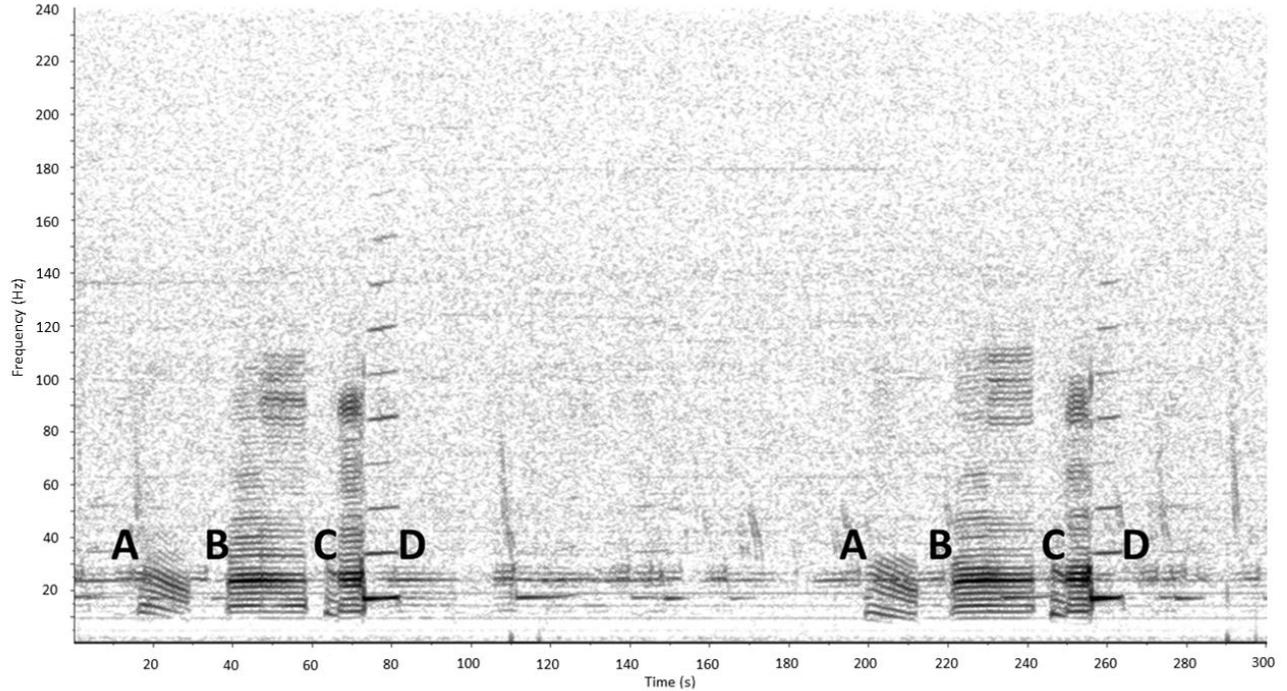


Figure 2. Example spectrogram of the New Zealand blue whale call type recorded at surveyed site MARU 2 on April 22nd, 2016 (1024-point FFT, Hann window, 90% overlap). The call type consists of four parts (A-D), and often occurs in long sequences.

Percent monthly presence for each site was normalized for recording effort by dividing the number of days containing the New Zealand blue whale call type by the number of recording days analyzed within the month:

$$\text{Percent Monthly Presence for Each Site (\%)} = \frac{\text{Number of days per month with acoustic presence}}{\text{Number of days analyzed per month}} * 100$$

The monthly site presence of all recording sites within and outside of the STB was averaged for each month, and reported as an average monthly array presence with standard error.

UAS flights and photogrammetry: Photogrammetry images of blue whales to derive metrics of body condition (length, width, health, pregnancy, lactation) were collected using a UAS (DJI Phantom 3), which was launched from the aft deck of the research vessel when weather conditions and whale behavior were favorable. The UAS was then directed to the whale and flown no lower than 30 m above the water over the whale with the camera in nadir. For calibration purposes, the UAS was flown above an object of known length (*e.g.*, the transom of the research vessel or a board) before each flight at variable altitudes.

Still images of the whales and the scaling object were extracted from UAS video using the Windows program *VLC Media Player*, and stills were only taken when the object of interest was in the center of the frame. All stills of the whales were taken when the animal was at the surface and their body was stretched out to its full length and not bent or curved. The known altitude of the camera during the capture of each still image was used to scale image pixel length to a metric unit using the new MATLAB-based program *Whale Calibration Object Measurement* (Burnett et al., *In Review*). Whale length measurements from the 2016 UAS flights were then made using the new MATLAB-based program *Whale Measurement* (Burnett et al., *In Review*).

Stable isotope analysis: Biopsy samples collected from blue whales during the 2014 and 2016 field seasons, and a homogenate sample of several individual krill ($n = 25$) collected in 2014, underwent bulk carbon and nitrogen stable isotope analysis. This analysis was carried out on a Delta V Plus continuous flow isotope ratio mass spectrometer linked to a Flash 2000 elemental analyzer using a MAS 200 R autosampler (Thermo-Fisher Scientific, Bremen, Germany) at the NIWA Ecological Stable Isotope Laboratory in Wellington, New Zealand. The $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values were compared between years to examine any shifts in feeding ecology between the two years.

New Zealand-wide blue whale sightings: A total of 553 opportunistically and systematically collected blue whale sightings across all New Zealand waters have been compiled. Our project represents the only directed blue whale survey in New Zealand waters to-date. Therefore, other sources of blue whale sightings include those compiled in the New Zealand Department of Conservation sightings database, reported by marine mammal observers during seismic surveys, and opportunistic sightings reported during surveys for other marine mammals (Table 1). The 553 blue whale sightings were reported between 1980 and 2017; 513 had precise sighting coordinates, whilst for the remainder of the sightings regional locations were provided. The temporal and spatial extent of these sightings were examined to conduct a preliminary assessment of blue whale distribution within New Zealand waters.

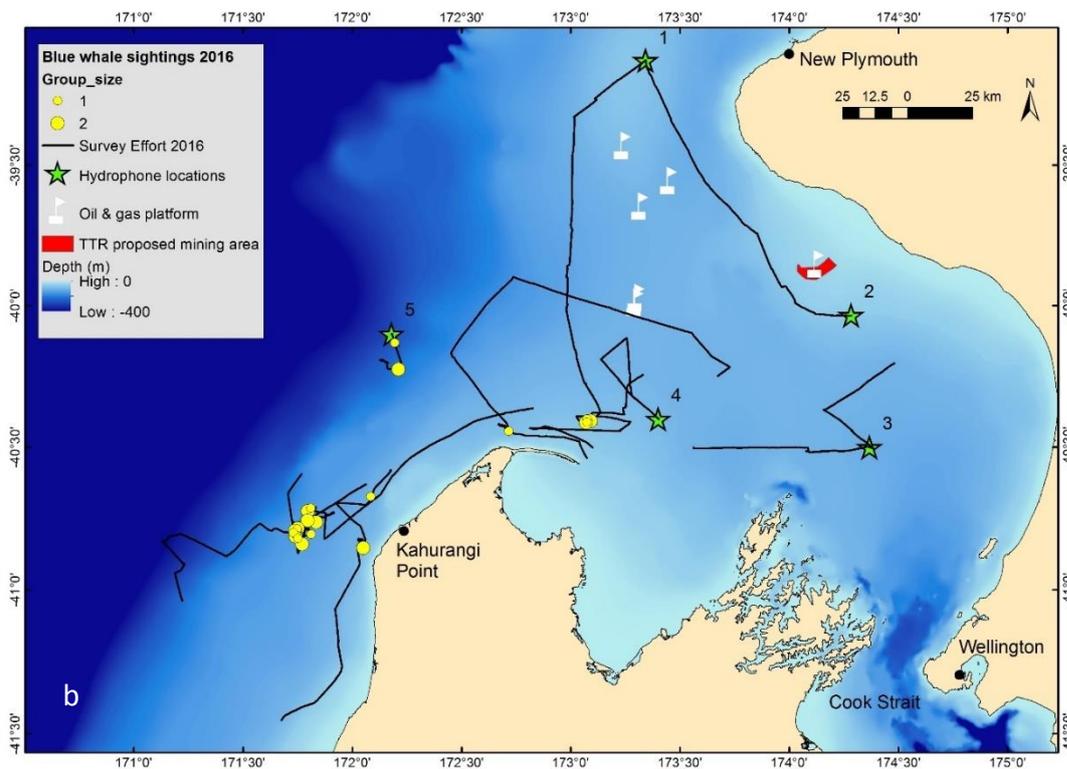
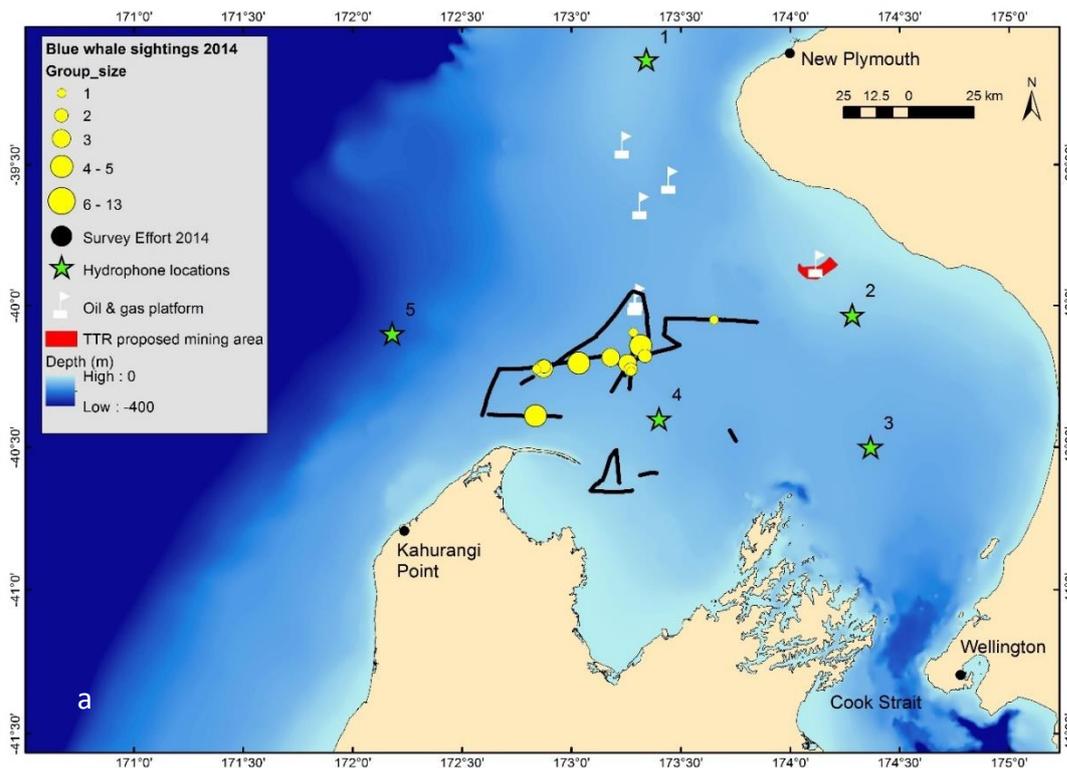
RESULTS

Field efforts: Each survey year yielded new insights and data regarding this population of blue whales in New Zealand. Despite half as much survey effort in 2014 compared to 2016 and 2017, all years of effort have provided a robust dataset for further analysis of ecology, biology, and population parameters (Table 2).

Table 2. Summary of field effort and data collected during the blue whale research program in the STB during the three years of study, and the cumulative total.

	2014	2016	2017	Total
<i>Survey days</i>	5	10	9	24
<i>Survey effort (nm)</i>	170	1,490	906	2,566
<i>Cetacean sightings</i>	14	39	48	101
<i>Blue whale sighting events</i>	10	22	32	64
<i>Number of blue whales sighted</i>	50	33	68	151
<i>Photos</i>	2,326	4,000	9,742	16,068
<i>Mother/calf pairs</i>	1	4	3	8
<i>Biopsy samples</i>	10	10	23	43
<i>Fecal samples</i>	2	8	9	19
<i>UAS flights</i>	0	8	23	31
<i>Number of whales flown over</i>	0	6	26	32
<i>CTD casts</i>	25	84	87	196
<i>Echosounder hours</i>	21	44	91	156
<i>Krill samples</i>	1	0	1	2

Distribution patterns: Blue whales were observed in the STB region in all survey years. In 2014 and 2017 most observations of blue whales were made within the central region of the STB, while in 2016 more blue whales were observed in the western region of the STB, west of Kahurangi Point (Fig. 3). Preliminary oceanographic assessment leads us to believe that this shift in blue whale distribution during 2016 was due to a strong El Niño event that caused elevated water temperatures across the region, which were notably higher than in both 2014 and 2017 (Fig. 4). The water temperatures in the STB reached 10°C warmer in 2016 than in 2014 or 2017. Blue whales were mostly seen off the west coast in 2016. In comparison, during 2014 and 2017 blue whale sightings were concentrated in the cold plume of upwelled water that is generated off of Kahurangi Point and curves around Farewell Spit into the STB (Shirtcliffe et al. 1990), as can be seen in Figure 4a and 4c. Additionally, few krill were observed at the surface and on the echosounder in 2016 compared to 2014 and 2017.



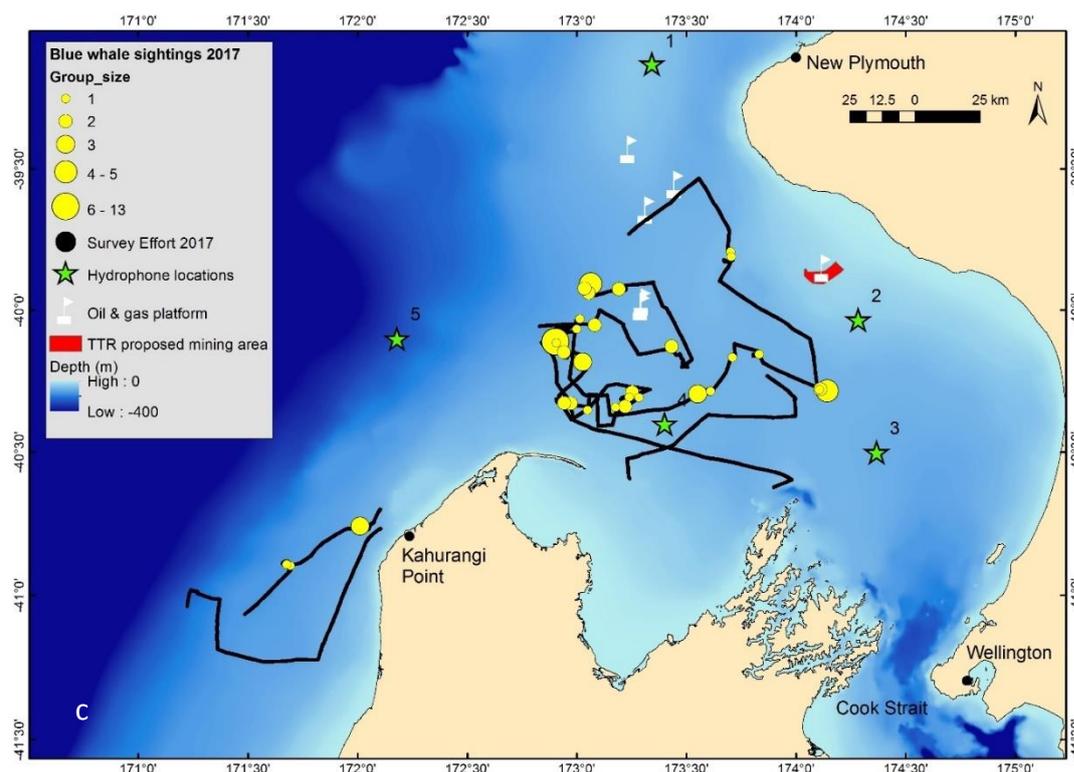


Figure 3. Blue whale vessel survey effort and location of sightings in the STB region during (a) 2014, (b) 2016, and (c) 2017. The deployment locations of the five MARU hydrophones are denoted. Oil and gas rigs and the area of proposed seabed mining are also identified.

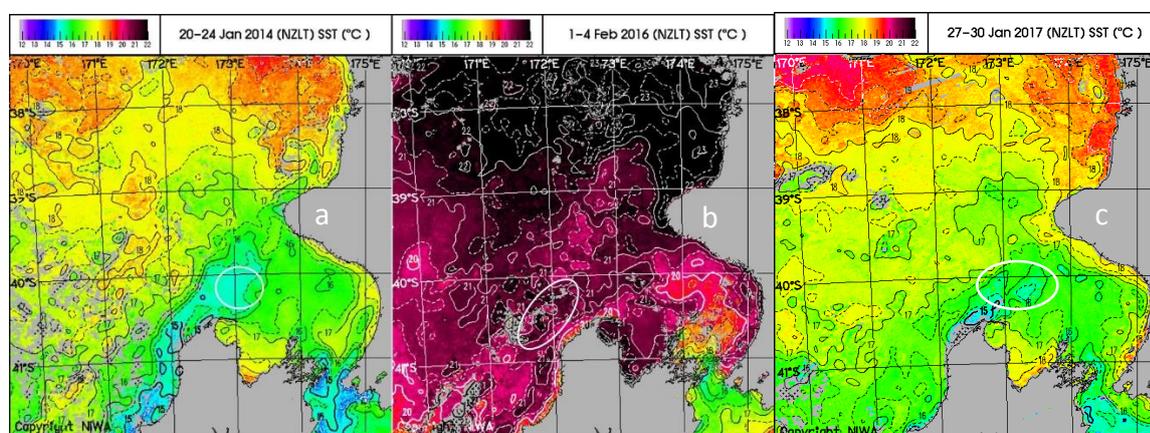


Figure 4. A comparison of satellite images of sea surface temperature (SST) in the STB region between late January 2014 (a), early February 2016 (b), and late January 2017 (c). The white circles on each image denote where the majority of blue whales were encountered during each field season.

Behavioral observations: The most commonly observed blue whale behavior during our survey effort was foraging. This behavior was characterized by whales staying in one area, moving slowly, diving and changing direction frequently, and occasionally lunging at the surface. Krill patches were also evident in the surface waters and on the echosounder display. During surface lunges, the pectoral fin and fluke were usually visible above the water, and sometimes the throat pleats were visible as well. Additionally, we observed surface lunge behavior from video footage captured by the UAS (Fig. 5; video viewable here: <https://www.youtube.com/watch?v=YARe1etnNZE&feature=youtu.be>). During this sequence, the whale approached a dense patch of krill (*Nyctiphanes australis*), rolled on its left side, and then rolled completely onto its right side to lunge and engulf the krill. The whale subsequently swam past numerous patches of krill that were smaller in size without lunging at them.

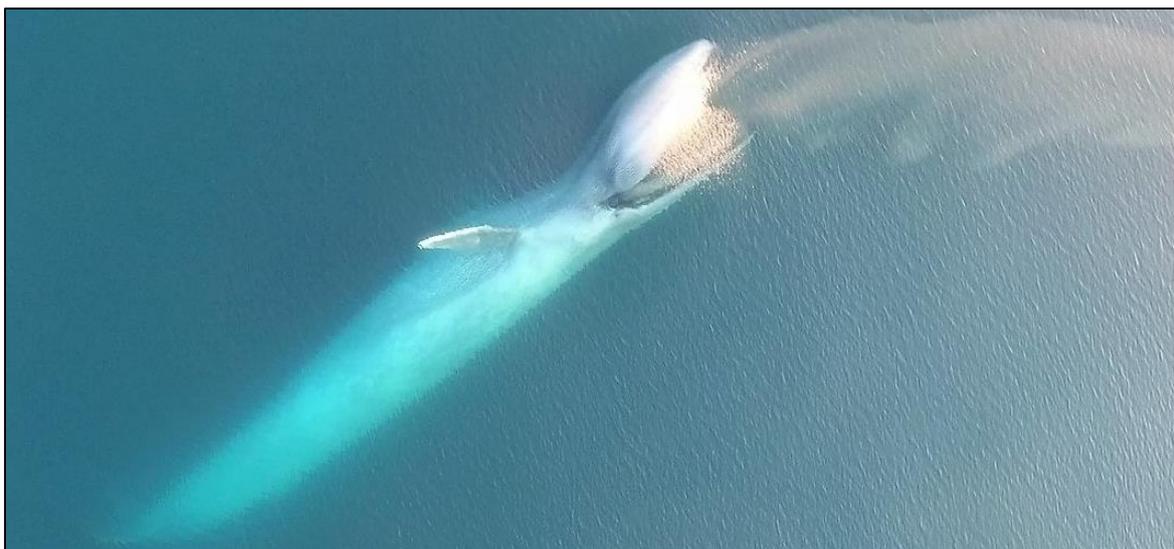


Figure 5. UAS still image of a blue whale surface lunge feeding. The krill patch is also visible in this image; the species of krill is presumed to be *N. australis*.

Eight mother and calf pairs were identified in the STB region during our survey effort over the total three year's observations, and one pair was seen multiple days in a row in the same area in 2017. In 2016, the UAS was flown over a calm mother and calf pair and we recorded 10 minutes of apparent nursing behavior (<https://www.youtube.com/watch?v=9hpfVmP0hJ4>). It is believed that this is the first aerial footage of this behavior in a baleen whale. The calf can be seen alternating between surfacing to breath and going under the mother and stationing at the approximate location of the mammary slits (Fig. 6). The pair were not moving/traveling in the water so it is unlikely that this position was facilitating transit, for example by using the echelon position.



Figure 6. Still images captured from the UAS video of the mother-calf pair nursing in the South Taranaki Bight region. The pair surface to breath (a) and then the calf stations under the mother (b). The calf's pectoral fins and flukes are visible under the mother.

In 2016, we observed a pair of blue whales racing for approximately 30 minutes at 15-18 knots, after which they slowed with occasional bursts of speed. The two animals stayed very close together and one animal was smaller than the other (Fig. 7). Genetic analysis of biopsy samples of these racing individuals determined that both were female.



Figure 7. Two blue whales engaged in racing behavior in the STB during the 2016 survey.

Two blue whales with apparent deformities were observed, one in 2016 and one in 2017 (Fig. 8). Both whales had a dish-like depression behind the blowhole and an unusual swimming pattern in which they appeared to “plow” through the water. The whale observed in 2016 also had a large protrusion on its right hand side, and its spine was visible indicating that the whale was likely malnourished.



Figure 8. Two whales with apparent malnourishment and/or deformities seen in (a) 2016 and (b) 2017 in the STB.

Photo-Identification: Over the three years of survey effort in the STB region, 107 blue whales were observed. Of those, a total of 88 unique individual blue whales were identified. A discovery curve showing the cumulative number of identified individuals for each sequential day of survey effort continues to increase with data collection efforts (Fig. 9), indicating that we have not identified most individuals in this population yet.

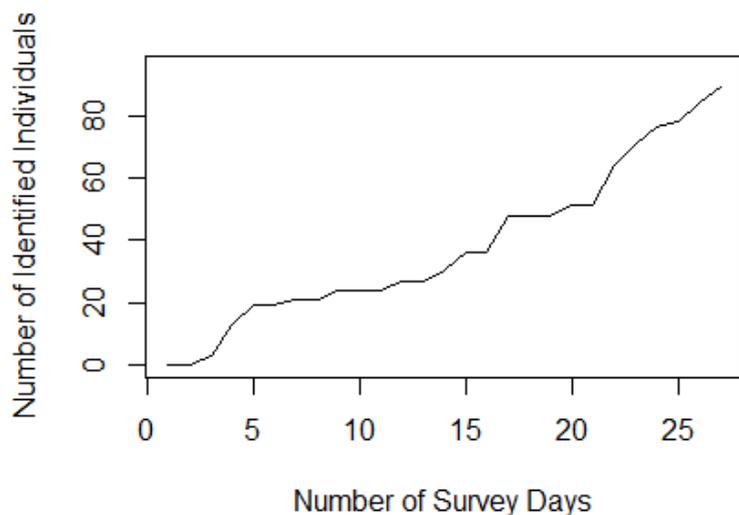


Figure 9. Photo-identification discovery curve from our survey effort, showing the cumulative number of photo-identified individuals with each sequential day of survey effort.

With all blue whale photo-identification records in New Zealand (Table 1) compiled with our images captured during survey effort in the STB region, our New Zealand blue whale photo-identification catalog consists of 140 unique individuals. Eight matches have been made between years within New Zealand waters (Table 3), and 16 whales have been seen multiple times within the same year. The inter-annual matches included one individual (NZBW031) that was seen in three different years in three different regions of New Zealand, and with a different calf each time. Another noteworthy resighting is of NZBW004, which was seen by our team in 2014 and again in 2016. In 2014 the whale appeared to be in good health (Fig. 10a), however in 2016 this whale had apparent deformities, including a collapsed dorsal fin, a dish-like depression behind the blowhole, and a very large protrusion which may have been a tumor or vessel strike injury (Figs. 8a, 10b). This match was initially made via genetics, as visual appearance of the animal had changed drastically, hindering photo-id matching. Yet, closer photo-id comparison of images between sightings has also confirmed this match (Fig 10).

No photo-identification matches have been made between a blue whale sighted in New Zealand waters with a cataloged photo of a blue whale sighted in Australian or Antarctic waters (n = 262 individuals; Table 1).

Table 3. New Zealand blue whale photo-identification matches made between years.

Whale ID	Sighting 1	Sighting 1 Location	Sighting 1 Catalog	Re-sighting	Re-sighting Location	Re-sighting Catalog
NZBW031	8-Nov-2010	Hauraki Gulf	University of Auckland	28-Jan-2014	South Taranaki Bight	Oregon State University, GEMM Lab
				11-Aug-2016	Kaikoura	Whale Watch Kaikoura, Wings Over Whales
NZBW003	27-Jun-2011	Cook Strait	Department of Conservation Cook Strait Survey	23-Jan-2016	South Taranaki Bight	Oregon State University, GEMM Lab
NZBW023	22-Feb-2013	South Taranaki Bight	Todd Energy Survey	5-Feb-2016	South Taranaki Bight	Oregon State University, GEMM Lab
NZBW004	25-Jan-2014	South Taranaki Bight	Oregon State University, GEMM Lab	26-Jan-2016	South Taranaki Bight	Oregon State University, GEMM Lab
NZBW008	1-Feb-2016	South Taranaki Bight	Oregon State University, GEMM Lab	5-Jan-2017	South Taranaki Bight	Chris Tessaglia-Hymes
NZBW011	31-Jan-2013	Westport	Australian Marine Mammal Centre	2-Feb-2016	South Taranaki Bight	Oregon State University, GEMM Lab
NZBW018	5-Feb-2016	South Taranaki Bight	Oregon State University, GEMM Lab	19-Feb-2017	South Taranaki Bight	Oregon State University, GEMM Lab
NZBW078	27-Jun-2008	Cook Strait	Department of Conservation Cook Strait Survey	Jan-2013	Kaikoura	Whale Watch Kaikoura

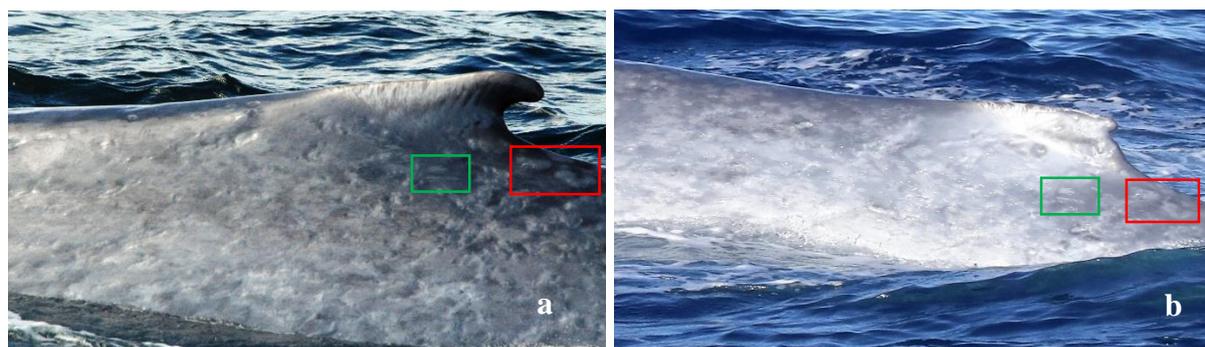


Figure 10. Blue whale NZBW004 photographed in (a) 2014 and (b) 2016 when it had apparent deformities (also see Fig. 8a). Note how the dorsal fin has collapsed in the photo taken in 2016. Genetic identification confirms this individual match. Matching photo-id skin pigmentations are highlighted in color-matched boxes.

Genotype identification and population comparison: All 20 STB biopsy samples, and six of the seven fecal samples amplified for 14 or 15 microsatellite loci and were retained as part of the quality controlled dataset. Matching of these genotypes identified four animals sampled twice by biopsy within sampling years 2014 and 2016 (confirmed by photo-identification), and three animals (from four samples) sampled by both biopsy and fecal collection (in 2016). After removing replicates, genotypes of the nine individuals sampled during the 2016 field season were compared to genotypes of the 12 individuals previously biopsied (nine from 2014 STB survey and three from NZCeTA). This comparison identified one individual sampled in the STB in both the 2014 and 2016 field seasons (Fig. 10). After removing this replicate, the New Zealand blue whale genetic catalogue (i.e., the DNA register) contains 31 individuals, which include 12 beachcast animals, 17 animals identified from biopsy samples, and two identified from fecal samples.

Control region haplotypes were sequenced from all eight of the new individuals sampled in 2016 (Table 4). Only two haplotypes were identified, ‘haplotype d’ and ‘haplotype e’, both previously described in this region (Torres et al. 2015). There was no significant difference in mtDNA haplotype frequencies between the NZCeTA and the STB collections ($F_{ST} = 0.00$, $p=0.88$). Comparison of the haplotype frequencies from the combined New Zealand collection to the Southern Ocean and Southeast Pacific populations showed highly significant differences for both F_{ST} and Φ_{ST} , but there was no significant difference between the New Zealand collection and either of the Australian datasets (Table 5). However, the haplotype diversity of the New Zealand dataset ($h=0.443$, ± 0.105 , Table 4) was significantly lower than any of the other blue whale populations tested ($p<0.001$), including the Australian population (Table 5, Fig. 11).

Table 4. The frequencies of mitochondrial DNA haplotype for individual blue whales biopsy sampled from the STB in 2014 and 2016, and from beachcasts around New Zealand (NZCeTA). Individual identification was confirmed by microsatellite genotypes. Haplotype diversity was calculated from the total sample of $n = 31$. The STB dataset represents 15 individuals identified from biopsy samples and two from fecal samples. One beachcast sample from the NZCeTA collection and one fecal sample failed. Haplotype codes follow LeDuc et al. (2007) except for BmuNZ18 described in Torres et al (2015).

	STB	NZCeTA	Female	Male	Unknown	Total NZ
haplotype d	13	10	11	7	5	23
haplotype e	1	2	2	1		3
haplotype ii	2	1	1	2		3
haplotype mm		1	1			1
BmuNZ18	1			1		1
Total	17	14	15	11	5	31
Haplotype diversity						0.443 \pm 0.105

Table 5. Results of pairwise comparisons of mitochondrial DNA haplotype (F_{ST}) and nucleotide (Φ_{ST}) diversity between New Zealand blue whales and three other populations: (1) The Southern Ocean, (2) the Southeast Pacific including Chile, Ecuador and Peru, and (3) two publicly available datasets from Australia (LeDuc et al. 2007, Attard et al. 2015). Mitochondrial DNA information from 31 New Zealand individual blue whales was used for these comparisons. Haplotype diversity for the New Zealand dataset is 0.443 ± 0.105 . Note: LeDuc et al. 2007 refers to the ‘Indian Ocean’ population, including samples collected from the southern and western coasts of Australia, the southwest Indian Ocean near Madagascar and from near the Maldives. Here we use only haplotypes from the samples from the southern and western coasts of Australia.

Dataset	Sample size	# haps	#haps shared with NZ	hap. diversity (h)	F_{ST}	P value	Φ_{ST}	P value
Southern Ocean	183	52	1	0.969 ± 0.004	0.233	< 0.001	0.314	< 0.001
Southeast Pacific	113	19	1	0.869 ± 0.012	0.280	< 0.001	0.356	< 0.001
Australia (LeDuc et al. 2007)	28	10	4	0.709 ± 0.091	0.015	0.162	0.000	0.586
Australia (Attard et al. 2015)	89	14	4	0.680 ± 0.053	0.022	0.072	0.009	0.171

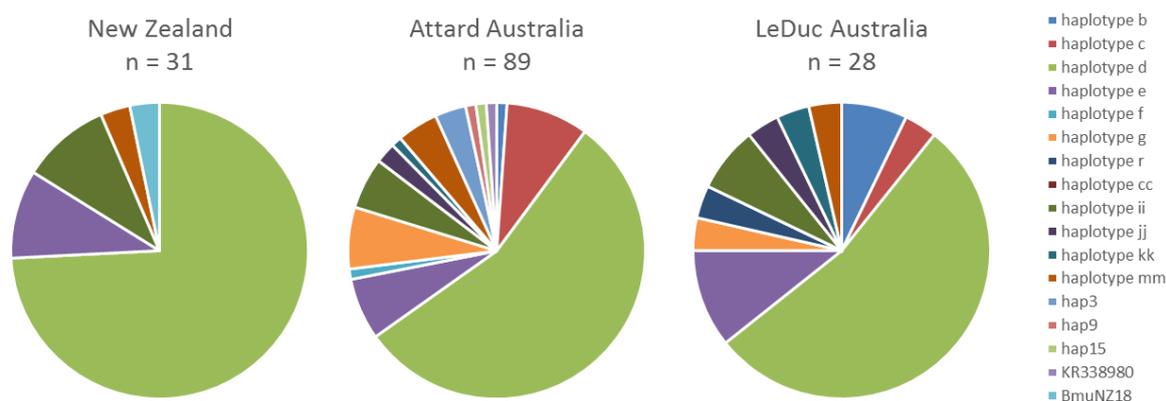


Figure 11. Haplotype frequencies of sampled New Zealand blue whales and the two Australian datasets (LeDuc et al. 2007, Attard et al. 2015).

Acoustics: In the approximately 11 months of acoustic data collected during hydrophone deployments 01 and 02, the New Zealand blue whale call type was detected regularly (> 69% daily occurrence) at each of the five surveyed sites (Fig. 3) within and surrounding the STB region (Table 6, Fig. 12). Blue whales were most frequently detected at survey sites MARU 1 and 5, with 96.6% and 99.7% daily detection of acoustic presence, respectively (Table 6, Fig. 12).

Table 6. Percent daily occurrence of the New Zealand blue whale call type at each surveyed site within and surrounding the South Taranaki Bight, New Zealand.

Site	# Recording Days Analyzed	# Days Acoustic Presence	Percent Daily Presence
MARU 1	298	288	96.6%
MARU 2	299	232	77.6%
MARU 3	299	205	68.6%
MARU 4	295	262	88.8%
MARU 5	302	301	99.7%

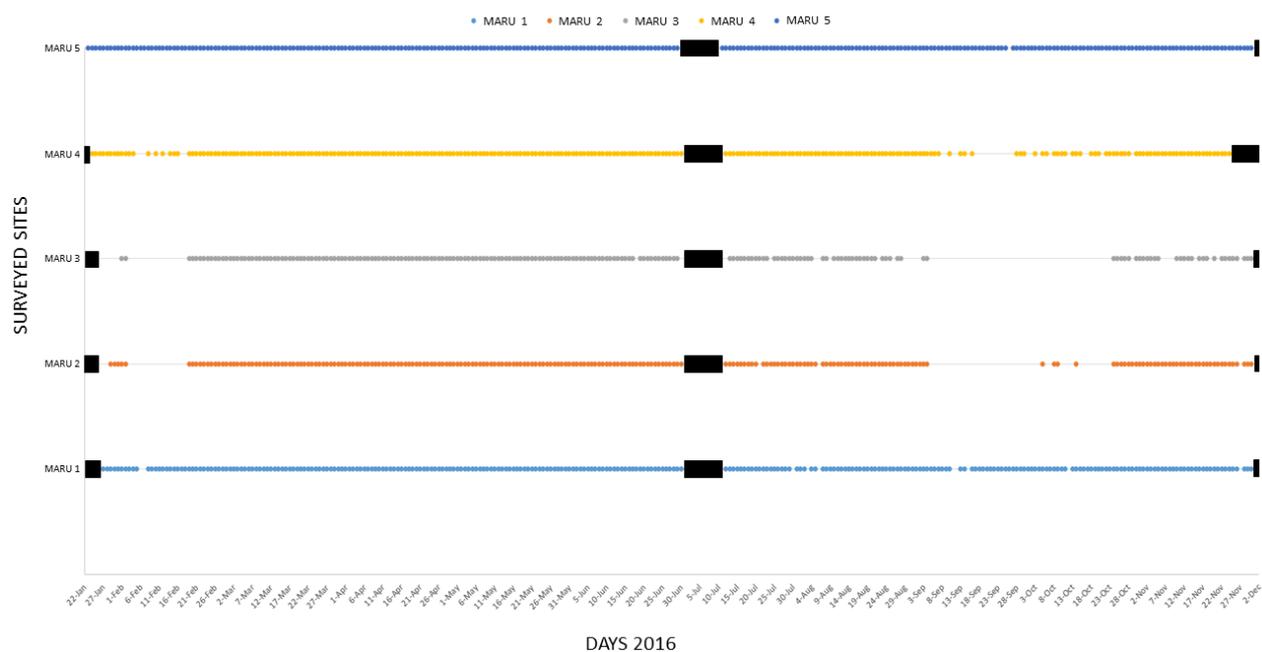


Figure 12. Daily acoustic presence of the New Zealand blue whale call type at all five survey sites. Colored dots indicate presence; black rectangles indicate no data were collected or analyzed during that period at that survey site.

With acoustic detections averaged across the entire hydrophone array, blue whales were acoustically detected within and surrounding the $STB \geq 70\%$ days per month during January-August and November 2016 (Fig. 7). Average blue whale vocal presence decreased to 50.7% days per month sampled in September 2016, and increased to 65.8% in October 2016 (Fig. 13). We believe the dip in blue whale acoustic detections during January and February 2016 is due to the unfavorable oceanographic conditions in the central portion of the STB caused by the strong El Niño event and elevated water temperatures (Fig. 4), which corresponds to a lack of visual sightings detected during the same time period (Fig. 3b).

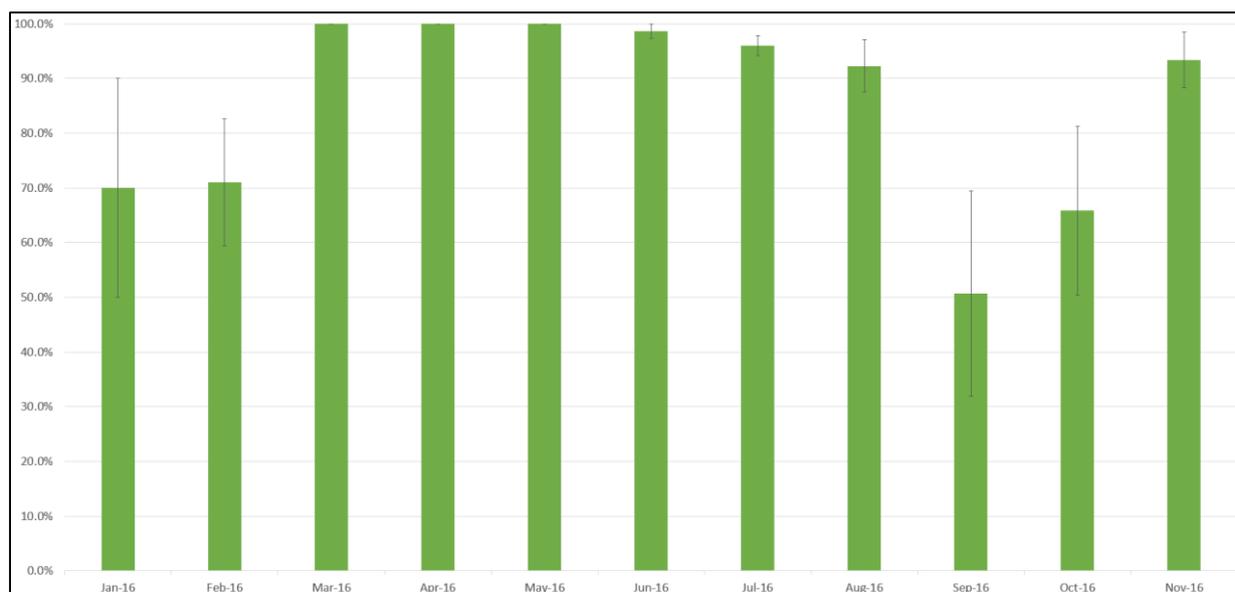


Figure 13. Blue whale average array monthly acoustic presence across all survey sites, \pm standard error.

UAS flights and photogrammetry: In 2016 the UAS was flown over six blue whales: four adults and two calves. The photogrammetric measurements determined that mean whale length was 19.92 ± 0.51 m for the adults (mean \pm standard error, $n=4$) and 14.44 ± 1.19 m for the calves (mean \pm SE, $n=2$).

Stable Isotope Analysis: In comparison to the stable isotope results from samples collected during the 2014 field season in the STB, the 2016 $\delta^{15}\text{N}$ values are similar, yet the $\delta^{13}\text{C}$ values are higher (Fig. 14). This result indicates that the blue whales had different feeding ecology between years, which may have been affected by the El Niño oceanographic conditions in 2016. Analysis of the krill and blue whale tissue samples collected in 2017 will help to elucidate blue whale foraging patterns and their relationship to environmental patterns.

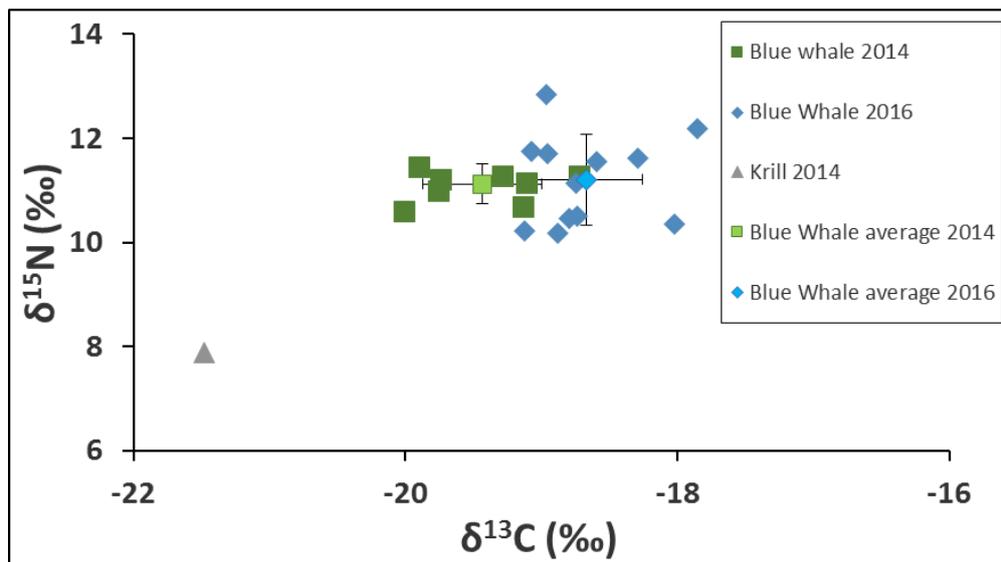


Figure 14. Stable isotope results from blue whale biopsy tissue samples collected from blue whales in 2014 and 2016, and a homogenate krill sample in 2014.

Opportunistic Sightings: Compilation of opportunistic blue whale sighting records in New Zealand waters reveal that blue whales have been reported during every month of the year (Fig. 15). November, January, February, and March are the months with the most sightings, and the least sightings were reported during the winter months. It is important to note that many of these sightings do not distinguish between ‘Antarctic’ and ‘pygmy’ blue whales. It is also worth emphasizing that this monthly distribution is composed of uneven survey effort, and therefore does not necessarily reflect the actual temporal distribution of blue whales in New Zealand waters. Rather, it is an attempt to tabulate when sightings have been reported, even though they were collected in a non-systematic fashion.

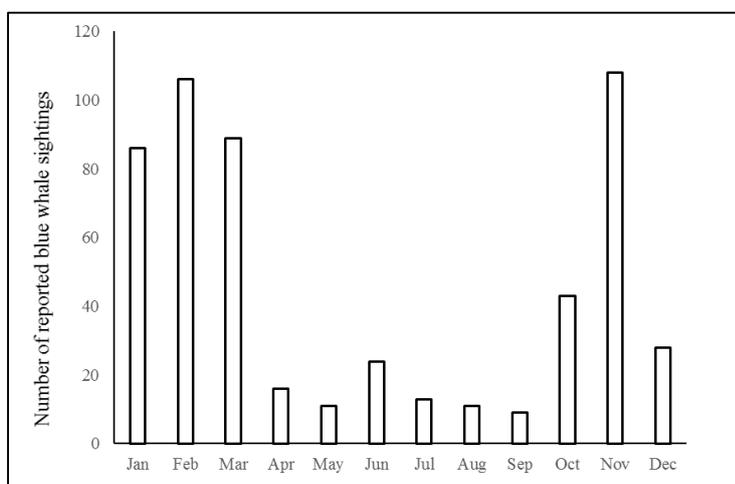


Figure 15. Cumulative number of reported blue whale sightings per month from all sighting records in New Zealand waters ($n=553$), uncorrected for survey effort and absence data (see text).

Blue whale sightings have been reported broadly across the New Zealand Exclusive Economic Zone (Fig. 16). The majority of reported blue whale sightings are from the STB region. Numerous reports are also clustered around the north end of the North Island. There are virtually no reports from the waters to the southwest of the South Island, although relatively few vessels transit this area. It is important to note that many of these sightings do not distinguish between ‘Antarctic’ and ‘pygmy’ blue whales. As with the temporal distribution of these sightings (Fig. 15), it is important to emphasize here that survey effort was uneven and non-systematic. Therefore, Figure 16 does not reflect the true spatial distribution of blue whales in New Zealand because no account has been made for absence and effort data.

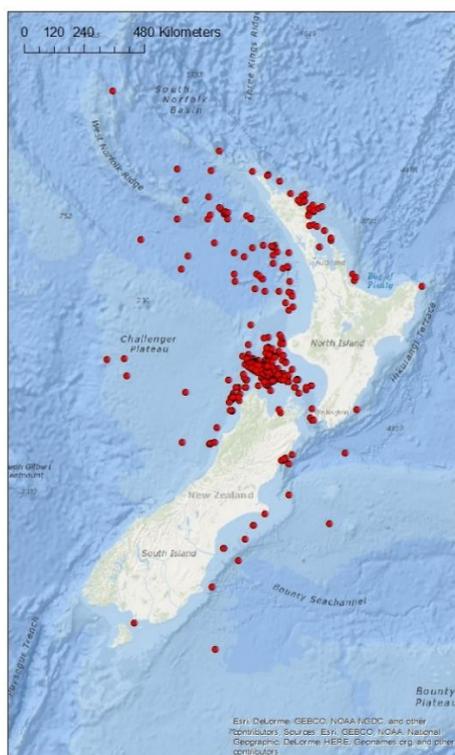


Figure 16. Geographic distribution of all reported sightings of blue whales within New Zealand waters, including our survey effort in the STB region and opportunistic sightings records reported between 1980 and 2017 (n=513).

DISCUSSION

Based on our multiple observations of blue whale feeding behavior, acoustic detection of blue whale feeding calls, and identification of *N. australis* – a known prey source for pygmy blue whales (Gill 2002), we are confident that the STB region is a blue whale foraging ground as hypothesized by Torres (2013). The frequent detection of the New Zealand blue whale call indicates that the STB region may also be used for reproductive and social behaviors. Additionally, the numerous sightings of mother and calf pairs and the documentation of nursing behavior provide strong evidence that the STB region is important for nursing and calf-rearing.

Many lines of evidence presented here lead us to now hypothesize that these whales form a New Zealand population of blue whales that are either resident or semi-resident in New Zealand waters:

- (1) The use of the STB region by blue whales for multiple critical life history functions.
- (2) Multiple photo-identification matches of individual blue whales within New Zealand waters across multiple years (maximum 6 years).
- (3) A lack of a photo-identified match between any blue whale observed in New Zealand waters with any individual observed elsewhere (Australia or Antarctica).
- (4) Genetic identification of a new haplotype currently undescribed in the Australian pygmy blue whale population, as well as significantly lower haplotype diversity compared to the Australian population.
- (5) Acoustic detection of the New Zealand call type in the STB region during all 11 months for which recordings have been analyzed.
- (6) Year-round records of blue whale sightings in New Zealand waters.

Previous studies also support the hypothesis of a New Zealand population of blue whales. The New Zealand blue whale call type has been detected in New Zealand coastal waters outside the STB region (Kibblewhite et al. 1967, McDonald 2006, Miller et al. 2014). Additionally, blue whale foraging behavior has been opportunistically reported in a few other locations around New Zealand – yet with reduced consistency as compared to the STB region – (Torres 2013, Olson et al. 2015), suggesting that blue whales may occasionally utilize other productive areas in New Zealand’s coastal waters in addition to the STB region.

Currently, blue whales are listed as ‘Migrant’ under the New Zealand Threat Classification System (Baker et al. 2016). If our work has identified a New Zealand population of blue whales as indicated by our preliminary analyses, our results may be used to update the threat classification accordingly.

The STB region is New Zealand’s most industrially active marine region; it is the site of active oil and gas extraction platforms, ongoing seismic surveys for more oil and gas reserves, extensive vessel traffic (Fig. 17), fishing activity, and a proposed seabed mining operation which would extract 50 million tons of iron sands from the seafloor over a 35-year period. Cumulative and isolated impacts on blue whales and their habitat from these activities should be carefully considered by environmental managers. In particular, elevated anthropogenic ocean noise may disturb blue whale behavior and physiology, with consequences for individual health and population viability. For instance, blue whales in the Gulf of St. Lawrence Estuary, Canada alter their acoustic behavior in the presence of seismic survey activity by calling more frequently to compensate for elevated ambient noise conditions (DiLorio & Clark 2010). Such increased calling can have energetic consequences for cetaceans (Holt et al. 2015). Furthermore, low-frequency noise from shipping traffic has been shown to increase stress levels in North Atlantic right whales, *Eubalaena glacialis* (Rolland et al. 2012). Habitat displacement is also a significant concern, whether caused by changes in ocean noise, prey distribution, or pollution. Our work demonstrates the importance of the STB as a blue whale foraging ground, justifying concern regarding accessibility to efficient feeding opportunities. Additionally, heavy vessel traffic across the STB region (Fig. 17) poses ship strike risk to blue whales, as seen in other regions of space-use conflict between baleen whales and vessel traffic (van der Hoop & Vanderlaan 2012, Constantine et al. 2015).

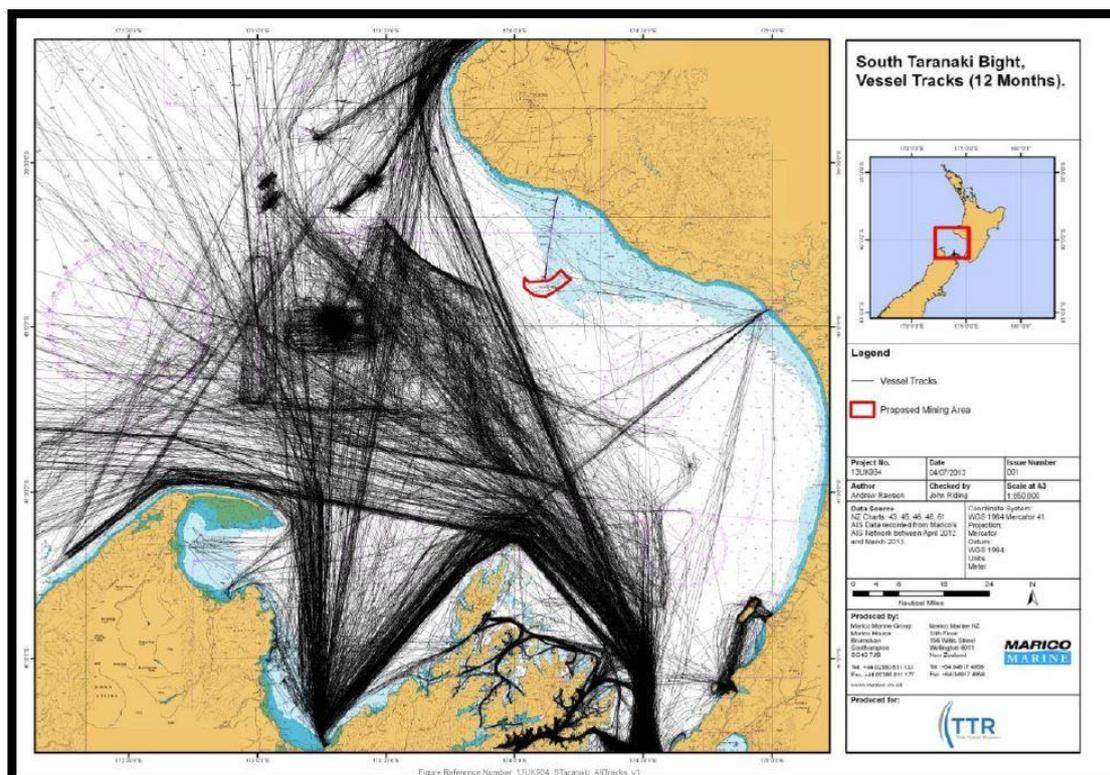


Figure 17. Vessel traffic patterns in the South Taranaki Bight region during 12 months from April 2012 through March 2013, derived from Automated Identification System (AIS) data. Map produced by Marico Marine NZ Ltd. for Trans-Tasman Resources Ltd (Rawson & Riding 2015).

The combination of threats posed by human activities in the STB, the significant use of the region by blue whales, and knowledge gaps about this population warrants continued evaluation of blue whale ecology, health, and response to anthropogenic impacts in the STB and New Zealand. Specifically, by gaining a better understanding of blue whale spatial and behavioral ecology the STB, it may be possible for industrial impacts on blue whales to be mitigated by dynamic management of activities in the area.

FUTURE RESEARCH

With mounting evidence that blue whales spend a significant amount of time in the STB, and potentially represent a distinct New Zealand population with strong residency patterns, a robust abundance estimate of this blue whale population is critical information for management purposes. Using both photo-identification and genetics data, we intend to produce capture-recapture abundance estimates for blue whales in the STB region and in New Zealand waters.

Genetic analysis will continue for the biopsy and fecal samples collected during the 2017 field season, and 2017 samples will be compared with the results presented in this report.

The hydrophone array will record blue whale vocalizations through early 2018, with a turnaround scheduled for June 2017 to recover data and replace battery supplies. The acoustic analysis from the hydrophone array will continue as the next portion of the data are recovered. Once the full two-year dataset is in-hand, we will investigate spatial and temporal patterns of blue whale call detection. Additionally, we will investigate relative call density in relationship to the sources and levels of ambient anthropogenic noise present in the STB soundscape.

We are currently processing the UAS images from 2016 and 2017 for photogrammetric analyses. With this photogrammetric analysis, we will assess the health and reproductive status of these whales (*e.g.*, malnourished, pregnant, lactating).

Hormone analysis (progesterone, testosterone, cortisol) of both blubber and fecal samples is underway through collaboration with colleagues at the Seattle Aquarium. We will assess how hormone levels vary between years and demographic and health status of individuals. The assessment of cortisol levels will allow us to evaluate stress levels in sampled blue whales; The pairing of cortisol levels with other hormone levels, morphometric data from photogrammetry analysis, environmental conditions from oceanographic data collection, and ambient noise data from the hydrophone array will allow us to identify potential contributors to elevated stress, such as pregnancy, seismic survey noise, or malnourishment.

Stable isotope analysis will continue on the blue whale biopsy samples and krill sample collected in 2017. These $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values will be compared with the 2014 and 2016 datasets to investigate shifts in foraging ecology between years.

Blue whale species distribution models (SDMs) will be generated to better understand New Zealand blue whale ecology and to enhance predictability of occurrence across the region. SDMs will be generated at two different scales: (1) within the STB region, and (2) across the New Zealand Exclusive Economic Zone (EEZ). Using the oceanographic and hydroacoustic prey data collected *in situ* during our three seasons of survey effort in the STB, we will develop a fine-scale SDM of blue whale habitat use in the STB relative to oceanographic patterns (*e.g.*, water temperature, mixed layer depth, maximum fluorescence) and prey availability (*e.g.*, krill density, depth, and patch size). Remotely sensed measurements of SST and chl-*a* will also be incorporated into this SDM to assess relevance and contribution at this fine spatial and temporal scale relative to the larger scale New Zealand wide SDM based solely on remotely sensed data and using all blue whale sighting records (opportunistic and systematic). Through these multi-scale SDMs we aim to enhance the predictability of blue whale distribution in the STB and across the New Zealand EEZ to improve conservation management decisions regarding industrial and other anthropogenic activities, including climate change.

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