First satellite-tracked movements of pygmy blue whales (*Balaenoptera musculus brevicauda)* in New Zealand waters

Kimberly T. Goetz[1,2], Simon Childerhouse[3], David Paton[4], Mike Ogle[5], Krista Hupman[1], Rochelle Constantine[6], Michael C. Double[7], Virginia Andrews-Goff[7], Alexandre N. Zerbini[2,8,9], Paula Olson[10]

[1]National Institute of Water & Atmospheric Research, Wellington, New Zealand

[2]Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, Washington

[3]Cawthron Institute, Nelson, New Zealand

[4]Blue Planet Marine, Canberra, Australia

[5]Department of Conservation, Takaka, New Zealand

[6]University of Auckland, School of Biological Sciences and Institute of Marine Sciences, Auckland, New Zealand

[7]Australian Marine Mammal Center, Australian Antarctic Division, Hobart, Australia

[8]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington

[9]Marine Ecology and Telemetry Research, Seabeck, Washington

[10]Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, La Jolla, California

Correspondence
Kimberly T. Goetz
Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, Washington, 98115-6349
Email kim.goetz@noaa.gov

There are currently two subspecies of blue whales recognized in the Southern Hemisphere – the Antarctic blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*B. m. brevicauda*) (Rice, 1998). Passive acoustic data have revealed the presence of both subspecies in New Zealand waters (Barlow et al., 2018; McDonald, 2006; Torres, 2013; Warren et al., 2020). Both subspecies are classified as 'data-deficient' by the New Zealand Threat Classification system (Baker et al., 2019). The International Union for Conservation of Nature (Cetacean Specialist Group, 1996) has not yet evaluated the status of pygmy blue whales (Pollock, 2019) but considers Antarctic blue whales 'critically endangered'(Cooke, 2018).

In the southern hemisphere and adjacent Northern Hemisphere Indian Ocean, five populations of pygmy blue whales are currently recognized: the north Indian Ocean (Sri Lanka & India), southeast Indian Ocean (Australia and Indonesia), southwest Indian Ocean (Madagascar & South Africa), southeast Pacific Ocean (Chile, Peru, Ecuador), and southwest Pacific Ocean (New Zealand) (Branch et al., 2007; McDonald, Mesnick, & Hildebrand, 2006). These populations can be distinguished by regional differences in call types (McDonald et al., 2006).

The southwest Pacific population of pygmy blue whales are widely distributed around New Zealand and acoustic recordings have documented their year-round presence in the South Taranaki Bight (STB, the large embayment between the North and South Islands, Figure 1) (Barlow et al., 2018; McDonald, 2006; Miller et al., 2014; Olson et al., 2015; Torres et al., 2013). However, despite extensive research on pygmy blue whales in New Zealand waters (Barlow, Bernard, Escobar-Flores, Palacios, & Torres, 2020; Barlow et al., 2018; Kibblewhite, Denham, & Barnes, 1967; Torres, 2013; Torres et al., 2017; Warren et al., 2020), the amount of time individual pygmy blue whales spend in New Zealand waters and whether animals are residents, migrant, or some combination of both, remains unknown. The unique call type associated with pygmy blue whales in New Zealand waters has been recorded in waters off eastern Australia and in Bass Strait (Balcazar et al., 2015; McCauley, Gavrilov, Jolliffe, Ward, & Gill, 2018), suggesting that animals may move between the two areas.

To better understand the pygmy blue whale movement and residency in New Zealand waters, we conducted a vessel-based survey with the aim of attaching satellite tags to several individuals. This survey also provided an opportunity to collect blue whale distribution data, photographic data for individual identification, and genetic data for subspecies confirmation. Both tracking and sighting data were linked to environmental data to quantify differences in oceanographic features between areas where animals were present and absent and in areas where animals spent significantly longer periods of time. Given the documented importance of the STB to blue whales, we expected satellite-tagged animals to spend some proportion of time in this region.

The blue whale voyage departed Wellington, New Zealand, on 28 January 2018 and returned to the same port on 10 February 2018. Visual surveys were conducted on-board the *M/V Star Keys*, with an eye height of approximately 7 m above sea level. A smaller 6 m vessel, ‘Brig’, outfitted with a specialized bowsprit, was housed on-board for tagging and biopsy operations. Due to limited time, survey tracklines were not standardized but rather focused in areas with known concentrations of blue whale sightings (Figure 1) (Barlow et al., 2018; Torres, 2013). During daily surveys, members of the research team rotated between three positions (left observer, recorder, right observer) and alternated between searching with and without 7 × 50 binoculars. Each observer spent an hour at each position (three hours on-effort) followed by two hours off-effort to minimize fatigue. A custom-built survey program was used to record all survey information which consisted of sighting (position, date, number of individuals, predominant behavior) and weather data (Beaufort, swell, sun position, glare, horizon visibility). Possible behaviors included: travelling, milling, breaching, mating, tail slapping, spy hoping and resting. If behavior could not be determined during the sighting event, it was recorded as ‘unknown’.

Location-only satellite tags (Wildlife Computers SPOT-303F with a 45-sec repetition rate) in a Type C (Andrews et al., 2019) configuration were used. Housing of these tags were made with surgical quality stainless steel and measured 300 mm in length and 24 mm in diameter. All tags were prepared and sterilized using the Tristel Trio wipes system. This process provided high-level disinfection on metal devices. Tags were set to 20 uplinks per hour and were tested before deployment to ensure successful ARGOS transmissions.

Satellite-tagging procedures followed those outlined in Double et al. (2014). Upon sighting a suspected blue whale, the vessel was guided towards the whale for species confirmation. If conditions were suitable, the ‘Brig’ was launched and the main vessel acted as a safety and support vessel. The ‘Brig’ driver approached the animal to within 5-10 m while the tagger deployed a satellite tag using a pneumatic system (Heide-Jørgensen, Kleivane, Øien, Laidre, & Jensen, 2001). Because the two blue whale subspecies cannot easily be distinguished visually, a biopsy sample was collected for subspecies confirmation. Using the Paxarms biopsy system (Krützen et al., 2002), a biopsy was only attempted after tag attachment or when conditions were not suitable for tagging. Before, during, and after tagging and biopsy operations, attempts were made to take photos for photo-identification using high-resolution digital SLR cameras. Because there is often a single opportunity to be within 10 m of a blue whale, the tasks were prioritized as follows: 1) tag deployment, 2) biopsy sample, and 3) photo-identification.

Given the priority of operations and time constraints, obtaining photographs of both right and left sides of individual animals was not always possible.

After collection, biopsy samples were stored in 90% ethanol and sent to Oregon State University (USA) for genetic analysis. Additionally, subsamples of biopsies were sent to the New Zealand National Cetacean Tissue Archive at the University of Auckland for curation. Standard DNA extraction protocols were followed using the phenol/chloroform method used in previous studies on blue whales in New Zealand waters (described in Barlow et al., 2018). Molecular sex identification, amplification and sequencing of a 410 bp of the mitochondrial control region, and genotyping of individuals using microsatellite markers were used for subspecies confirmation (Attard et al., 2015; LeDuc et al., 2007; Sremba, Hancock-Hanser, Branch, LeDuc, & Baker, 2012; Torres-Florez et al., 2014).

Photographs for each sighting event were examined for unique flank pigmentation patterns and dorsal fin shapes to distinguish between individuals. Unique individuals were then compared between sighting events. All data collected for photo-identification were uploaded to the Southern Hemisphere Blue Whale Catalogue, supported by the International Whaling Commission (Galletti Vernazzani, Olson, & Salgado-Kent, 2019).

Satellite-tracking data were processed using a forward-looking particle filtering model, which accounts for the errors associated with each ARGOS location class, to interpolate hourly locations (Tremblay, Robinson, & Costa, 2009). To examine residency time, we used the 'Hotspot Analysis' tool in the Spatial Statistics toolbox of ArcMap 10.7 (ESRI, 2019). This tool uses the Getis-Ord Gi* statistic (Getis & Ord, 2010) to identify statistically significant spatial clusters of low (cold-spots) and high (hot-spots) values displayed by the 90, 95, and 99% confidence levels. Because transit rate was used as the weighting variable, cold- and hot-spots represented areas where low or high transit rates were significantly clustered, respectively. Clusters of lower transit rates represent areas where tagged animals spent longer periods of time, or had higher residency time. Animals are likely to spend more time in areas where prey are abundant, resulting in noticeable changes in behavior such as increased turn angles and decreased travel speeds (Barraquand & Benhamou, 2008; Bovet & Benhamou, 1988). These behavioral changes are likely to occur when prey are aggregately distributed, thus, resulting in increased search activity in a given area (Fauchald & Tveraa, 2003). Therefore, we presume that blue whales spend more time in areas that are likely to provide suitable foraging habitat.

Finally, we examined both water depth and satellite-derived daily and long-term daily mean sea surface temperature (SST) along the survey trackline and along the track of each satellite-tagged blue whale. To examine water depth, we downloaded ETOPO-1, a 1 arc-minute global relief model of the earth's surface from the National Geophysical Data Canter (Amante & Eakins, 2009). Additionally, 0.25° resolution daily Optimum Interpolation Sea Surface Temperature (OISST) datasets for daily SST and long-term daily mean sea surface temperature (LT-SST) were provided by NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, and were available for download at https://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.highres.html (Reynolds et al., 2007). Daily mean LS-SST data were calculated from 1980-2010 daily global SST values.

The center point of each 0.25° cell that overlapped the survey trackline was extracted and assigned a 1 or 0 to indicate the presence or absence of blue whales, respectively, based on sightings data. For each point, we extracted water depth, daily SST, and daily mean LT-SST data corresponding to the day we surveyed the cell. Similarly, we extracted the same environmental data for each point along the track of the two satellite tagged whales. R statistical software (version 4.0.3) (R Core Team, 2017) was used to produce violin plots and perform Mann-Whitney U-tests for non-parametric data to test for significant differences ($p < 0.05$) between cells where blue whales were present and absent along the survey trackline and between cold- and hot-spots at the 99% confidence level, where tracked animals exhibited significant clusters of higher and lower residency times, respectively.

The total time and distance of on-effort survey data was 72.5 h and 1,637.5 km over eight survey days (Figure 1). Eleven sightings of blue whales, consisting of 14 unique individuals, were documented (Table 1, Figure 1). Five sightings were located along the coastline from Farewell Spit to Kahurangi Point while the other six were located further south and further offshore, between Karamea and Greymouth (Figure 1). ‘Travel’ was the only identified behavior for four of the sightings (Table1). Due to the presence of two major storm events, ex-tropical cyclones *Fehi* and *Gita*, surveys were not conducted 31 January-2 February and 5-6 February.

For the area surveyed, mean daily SST was 20.7 ± 0.7 °C ($\bar{x} \pm SD$), ranging between 19.2 and 22.4 °C and was significantly higher than the mean daily LT-SST of 18.1 ± 0.5 °C ($U = 6{,}241$, $p < 0.001$) (Figure 1). Daily mean LT-SST values ranged between 16.4 and 19.1 °C, and, therefore, did not overlap with the range of temperature values found during our 2018 survey (Figure 2). Mean daily SST in cells where blue whales were present were not significantly different from areas where blue whales were absent. However, the inter-quantile range of mean daily SST values where blue whales were found (20.2-20.4 °C) was narrower than where blue whales were absent (20.2-21.5 °C), though this may be due to the smaller number of presences (Figure 2). Mean water depth was significantly deeper in areas where blue whales were present than areas where they were they were not seen (present: -148. 4 m ± 53.4; absent: -109.3 ± 61.7 m; $U = 423.5$, $p = 0.04$).

During the entire survey, we deployed four satellite tags: one where the animal was missed, one which barely penetrated the animal and fell off after several hours, and two that were successfully deployed on adult blue whales. In addition, we collected genetic samples (three biopsies and one sloughed skin sample) from four animals, including the two successfully tagged blue whales, and obtained nearly 300 photographs of sufficient quality for individual identification purposes (Table 1). The genetic analyses of tissue samples confirmed that the four biopsied blue whales were pygmy blue whales and examination of the photographs revealed that all sighting events contained unique individuals, except two of the three blue whales traveling together in sighting nine on 8 February were also present in sighting 10 on 9 February (Table 1). These two animals travelled ~10 km in the 14.9 hours between sighting events.

The two satellite-tagged pygmy blue whales spent between 0.5 to 3 days near the tagging site in Karamea Bight before leaving the area (Figure 3). The female whale (tag 46657) travelled over 500 km north along the west coast of the North Island before transmissions ceased near Auckland on 14 February, six days after deployment (Figure 3). The tag on the male whale transmitted for 47 days. Shortly after tagging, this animal traveled through the STB and Cook Strait and then south along the east coast of the South Island where it spend time in cooler waters before circumnavigating the entire Island and returning to the STB by which time water temperatures were lower (Figure 3). During this time, the animal travelled a minimum of 3,200 km (not accounting for detailed movement that may have occurred during a temporary loss of transmissions between 05-13 March) before tag transmissions finally ceased on 27 March 2018 (Figure 3).

Hotspot analysis identified six significant spatial clusters (consisting of a total of 87 points) of lower transit rates (cold-spots), representing areas where the two tracked whales exhibited higher residency time (Figure 4). The female pygmy blue whale spent ~14 hours in a single identified cold-spot located west of Auckland while the male pygmy blue whale spent time in five identified cold-spots located: 1) in the Karamea Bight, 2) between Cook Strait and Bank's Peninsula, 3) ~90 km southwest of Bank's Peninsula, 4) ~200 km northeast of Westport, and 5) ~110 km east of Farewell Spit (Figure 4, Table 2). Time spent in areas with higher residency time ranged from 0.6 to 3.6 days, the longest of which corresponded to the area south of Banks Peninsula (Table 2, Figure 4). While we cannot say with certainty why pygmy blue whales exhibited higher residency time in some areas and not others, it is possible that that oceanographic conditions in these areas created favorable foraging conditions or that whales were searching for food in areas which were previously known to provide suitable foraging habitat.

Overall, the mean water depth for telemetry locations identified as cold-spots was significantly shallower than for those identified as hot-spots (cold-spots: -505.8 ± 508.9 m, n = 298, hot-spots: -1,352.5 ± 1,623.4 m, n = 87, U = 15,545, p = 0.005). Both mean daily SST and daily mean LT-SST within identified cold-spots were significantly warmer than those for hot-spots (mean daily SST cold-spots: 18.8 ± 1.9 °C, hot-spots: 17.7 ± 1.8 °C, U = 17,074, $p < 0.001$; daily mean LT-SST cold-spots: 17.5 ± 1.3 °C, hot-spots: 16.2 ± 1.7 °C, U = 17,439, $p < 0.001$) (Figure 5).

Blue whales are large predators that require the consumption of large dense krill aggregations in order to meet their high energetic demands (Croll et al., 2005; Fiedler et al., 1998). These aggregations are often found in highly productive coastal waters downstream from upwelling centers (Croll et al., 1998; Fiedler et al., 1998; Rennie et al., 2009). Upwelled water is created when alongshore winds bring cold, nutrient-rich waters to the surface. As such, blue whales are known to track areas of upwelling because conditions are favourable for krill. The link between upwelled water and blue whales is well documented in Australia (Gill et al., 2011; Rennie et al., 2009), Chile (Buchan & Quiñones, 2016), and California (Fiedler et al., 1998).

In the coastal waters of New Zealand, the STB region contains a consistent upwelling system (Shirtcliffe et al., 1990; Stevens, O'Callaghan, Chiswell, & Hadfield, 2019) that is known to provide important foraging habitat for pygmy blue whales (Barlow et al., 2020; Barlow et al., 2018; Torres, 2013). This upwelled water originates further south, inside the Kahurangi Shoals, where deep water reaches the surface before flowing north and is only generated by the presence of a persistent Westland Current and an on-shore westerly wind (Chiswell, Zeldis, Hadfield, Pinkerton, & research, 2017; Shirtcliffe et al., 1990). Under typical conditions, upwelled water in the STB results in large aggregations of krill (Bradford-Grieve, Murdoch, & Chapman, 1993; J. M. Bradford & B. Chapman, 1988).

Based on past research (Barlow et al., 2020; Torres et al., 2017), we expected to find blue whales foraging in the STB during our survey. Instead, blue whales were found further south, further offshore, in small numbers, and were not observed surface feeding. Additionally, neither of the satellite-tracked animals spent any notable amount of time in the STB region. A southward and offshore shift in blue whale distribution was also observed by researchers in 2016 and was thought to be due to elevated water temperatures and unfavorable oceanographic conditions associated with the El Niño event which led to reduced krill presence in the STB (Torres et al., 2017). These trophic linkages were later quantified by Barlow et al. (2020), which showed that oceanographic regimes influence krill density and availability, and, therefore, serve as a proxy for blue whale presence. Warm regimes, like that of 2017/18, are characterized by minimal water column mixing with fewer and less dense krill aggregations which leads to fewer blue whales (Barlow et al., 2020).

During our survey of the STB and the region around Farewell Spit, SSTs were higher (20-24 C˚) than during previous blue whale surveys (15-18 C˚) (Torres et al., 2017) and significantly warmer than the 1980-2010 climatological mean SST. These higher temperatures were the result of an unprecedented marine heat wave which produced an average SST anomaly of 3.7 °C and a max of 5 °C in some areas around New Zealand (Chiswell & Sutton, 2020; Salinger et al., 2019). Higher than average SSTs resulted from higher than normal sea level pressure that began in October 2017 and continued through December (BoM & NIWA, 2018). The high pressure reduced cloud formation, resulting in more sunny conditions which warmed the surface of the sea and low winds which suppressed vertical mixing between the upper and lower ocean in the subsequent months (BoM & NIWA, 2018). Between November 2017 and February 2018, sea level pressure resulted in more frequent northerly and north-easterly winds than normal, consistent with La Niña conditions (BoM & NIWA, 2018). Within the duration and area of our survey, SST dropped 1.5 - 2.7 °C after the passing of ex-tropical cyclones *Fehi* and *Gita* but were still above the daily mean LT-SST values.

The 2017/18 marine heat wave impacted many parts of New Zealand's marine ecosystem. Species, such as kingfish and the Queensland groper, that are normally found in tropical or subtropical waters were present further south in New Zealand waters (Lewis, 2018; Roy, 2018). Additionally, snapper spawned six weeks earlier than normal (Morton, 2018) and farmed salmon in New Zealand's Marlborough Sounds experienced severe mortality (Eder, 2018). During our survey, both blue whales and the tuna fishing fleet were observed further south than previous years and were located in areas where large swarms of *Cyclosalpa affinis*, a large salp normally found in tropical and sub-tropical waters, were present (Henschke, Everett, Richardson, & Suthers, 2016; Van Soest, 1998).

For the two blue whale sighting events located at the base of Farewell Spit and the additional three near Kahurangi Shoals, located northwest of Kahurangi Point, whales were not observed foraging but rather exhibited directed southbound travel at a rate that made tagging impossible. Warm temperatures and calm winds caused lower than normal vertical mixing between warm surface ocean and cooler deeper waters along the northwest coast of the South Island (BoM & NIWA, 2018) which may explain why both satellite-tagged whales spent little time in the greater STB region. Further south, four blue whale sighting events occurred west of the Karamea Bight and an additional two occurred in offshore waters between Greymouth and Westport. Whales in this area appeared to be feeding on krill at depth as evidenced by red faecal matter (Lefebvre, Bargu, Kieckhefer, & Silver, 2002). While we do not have any quantitative evidence of upwelling, SSTs were lower than those found in the STB (Figure 1), and the simultaneous swarming of *C. affinis* indicates that nutrient-rich water and high phytoplankton biomass were present in the area (J. Bradford & B. Chapman, 1988; Deibel & Paffenhöfer, 2009)

In addition to the greater STB, blue whales have been documented in several other areas around New Zealand (Barlow et al., 2018; McDonald, 2006; Miller et al., 2014; Olson et al., 2015; Warren et al., 2020). However, the extent to which these areas provide suitable foraging habitat for blue whales is unknown. The location, movement, and residency time of two satellite-tracked pygmy blue whales provides the first indication of where pygmy blue whales may be foraging in other locations when oceanographic conditions are not conducive for upwelling in the greater STB. One of the tracked animals travelled through Cook Strait and down the east side of the South Island where it spent the majority of its time in the Canterbury Bight, just south of Bank's Peninsula. In this area, the Southland Current system flows northward along the southeast shore of New Zealand's South Island and is very important in determining local oceanographic conditions (Sutton, 2003). The Southland Front separates a narrow coastal band of warm, salty water of subtropical origin from offshore cold, fresh subantarctic water (Hopkins, Shaw, & Challenor, 2010; Sutton, 2003). The mixing of warm nutrient-poor subtropical waters and nutrient-rich subantarctic waters causes elevated productivity in the area south of Banks Peninsula (Hopkins et al., 2010), likely creating suitable foraging conditions for blue whales and, thus explaining the significant amount of time spent in the area by one of the tracked animals.

While the results of the hotspot analysis which found that whales spent the majority of their time in warmer, shallower areas (cold-spots) than when transiting (hot-spots) are contrary to the presence/absence data that showed whales were present in cooler, deeper waters within the surveyed area, a large portion of the identified hot-spots were located further south or more than 250 km from the west coast of the South Island. As such, the cooler temperatures within identified hot-spots were likely a function of being located in deeper offshore water as opposed to an indication of upwelling. Similarly, the warmer, more coastal waters where cold-spots were located does not preclude the presence of upwelling but rather that these areas were warmer and shallower than identified hot-spots. Also, the survey occurred during the peak of a marine heat wave when waters were much warmer than normal all around New Zealand while the telemetry data were collected later, after the passing of several major storm events which brought cooler waters to some areas (Figures 1 & 3). After initially passing through the STB, one of the tagged whales returned to and spent time in the area after temperatures had decreased. While the results from our survey support the findings of Barlow et al. (2020) in which blue whales shifted their distribution to deeper offshore waters in response to a warm oceanographic regime, more telemetry data are needed to quantify fine scale responses of blue whales to climactic variation and how such responses might influence overall health and body condition.

Over the past century, marine heat waves have increased in both frequency and duration, largely due to increasing mean SST (Oliver et al., 2018). By 2100, SST around New Zealand is projected to increase by 2.5 C along with a 15% and 4.5% decrease in mixed layer depth and primary production, respectively (Law et al., 2018). Similarly, within this same time period, Hazen et al. (2013) estimates that blue whale habitat will decrease by ~20% as the result of long term climactic shifts. Predictions on how climate change might impact the pygmy blue whale population around New Zealand is unknown. However, Chiswell & Sutton (2020) tested the paradigm that future warming will lead to shallower mixing and less primary production and found that this pattern will hold true north of the Subtropical Front, which includes the STB region, and that either the opposite or no relationship will occur elsewhere around New Zealand. These findings suggest that blue whales may seek foraging areas outside the STB when SSTs are anomalously high such as during the 2017/18 marine heat wave. To better understand the impact of climate change on this subspecies, additional tracking data across multiple years and climactic regimes needs to be collected.

We acknowledge that limited conclusions can be drawn from one year of data collected during New Zealand’s largest marine heat wave to date and that ‘typical’ or population-level movement of pygmy blue whales cannot be accurately assessed. While we were unable to confirm whether individuals from the southwest pygmy blue whale population travel between New Zealand waters and waters off eastern Australia and Bass Straight, this study provides novel data on pygmy blue whale movement and further supports the idea that that at least some animals may be resident to New Zealand waters for at least part of the year (Barlow et al., 2018; Torres, 2013). Furthermore, results from this study show that pygmy blue whales spend time in areas outside the STB, though the amount of time is likely driven by the presence of upwelling conditions with varies from year to year. These findings suggest that future efforts to protect the pygmy blue whale population in New Zealand waters will likely need to be dynamic, moving in both space and time, to account for the ephemeral nature of these animals and their prey under different climactic regimes (Maxwell et al., 2015).

Table 1 Summary of tagged, biopsied, and photo-identified blue whales by sighting number, number of individuals (Ind's), and predominant behavior, if known, during the 2018 blue whale tagging voyage. Tag ID and number of days deployed are provided for each satellite-tagged animal. If a biopsy sample was collected, sex is provided. Images obtained for photo-identification (Photo-ID) are categorized as left (L), right (R) or both (LR) for each individual with 0 indicating no data.

Date	Sight. #	Latitude	Longitude	Ind's	Behavior	Tag ID (days)	Biopsy (sex)	Photo-ID
30-Jan	1	-40.469	172.650	2	Travelling	NA	N	L, R
30-Jan	2	-40.468	172.636	1	Travelling	NA	N	0
3-Feb	3	-40.621	172.228	1	Travelling	NA	N	0
3-Feb	4	-40.647	172.222	1	Unknown	NA	N	LR
3-Feb	5	-40.679	172.200	1	Unknown	NA	N	0
7-Feb	6	-42.026	170.854	1	Travelling	NA	Y (1F)	L
7-Feb	7	-41.583	171.015	1	Unknown	NA	N	0
8-Feb	8	-41.249	171.151	2	Unknown	NA	N	L, 0
8-Feb	9	-41.229	171.559	3	Unknown	46636 (47)	Y (1M)	LR, LR, L
9-Feb	10*	-41.294	171.475	2	Unknown	N	Y (1M)	LR, LR

Date	**Sight. #**	**Latitude**	**Longitude**	**Ind’s**	**Behavior**	**Tag ID (days)**	**Biopsy (sex)**	**Photo-ID**
9-Feb	11	-41.269	171.161	1	Unknown	46657 (6)	N (1F)**	LR

*Indicates a duplicate sighting, two of the three animals in sighting 9 were also present in sighting 10. Note that biopsies of animals in sightings 9 and 10 were collected from different animals.

**Sloughed skin after a surfacing event was obtained for genetic analysis.

Table 2 Time that satellite-tagged pygmy blue whales spent in cold-spots within New Zealand waters as identified in Figure 4. The Getis-Ord Gi* statistic was used to identify statistically significant spatial clusters, at the 99% confidence level, of low transit rates (cold-spots) or areas where tagged pygmy blue whales exhibited higher residency times than for other areas along the track.

Tag ID	**Cold Spot ID**	**Start**	**End**	**Total (days)**
46657	1	2/13/2018 4:21	2/13/2018 18:21	0.58
46636	1	2/8/2018 6:13	2/10/2018 22:13	2.67
	2	2/18/2018 7:13	2/19/2018 13:13	1.25
	3	2/21/2018 13:13	2/25/2018 3:13	3.58
	4	3/17/2018 23:13	3/19/2018 18:13	1.79
	5	3/21/2018 14:13	3/24/2018 3:13	2.54

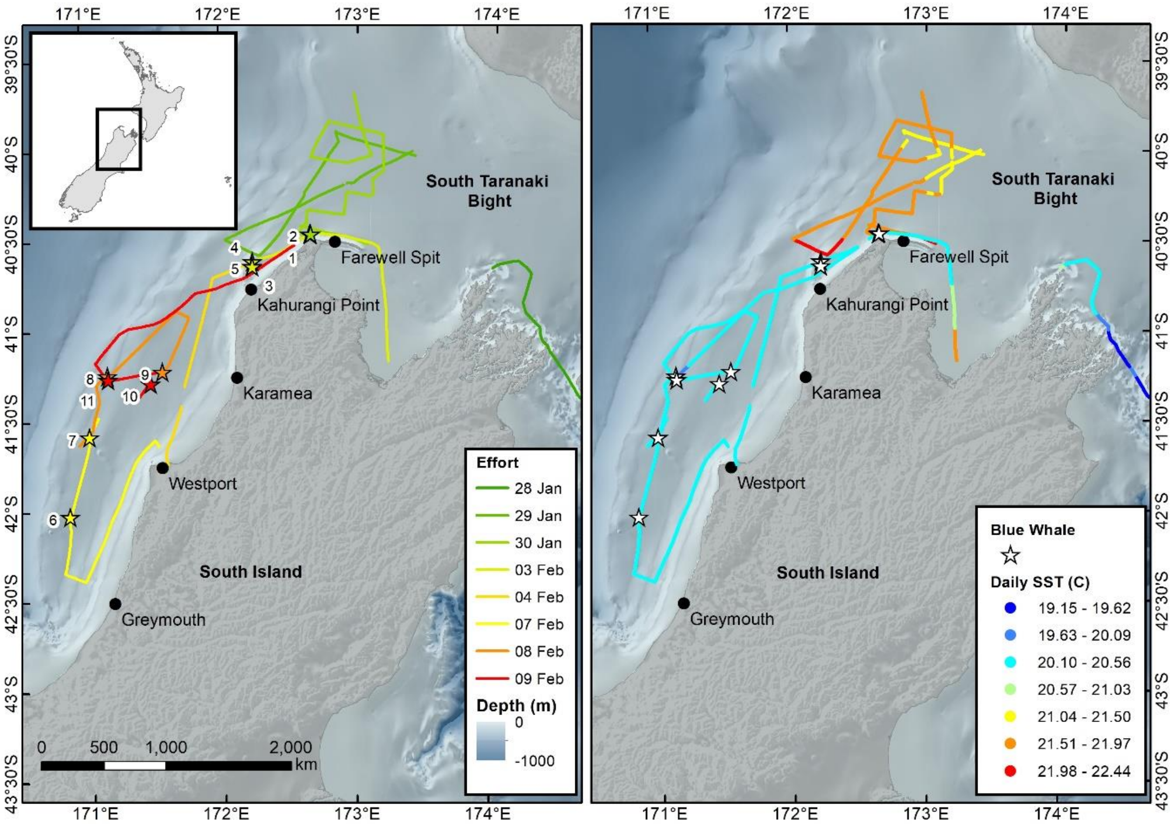

Figure 1 Blue whale sighting events (stars) and on-effort tracklines color-coded by survey day (left) and daily sea surface temperature (right) during the 2018 blue whale voyage in New Zealand waters.

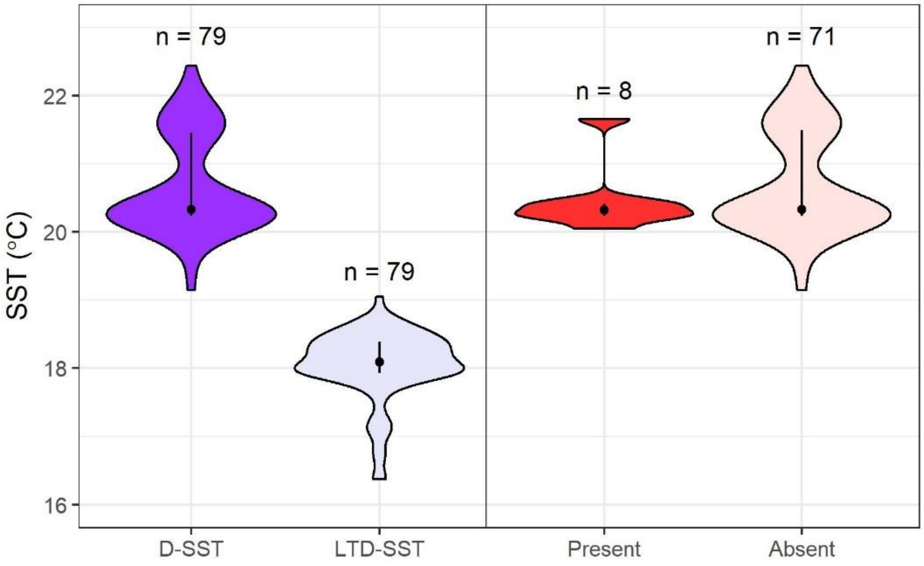

Figure 2 Summary of daily and mean long term daily sea surface temperature (SST,°C) for all 0.25° cells surveyed (left) and daily SST for cells with and without blue whales present (right) during the 2018 blue whale voyage in New Zealand waters. Both panels show median and interquartile ranges and the distribution of the data is indicated by the shape of the violin plot. While there were a total of 81 cells, 4 cells did were removed due to missing data.

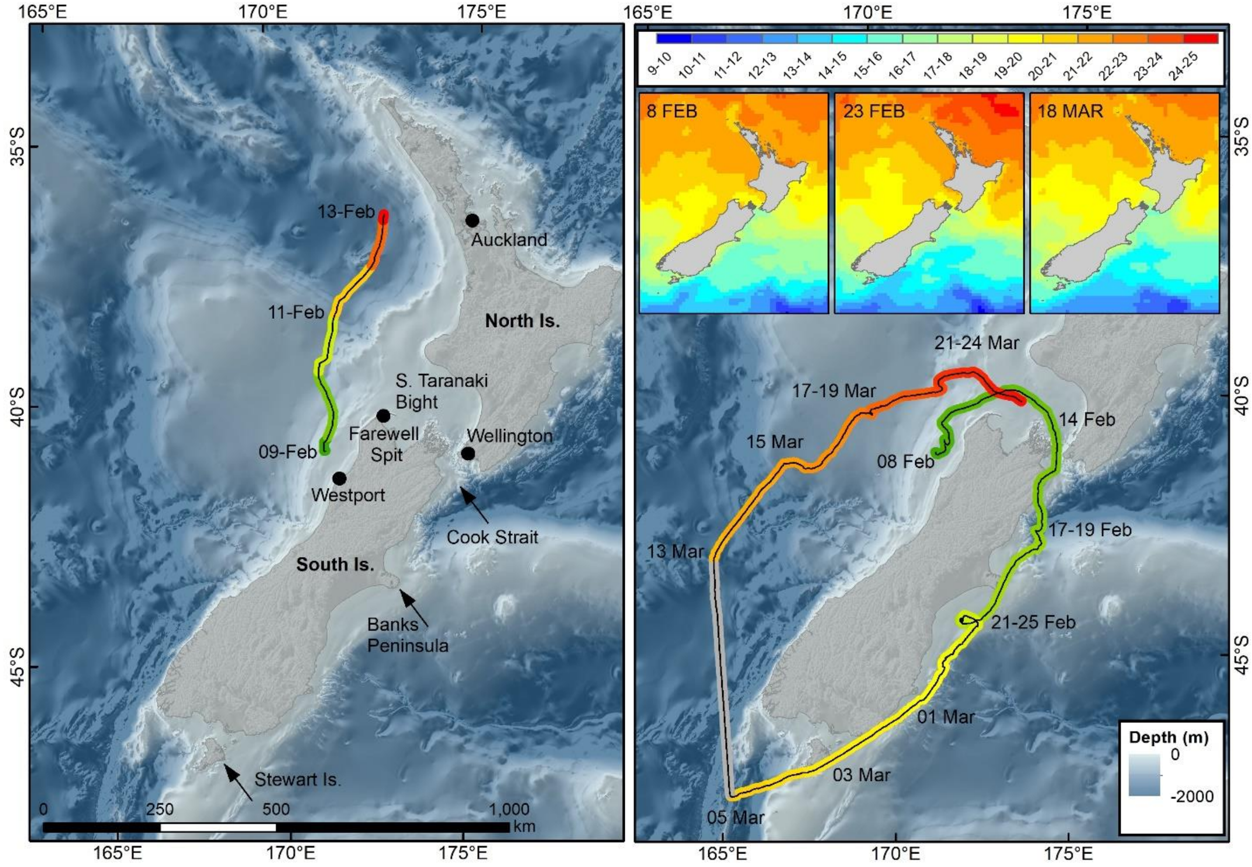

Figure 3 Tracking data from two pygmy blue whales that were satellite-tagged during the 2018 blue whale voyage in New Zealand waters. The green-to-red gradient reflects the start (green) and end (red) of eachtrack. Note that transmissions from the female (tag 46657, left) and male (tag 46636, right) pygmy blue whales ceased 14 February and 27 March 2018, respectively. The light gray track between 05-13 March indicates a temporary loss of ARGOS transmissions. Three inset panels (top right) show daily sea surface temperate (°C) on 8 February, 23 February and 18 March 2018.

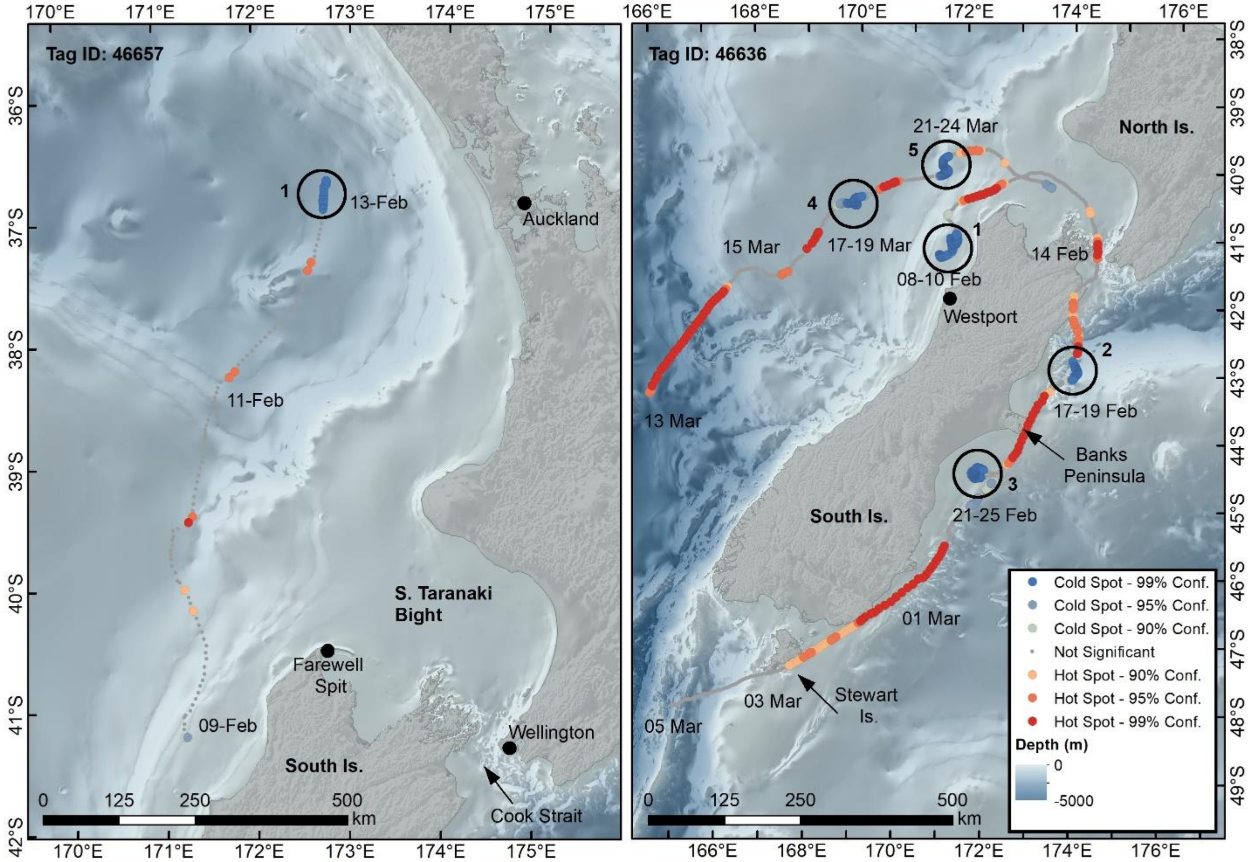

Figure 4 Results of 'hotspot analysis' for two pygmy blue whales, female (tag 46657, left) and male (tag 46636, right) satellite-tagged during the 2018 blue whale voyage in New Zealand waters. Blue and red points indicate statistically significant clusters (Getis-Ord Gi* statistic) of low and high transit rates, respectively and are displayed by the 90, 95, and 99% confidence levels. Black circles with labelled numbers identify cold-spots at the 99% confidence level, or areas where whales exhibited higher residency time.

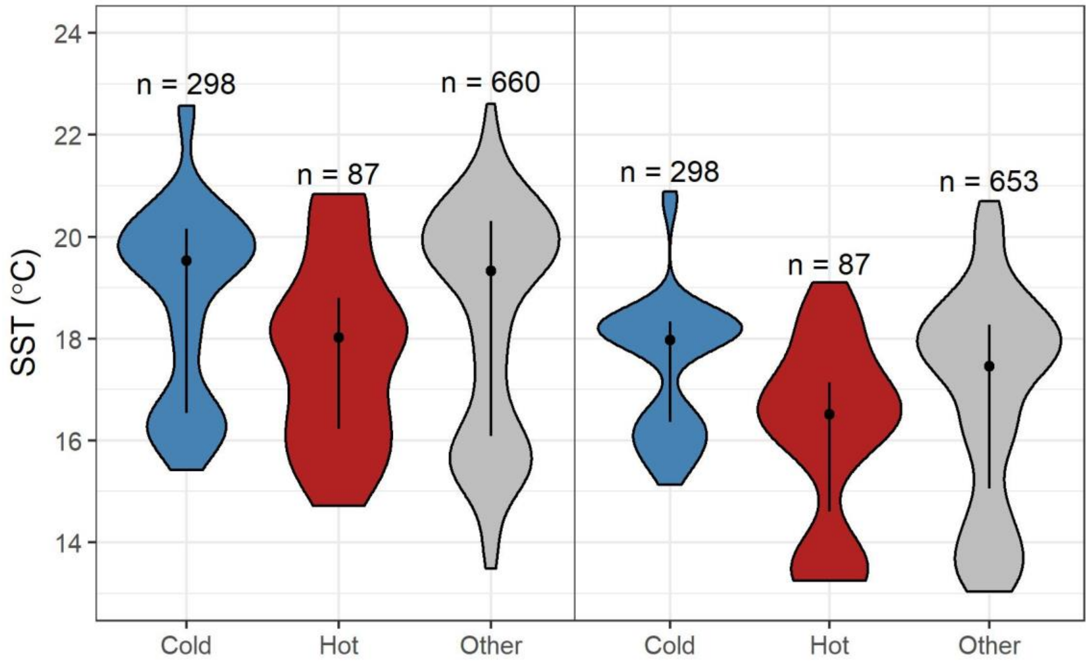

Figure 5 Summary of daily (left) and mean long term daily sea surface temperature (SST,°C) for all telemetry points identified as 'cold-spots' (blue), 'hot-spots' (red), and 'other' (grey) (not identified as either) according to the Getis-Ord Gi* statistic. Cold-spots are areas where the two tagged pygmy blue whales exhibited slower transit rates, or higher residency time. Both panels show median and interquartile ranges and the distribution of the data is indicated by the shape of the violin plot

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