SC/67B/NH/09

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INTERNATIONAL WHALING COMMISSION

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ABSTRACT

In 2015 the first detailed description globally of a population of Omura's whale (*Balaenoptera omurai*) was published, based on two years of focused field work off northwest Madagascar. Since then a focused, multidisciplinary study of the population was conducted in 2015 and 2016, reported here. Field surveys off Nosy Be, Madagascar were conducted for four weeks in 2015 and six weeks in 2016, tallying 202 encounters with Omura's whales, and collecting 55 skin biopsies for DNA and 14 fecal samples. Frequent photographic re-sights of individuals were evident within seasons and several noted across seasons, including at least one reproductive female that was sighted in four of six years from 2012 to 2017, once with a calf, suggesting strong site fidelity. Feeding was observed on a near-daily basis, on dense patches of krill identified morphologically as *Pseudeuphasia latifrons*, which seem to appear in response to dense blooms of a cyanobacteria *Trichodesmium* sp. Passive acoustic monitoring (PAM) was conducted at four sites spread across 80km for one year. Omura's whale song was present year-round indicating residency of the Omura's whale population in this region, with evident spatial and temporal heterogeneity. Four individuals were satellite tagged yielding telemetry tracks ranging from 30 to 58 days. Satellite tagged individuals remained in a restricted range of no more than 405km (mean among individuals of 283km) along the northwest coast of Madagascar, with all individuals moving multiple times throughout their individual ranges. Analysis of movement behavior using behavioral switching state-space model indicated highly localized movement patterns, involving short periods of transiting between specific areas where the whales would then linger for several days displaying primarily localized movements, likely feeding. Habitat suitability modelling indicated favorable conditions for Omura's whale along the west coast of Madagascar, defined primarily by shallow depth and some undefined influence of primary productivity, with little other predicted suitable habitat throughout the Southwest Indian Ocean. Combination of these data sources indicate that this is a resident, non-migratory population whose distribution is likely determined by local shallow water ecological processes and patchy and ephemeral prey resources. Furthermore, this population of Omura's whale may be isolated within a fragmented oceanic/global range for the species. Likely threats to the Madagascar population include entanglement in local fisheries, impacts from oil and gas exploration, and most imminent the risk of coastal water contamination from a recently initiated mining operation for Rare Earth Elements. Future work should include a long-term latitudinal study that incorporates multiple methodologies to investigate all aspects of the species biology and conservation threats to the population. Therefore the development of sustained or long-term funding sources is currently a critical requirement for the continued investigation of this population and success of the project.

INTRODUCTION

The Omura's whale (*Balaenoptera omurai*) was recently described and established as a distinct species with an ancient lineage, phylogenetically distinct and basal to a Bryde's whale (*B. edeni/ brydei)* and sei whale (*B. borealis*) clade (Wada et al. 2003, Sasaki et al. 2006). Historically, the species was mistakenly identified as Bryde's whale, and prior to recent work in Madagascar (Cerchio et al. 2015), the species was known only from a handful of historic whaling and stranding specimens from the Western Pacific and East Indian Ocean (Wada et al. 2003, Yamada et al 2006, 2008,Yamada 2010), with no detailed confirmed observations in its natural habitat.

Field surveys conducted from 2011-2013 established the northwest waters of Madagascar as a cetacean biodiversity hotspot, documenting 15 different cetacean species including: blue whales, humpback whales, Omura's whales, Antarctic minke whales, sperm whales, Cuvier's beaked whales and nine dolphin species (Cerchio et al. 2014a). This work also revealed the region to be an important habitat for a population of Omura's whales, the first identified in the western Indian Ocean. Extensive field observations from 2013-2014 of the small rorqual in the Nosy Be region of Madagascar, including genetic species confirmation for 18 animals, allowed the first accurate description of external appearance of Omura's whale (Cerchio et al. 2015). Sightings data included documentation of mothers with young calves and foraging behavior (including surface lunge feeding). Acoustic recordings in the presence of the whale and from archival recorders yielded a vocalization that was stereotyped and rhythmically repetitive, and at times heard in choruses of multiple individuals. These aspects of the vocalization are indicative of song of other balaenopterids (Watkins et al. 1987, 2000, McDonald et al. 2006), and are therefore suggestive of a breeding display. Eco-tourist groups in the area reported these "petite rorquals" throughout the year during their period of operation from April to December. This region therefore appeared to support both breeding and feeding habitat for a potentially small and resident population.

Following on the data collected during 2011-2014, which were part of more broad assessments of cetacean biodiversity, our team initiated a focused two-year study of the Omura's whale population during 2015-2017. This project is multi-disciplinary and here we report new findings from general boat-based field surveys, photographic identification, feeding ecology observations, long-term passive acoustic monitoring, satellite telemetry and habitat suitability modelling. We summarize the unfolding understanding of this species' life history patterns and ecology based upon these new data, establishing year-round residency and local movements, and comment on conservation concerns for the study population.

METHODS

2015 and 2016 Field Surveys

Two field expeditions were conducted off Nosy Be, Madagascar, during November/December 2015 and 2016. The field bases were set up on the west coast of Nosy Be, on the island of Nosy Sakatia in 2015 and town of Ambondrona in 2016 (Figure 1). As in previous years, all work was conducted from an 8m outboard boat, and standard protocols were used for documenting effort and sightings, individual identification photography, and collection of biopsies (Cerchio et al. 2015). In addition, opportunistic plankton tows were conducted in the vicinity of feeding whales during both field seasons. In 2016, field work also included the deployment of satellite tags, described in detail below.

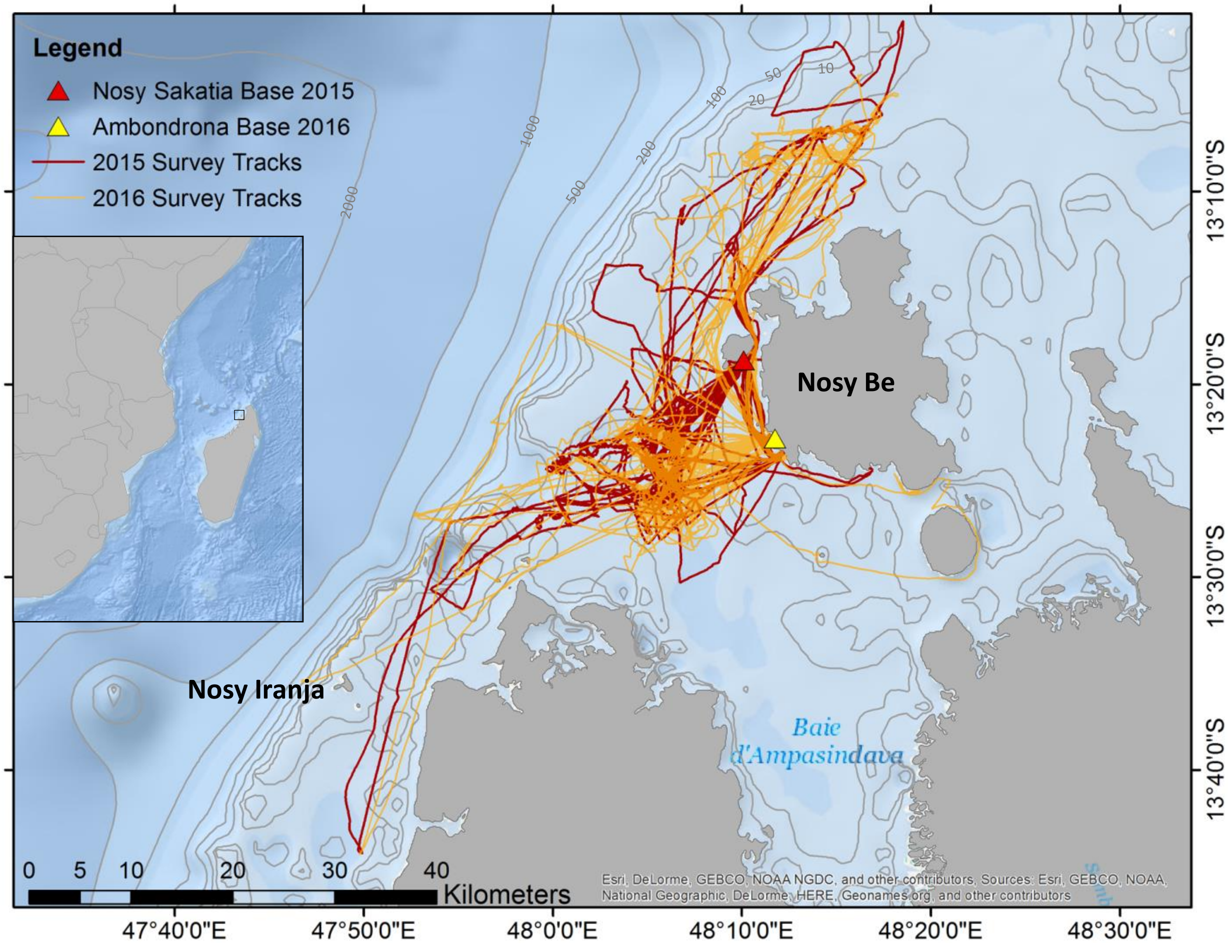

Figure 1. Map of the study region indicating effort in form of all boat tracks in 2015 and 2016. Field seasons were conducted from November 8 to December 2, 2015, and October 31 to December 11, 2016.

Passive Acoustic Monitoring (PAM)

During 2015/2016 four PAM recorders, SoundTrap 300 STD (oceaninstruments.co.nz), were used to monitor the near-shore environment for Omura's whale and other cetacean vocalizations. After a short deployment to test recorder function during November 2015, the recorders were deployed 20-40 km apart along shelf waters (see Figure 2) with the goal of monitoring for a 12-month period. For this configuration, two recorders were placed at the extreme north (Banc du Goliath) and south (Baramahamay) of our practical study range, separated by approximately 80km, and two were placed in the core area of our study range separated by approximately 20km (Banc de Rosario and Ankazoberavina). The southern site and the two core sites were previously monitored during a 3-week pilot deployment in 2014, in which many Omura's whale vocalizations were recorded. The most northern site was new, chosen to monitor the area near the site of a large aggregation encountered in 2015, near the Banc du Goliath. The recorders were attached to static mounts placed on the bottom by SCUBA diving, at depths ranging from 37 to 39m, and set to record on a duty cycle for a 10 minute period every 30 minutes, at a sample rate of 24kHz. Recorder endurance was estimated at 6.5 months, and two deployments were conducted. Upon retrieval and downloading of data from each deployment, acoustic files were down-sampled to 2kHz to reduce size and increase manageability of the data set for low-frequency analysis.

An automated detector for the Omura's whale song unit identified in Cerchio et al. (2015) was developed using the band-limited energy detector of Raven Pro 1.5 (Cornell Bioacoustics Research Program).

Several signal-to-noise (SNR) thresholds for detection were tested on one week of data from Banc du Goliath, and a threshold of 5dB was chosen. This SNR threshold yielded a true detection rate of 81.3% of all phrases and false detection rate of only 1.9%, thus providing a conservative estimate of the total number of detections. The detector was run on all data from all sites, and examination of one week from each month (ca. 25% of data) indicated varying rates of false detections due to particularly noisy conditions on some recorders and months. Therefore, detector results were further manually browsed to verify all detections, removing detections of other species and all false detections. The resultant output allowed confident evaluation of conservative counts of Omura's whale song phrases (recognizing an estimated 81% detection rate).

Satellite Telemetry

A primary component of the 2016 field season was to tag Omura's whales with satellite transmitters and use satellite telemetry techniques to document the movements, range and habitat utilization of Omura's whales in the Nosy Be region. Satellite telemetry has been successfully used to describe the movements of several baleen whale species (humpback whales: Zerbini et al. 2006, 2011, Cerchio et al. 2016; Blue whales: Bailey et al. 2009; fin whales: Bentaleb et al. 2011; sei whales: Olsen et al. 2009; oceanic Bryde's whales: Murase et al.2016). Prior to our study there had been no attempts to tag an exclusively tropical, presumed non-migratory baleen whale (i.e., Omura's whales or coastal Bryde's/Eden's whale, *Balaenoptera edeni edeni*). Therefore, anticipated results from this work not only provide new information on the study species, but novel inferences for the unique life history pattern of species in this ecological niche. Funding allowed for the purchase of four Wildlife Computer SPOT6 satellite tags mounted on the LIMPET (Low Impact Minimally Percutaneous Electronic Transmitter) tag design (Andrews et al. 2008, Durban & Pitman 2012). The LIMPET tag was deployed via a Dan-Inject compressed air rifle and has minimal impact on the animal. The tag anchors with two barbed titanium posts which penetrate 6.5 cm into the dorsal fin (as compared to fully implantable tags which penetrate ca. 20-30cm through the blubber and anchor in muscle tissue fascia) making it ideal for small rorqual whales such as the Omura's whale.

Satellite tags were programmed to duty-cycle throughout each day in synchrony with predicted pass-over periods of ARGOS satellites, turning the tags off when no satellites were overhead; battery life was further maximized by reducing the duty cycles after one month for tags that had exceptional attachment periods. Location data were obtained from Service ARGOS by instruments on satellites from NOAA and the European Organization for the Exploration of Meteorological Satellites (ARGOS User Manual, © 2007-2016 CLS, http://www.argos-system.org/manual). Raw data included a location class defined by increasing number of messages and decreasing uncertainty from Z, B, A, 0, 1, 2 to 3, and an estimate of spatial elliptical error. Prior to analysis, we removed all locations with class of Z (the least accurate), and applied a speed filter that removed all locations that resulted in a leg speed greater than a threshold speed (Garrigue et al. 2010) conservatively set to 20 km/hr, as well as removing positions on land, in order to remove the most likely unrealistic positions.

We fitted a hierarchical behavioral switching state-space model, SSSM, (Jonsen et al. 2003, Breed et al. 2009), that yields better estimates of the locations and the uncertainty in those locations than raw tracking data, and allows inference of the tagged whales' movement behavior. SSSM draws on all of the data and the animal's behavior (e.g., speed and turning angles) to predict the probability of an animal being found at a certain location (Jonsen et al. 2003). We estimated locations and associated credibility intervals four times daily, equivalent to a 3-hour time step. Behavioral state was classified on the basis of two parameters, mean turning angle (θ) and autocorrelation in speed and direction (γ). We ran two Markov chain Monte Carlo (MCMC) chains in parallel, each for 50,000 iterations, including a burn-in of 20,000 iterations which were discarded. The remaining samples were further thinned by retaining every 30th sample to reduce autocorrelation; the retained iterations were used to estimate the mean and variance for each location and its respective behavioral state. Thus, the posterior distribution for each parameter was based on 1000 samples from each chain giving a total of 2000 independent samples. The two behavioral states were differentiated by a separation of the values of the two parameters (θ and γ), resulting in "b-mode" state values of 1 or 2 for each iteration, and a mean b-mode calculated for each estimated position across all iterations. We nominally referred to the two states as: 'transiting', which were highly directional (turning angles near 0°) and consistent long-distance movements, likely representing transits between distinct habitats (b-mode state of 1); and 'localized', which were more variable movements with a higher rate of acute turning angles (near 180°), likely representing searching behavior or meandering within important habitats (b-mode state of 2). For each position a mean b-mode was calculated across iterations, and was classified as transiting movement for b-mode<1.25, undetermined movement for 1.25<b-mode<1.75, and localized movement for b-mode>1.75.

Habitat Suitability Modelling

The process of species distribution modelling (SDM) associates species occurrences with environmental data, fits a quantitative relationship between those data, and projects the relationship(s) onto a region and/or time of interest. Depending upon the data available and the modelling algorithms used, SDMs can provide estimates of habitat suitability, probability of occurrence, density and/or abundance estimates. As a first step in applying SDMs to the Madagascar Omura's whale dataset, we modelled habitat suitability – an estimate of the favorability of an area for a species or population. Our initial approach utilized the maximum entropy SDM algorithm (Phillips et al. 2006), executed in the software MAXENT version 3.3.3 (https://biodiversityinformatics.amnh.org/open_source/maxent/), which is a machine learning method used to fit large amounts of data very quickly. This model provided a relative index of habitat suitability for each 1km^2 cell, and the resulting habitat maps are presented with a continuous index of habitat suitability for each grid cell. The positional data input into the model were presence-only, a combination of boat-based sightings and satellite telemetry positions. Each dataset was applied separately and then combined, and assessment of results led us to conclude that the combined dataset was most informative. Seven environmental variables were assessed from remote sensing data for the larger Southwest Indian Ocean region, measured on a 1km^2 grid resolution (including Bathymetry, Photosynthetically Active Radiation, Salinity, Wind, Chlorophyll, UV Radiation, and Sea Surface Temperature).

RESULTS AND DISCUSSION

The 2015 field expedition was conducted off Nosy Be, Madagascar, between 8 November and 2 December 2015, with a total of 20 boat-days conducting research, whereas the 2016 field expedition was conducted between 31 October and 11 December 2016, with a total of 26 boat-days. During 2015, we conducted a total of 168 hours on the water covering 1868km of survey tracks, and in 2016, a total of 296 hours covering 3602km of survey tracks (Figure 1).

Omura's whale sightings

During the two field seasons there were a total of 203 encounters with Omura's whales, comprising 210 individuals, though not accounting for re-sights between groups. These sighting numbers was about five times higher than sightings during 2011 to 2014 (Table 1, Figure 2). Although likely due in part to focusing survey effort in areas of concentrations of whales during 2015/2016, this increase in sightings is thought to also be related to a higher encounter rate due to increased density/abundance of animals during 2015 and 2016 (as also suggested by local tour operators and fisherman). Five different mother and calf pairs were sighted in 2015, two of which were sighted on two different days each with an interval of three days, and four mother-calf pairs were sighted in 2016, two of which were sighted on multiple consecutive days. This is notable, since in 2014 we saw no mother-calf pairs and in 2013 we sighted only three. Whales were typically encountered in loose aggregations, so that when one individual was encountered there were often several others within 100s of meters to several kilometers. The largest aggregation of Omura's whales documented to date was encountered in 2015, with photographic identification indicating a minimum of 12 individuals within a 2x5km area that was surveyed over a 3 hour period (Figure 3). This aggregation was documented far off the north coast of Nosy Be just south of a submerged bathymetric feature called Banc du Goliath, an area not surveyed in previous years. A total of 55 biopsy samples were collected from Omura's whales in 2015 and 2016, bringing the total number of samples to date to 78. Defecation was frequently observed, and 14 fecal samples were collected from whales engaged in feeding. In addition, 17 plankton samples were collected using a small hand-towed plankton net through areas where whales were actively feeding.

Table 1. Omura's whale sightings and associated data collected off Nosy Be, from 2011 to 2016.

	2011	2012	2013	2014	2015	2016	**Total**
Number of groups encountered	2	4	13	25	84	119	**247**
Number of individual sightings*	3	4	19	26	93	127	**272**
Numbers of different mother/calf pairs	1	0	3	0	5	4	**13**
Number of biopsy samples	1	3	10	9	33	22	**78**
Number of fecal samples	0	0	1	0	11	3	**15**
Number of plankton tow samples	0	0	0	0	6	11	**17**

*Not accounting for re-sights of individuals between encountered groups

Individual identification photographs were taken during all encounters with Omura's whales. We have defined five separate features that are useful for the individual identification of Omura's whales: the right and left side of the dorsal fin (shape and scarring), right "blaze" pigmentation, right "chevron" pigmentation, and left "chevron" pigmentation. Development of a database, protocol and software platform that will allow simultaneous display and comparison of multiple features is underway, and current reported photo-ID results are anecdotal. Numerous photographic recaptures of individuals were noted between days within the seasons. This was often characterized by several animals being sighted from day to day in the same general area over a period of several days. We have also recognized a few well-marked and therefore particularly distinctive individuals re-sighted across years. One individual, recognized as a female based upon the presence of a calf, was sighted in 2012 as an adult in an aggregation, in 2013 as a mother with a young calf, and again in 2015 and 2017 as a lone adult. Such a re-sighting history, particularly in this case of a reproductive female, suggests strong site fidelity and thus a resident population. We expect there to be other examples of such recapture series once the multi-year photo-ID data are fully analyzed.

Observations on Feeding Ecology

Feeding was frequently observed in both field seasons, involving both surface and subsurface lunging. Observations of feeding typically fell broadly into two qualitative categories. First, brief instances in which a whale was encountered and then observed to lunge once or twice in an area, and then move away not to be seen again, essentially disappearing from the perspective of the boat. These were interpreted as prospecting behavior, in which whales would move around through their habitat, searching for food patches and apparently making "test" lunges, perhaps to assess feeding value. Alternatively, a whale or multiple whales would be observed repeatedly lunging in an area for extended periods, sometimes for hours or over the course of a day. These were clearly cases in which a whale or group of whales had identified a patch of prey to exploit, and at times aggregated in numbers to feed.

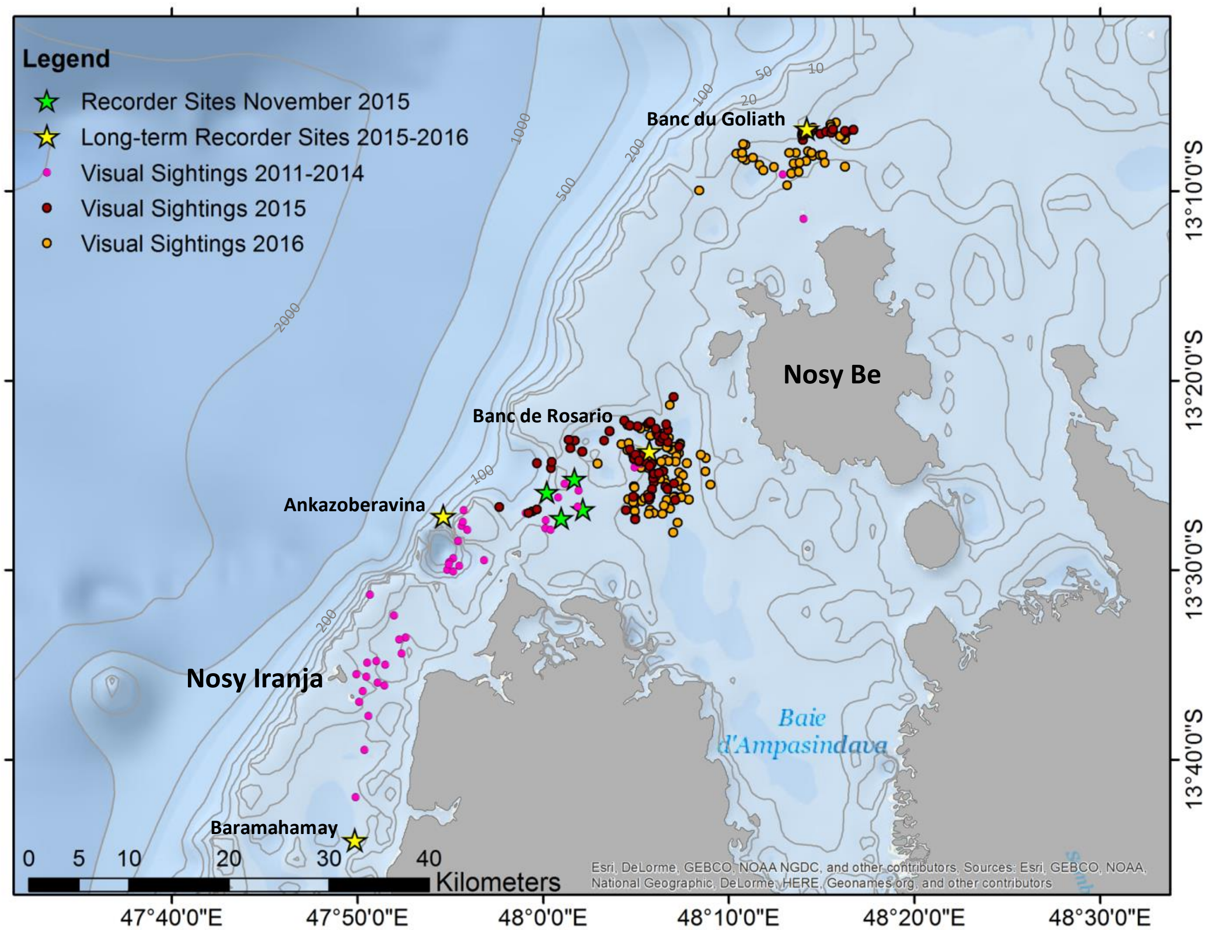

Figure 2. Map of study region indicating all sightings of Omura's whales in our study range. Sightings are shown separately for 2011-2014 (majority from 2013 & 2014 when based on Nosy Iranja), for 2015 and for 2016 (when based on Nosy Be, see Figure 1).

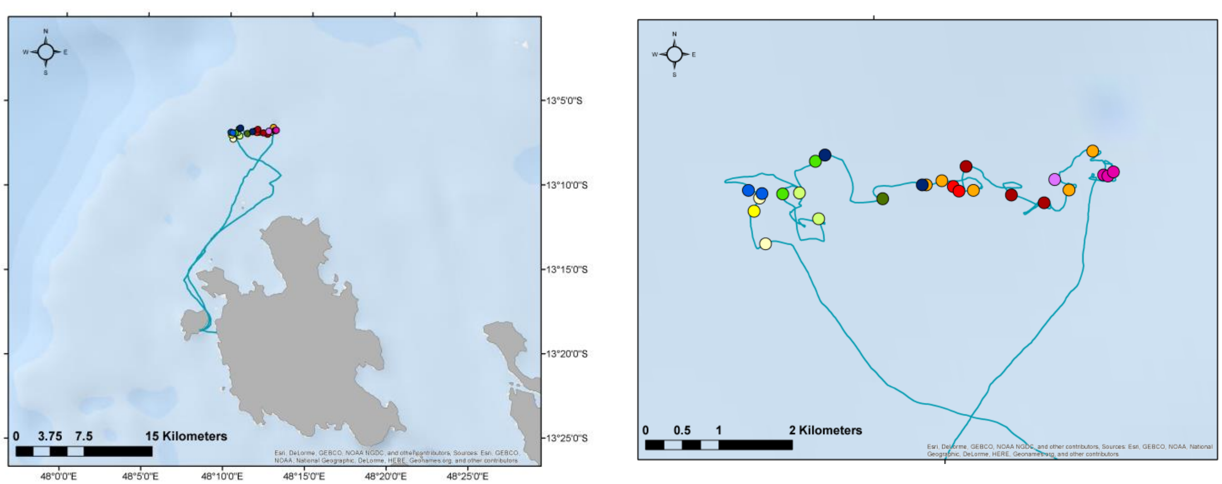

Figure 3. Boat track example illustrating an aggregation of a minimum of 12 Omura's whales. An approximately 2x5km area (right) was surveyed over 3 hours in 2015; each different color marker indicates the position of a different individual as determined by photo identification.

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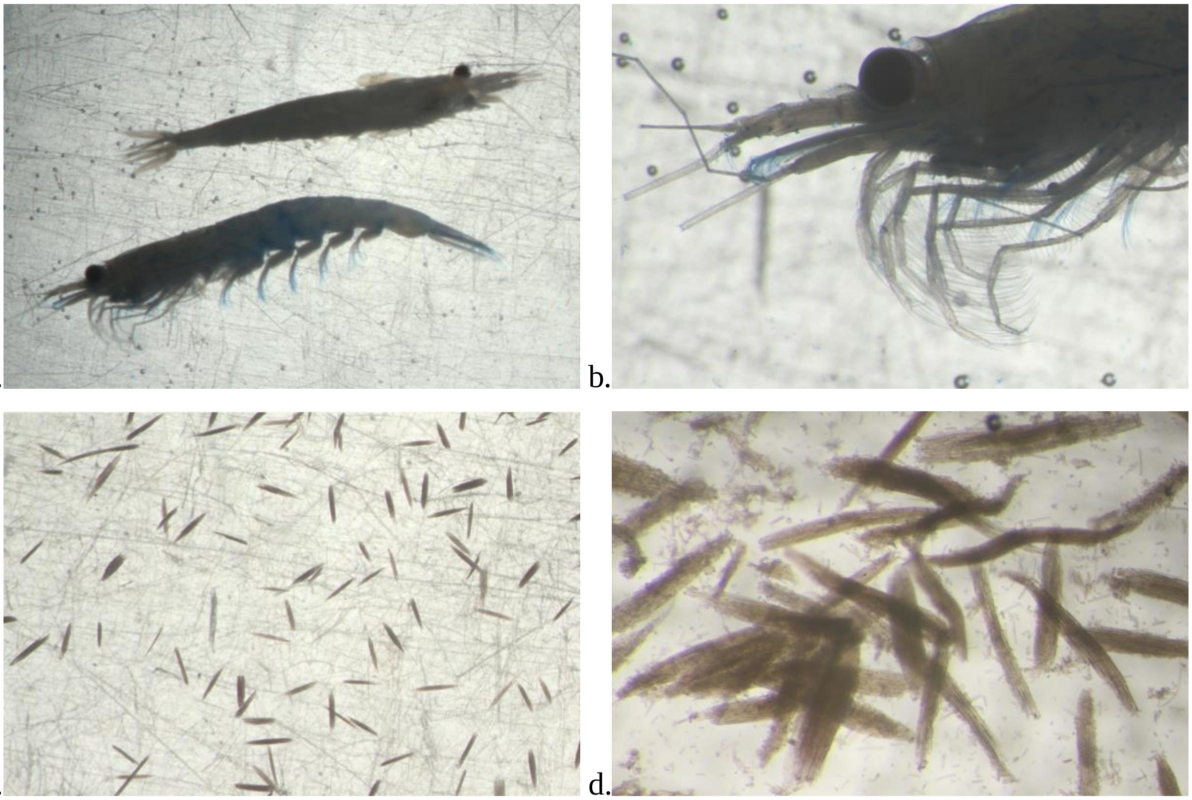

Figure 4. Euphausiid species *Pseudeuphausia latifrons* and cyanobacteria *Trichodesmium* sp. (a,b) *Pseudeuphausia latifrons* collected in vicinity of feeding Omura's whales. Whales were seen lunging on swarms of these euphausiids on several occasions in 2015 and 2016. Cyanobacteria *Trichodesmium* sp. (c,d) observed in extensive surface mats preceding development of large swarms of *P. latifrons* and presumed to be basis of local primary productivity. Microscopy photography and species identification by Nancy Copley & Peter Wiebe, WHOI.

Specific prey was not always obvious, and feeding on fish was never observed. Most commonly there were no densely aggregated prey obvious in the water column; this was typically the case during brief "prospecting" feeding observations when whales made a few lunges and then left the specific area. On other occasions, repeated lunging was observed even though there was no obvious prey near the surface. Feeding on dense patches of a small krill was observed episodically, representing the first such documentation of active feeding on a prey item for this species. Krill were sampled with a small plankton net, pulling the net through the upper meter of the water column behind a lunging whale, or through a patch that a whale had just lunged on. Sampled krill were identified morphologically as *Psuedeuphausia latifrons* (by Nancy Copley & Peter Wiebe, WHOI; Figure 4 a&b), a small, diurnal species that is known from shallow coastal waters throughout the Indo-Pacific, but had not been previously identified in the Southwest Indian Ocean. The species is noted from stomach contents of Bryde's whales in the eastern Indian Ocean during the Japanese scientific catch that yielded the first specimens of Omura's whale (Kawamura 1980).

During November/December 2016, a clear trophic progression or cascade was observed. Early in the season there were few obvious observations of food resources on the water, and feeding observations of Omura's whales were scarce and ephemeral, primarily falling into the "prospecting" category. Over the course of 2 weeks blooms of a cyanobacteria *Trichodesmium* sp. (identified by Nancy Copley & Peter

Wiebe, WHOI; Figure 4 c&d) began to appear and progressed to form extensive mats over large stretches of shelf habitat. This was eventually followed by dense patches of *P. latifrons* that were fed upon by aggregations of Omura's whales for extended periods over the last 2 weeks of field work. Multi-species feeding aggregations were commonly observed involving large assemblages of mobula rays (50+) and whale sharks. Although this conspicuous sequence of events had not been observed before, these episodic blooms of euphausiids had been noted in previous seasons, with patches of krill lasting for several days at a time before dissipating. It is speculated that this productivity cycle may be seasonal in nature and drive the co-occurrence of the observed planktivorous megafauna assemblage on a yearly basis during September through December.

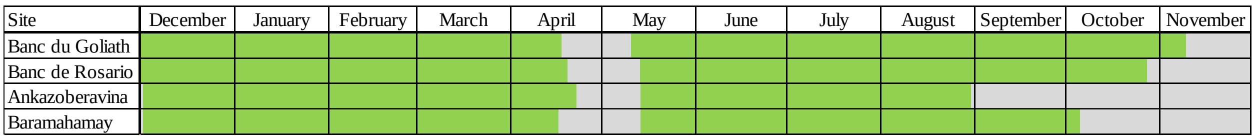

Figure 5. Temporal map of recordings from 1 December 2015 to 30 November 2016 at four sites indicated on Figure 2 from north to south. Green shading indicates acoustic data recorded on a 33% duty cycle, 10 minutes every 30 minutes, and grey shading indicates periods with no data.

Passive Acoustic Monitoring

Acoustic Monitoring Effort

Recorders were deployed on 1 and 2 December 2015 and retrieved between 26 April and 11 May 2016. Evaluation of recordings indicated that the recorders performed well from December 2015 to April 2016, recording 10-min samples every 30 minutes as programmed, but stopped recording about 1-2 weeks earlier than expected. Examination revealed a fault in the recorder firmware, requiring reprograming and repair during the field effort. The recorders were successfully redeployed at the same four sites during 11 and 14 May 2016, resulting in a recording gap of approximately three weeks. Upon retrieval of the recorders in November 2016, it was found the same fault occurred and three recorders again stopped recording 2-3 weeks earlier than expected and one stopped 2 months earlier than expected. The recorders operated from 1 December 2015 to 10 November 2016 (Figure 5) for a cumulative 1,161 recorder-days, recording at 33% duty cycle for 27,866 hours, and yielded a total of 9,287 hours of acoustic data. Analysis of the recordings is ongoing, and current results include several significant findings as follows.

Acoustic Detections of Omura's Whales

A cursory review of all recorder data indicated the presence of Omura's whale song documented in all months from December 2015 to November 2016. As described in Cerchio et al (2015), Omura's whale song consists of a stereotyped broadband low-frequency phrase repeated at a regular interval for extended periods of time (Figure 6). Examination of recordings indicated at least two distinct phrase types, referred to as Type1A and Type1B (Figure 6a & b). Both contain the same broadband amplitude-modulated unit (Unit A) that spans approximately 15 to 50Hz, with a peak frequency at 36.1Hz (s.d. 6.19Hz) and duration of 9.2sec (s.d. 0.92sec) (Cerchio et al 2015). Phrase Type 1A consists of only this unit (Figure 10a), whereas Type 1B contains this unit followed by an approximately 4 sec narrowband unit at 17Hz (Unit B; Figure 6b).

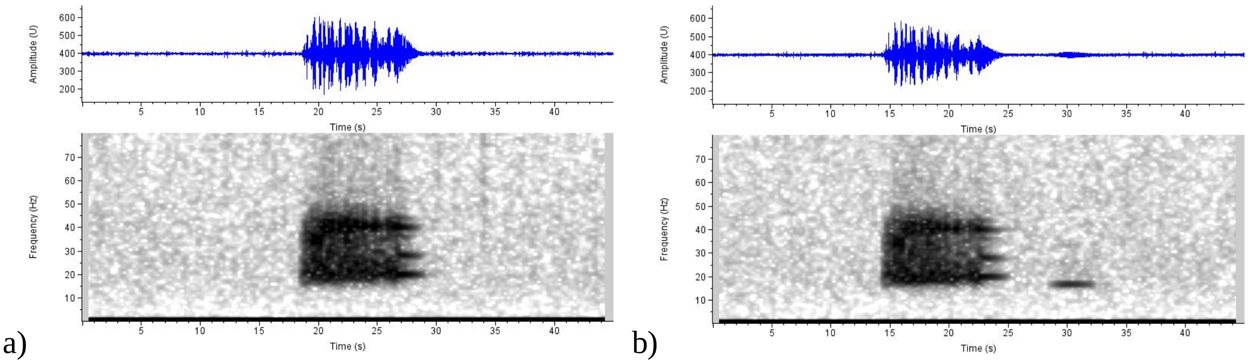

Figure 6. Sound spectrograms illustrating Omura's whale song phrases, sequence and chorus. Sound spectrograms and waveform envelope (in blue, top line only) are shown illustrating: a) song phrase Type1A, containing only the amplitude-modulated UnitA; b) song phrase Type1B, containing UnitA and narrowband tonal UnitB.

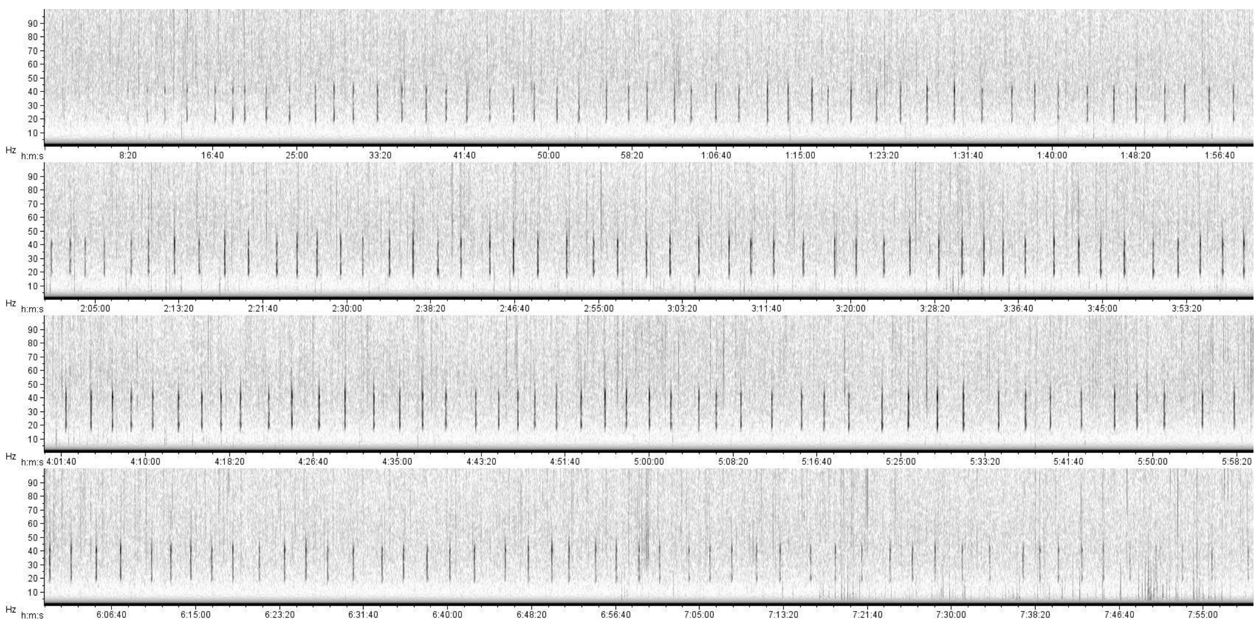

Figure 7. Spectrogram illustrating an uninterrupted 8-hour sequence of Omura's whale song. This uninterrupted and consistent sequence is presumed to be a single singing individual.

Continuous long-term recordings from November 2014 indicated that the song phrase is repeated at regular intervals, with uninterrupted series that at times lasted for long periods. A total of 215 individual sequences were isolated, each presumed to be a single individual singer with an unambiguous continuous song sequence. Series ranged from 3 to 250 repeated phrases, and the longest uninterrupted sequence lasted for at least 13.3 hours (see Figure 7 for an 8hr example). Average repetition rate for individuals ranged from 145.5sec to 237.6sec with a mean across individuals of 189.7sec (s.d. 19.04), measured from 118 series with ≥20 consecutive phrases. Frequently, overlapping series with different SNRs and acoustic quality were recorded, indicating choruses of several individuals. Therefore, summation of the number of detected song phrases in a 10-min sample, or across an entire day of samples, is indicative of Omura's whale presence, singing activity and the relative number of singing whales in the vicinity of the recorder.

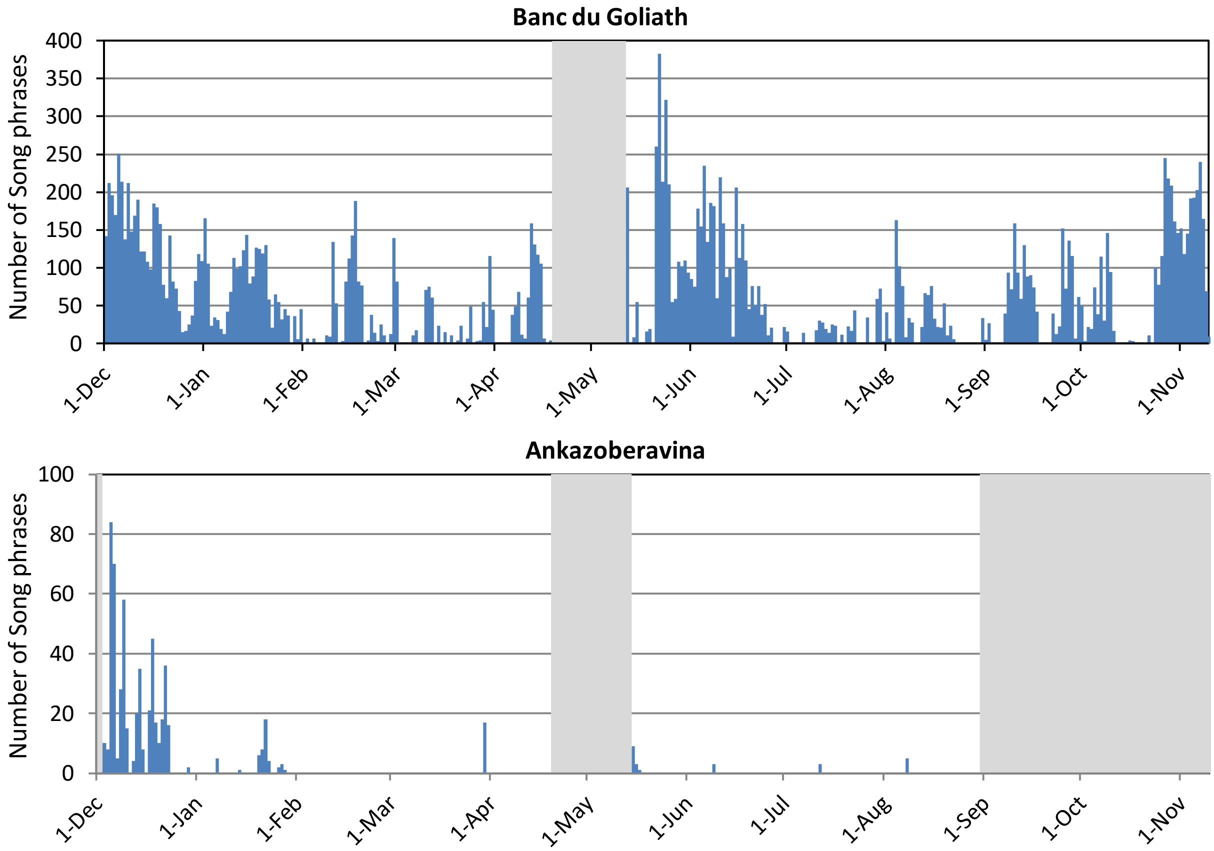

Figure 8. Daily counts of Omura's whale song phrases from 1-Dec 2015 to 9-Nov 2016. Data from two of four sites are illustrated, at the Banc du Goliath site north of Nosy Be Madagascar, and the Ankazoberavina site to the southwest of Nosy Be (note 4x differential in y-axis scale, due to far greater singing activity on Banc du Goliath). Data were recorded on a 33% duty cycle of 10 min every 30 min, so totals represent total number of phrases detected during 8hr of recording each day. Grey indicates days with no data or incomplete data.

There was apparent temporal and spatial variation in the occurrence of Omura's whale song among the four recorder sites during the 2015/2016 recording period. Initial review of all data from December 2015 to November 2016 indicated that occurrence of singing is clearly most prominent at the northernmost site, and relatively rare at the two most southern sites after December. Song was recorded during December on a daily basis, sometimes in dense choruses of multiple individuals, at all sites. Occurrence then subsided in January, particularly at the southern sites, and was sporadic or rare thereafter. Whereas occurrence of song appeared to decline during January in the three southern sites, at the most northern site it was very common throughout January and then intermittently recorded in all months thereafter, with dense choruses occurring throughout the year.

Detailed analysis of recordings has commenced to assess occurrence of Omura's whale song throughout the year and has been partially completed. The band-limited energy detector was designed for UnitA (Figure 6) in order to detect all occurrences of both Phrase Type1A and Type1B. The detector was run on data from all sites and detector verification has been completed for two sites (Goliath and Ankazoberavina). At the Goliath site, Omura's whale song was present throughout the entire recording period with no indication of strict seasonality despite fluctuating in rate of occurrence throughout the year (Figure 8). This suggests that the population does not seasonally migrate out of northwest Madagascar waters, although there is apparent variation in singing activity throughout the year. Song was present daily from 1 December to the end of January, and then was intermittently present throughout the year with several strong peaks in activity, the most prominent being late May to late June, and late October to mid-November when recording stopped. The longest stretch of days without any song detections was 8 days in late August; however, even this hiatus was shortly followed by a period of high activity in mid-September (Figure 8).

Singing activity at Ankazoberavina was markedly less than at Goliath, with singing heard consistently only in December, but even in that month at less than half the occurrence rate as during the same days at Goliath (Figure 8). After December, song was recorded at Ankazoberavina on less than one day per month overall, with no activity from late January to late March. This indicates that despite Omura's whales being resident year-round in the Nosy Be region, there is distinct micro-geographic variation in their distribution and preferred habitat during the year. Furthermore, it emphasizes the importance of broad sampling throughout a region, as had acoustic monitoring only been conducted at Ankazoberavina, a very different conclusion would have been had drawn than from the monitoring at Banc du Goliath.

Assessment of hourly rates of song phrases/sample (using Goliath data) gave no indication of a cyclic diel trend in singing activity across the complete sampling period, unlike other singing balaenopterids for which strong diel trends have been repeatedly found (e.g., the preference for humpback whales to sing during dark hours, Cholewiak 2008, Cerchio et al. 2014b).

Satellite Telemetry Tracking of Omura's Whales

Satellite Telemetry Results

During the November 2016 field season, all four satellite tags were successfully deployed on four individual Omura's whales (Table 2, Figures 9 and 10). The first tag was deployed on November 5, during the first week of field work. Thereafter, the daily acquired positions of that individual (nicknamed "Tadasu", in honor of T.K. Yamada, leader of the team that first described the Omura's whale) assisted in the localization of aggregations of Omura's whales for further research including deployment of the three remaining tags. The second tag was deployed on November 22 (on an individual nicknamed "Shiro", in honor of S. Wada, the first author of Wada et al. 2003), and the third and fourth tags were deployed on November 30 during a day in which aggregations of whales were found feeding on particularly dense swarms of krill (on individuals named "Mamy", after our Madagascar national partner, and "BB" after R.L. Brownell).

Tag transmission periods ranged from 30 to 58 days (Table 2). Cessation of transmission likely was due to the tag being rejected and falling out of the dorsal fin. The two shorter tag durations (30 days for Tadasu, and 32 days for BB) were from tags that were placed higher on the dorsal fin, midway between the base and the tip, whereas the two that lasted longer (48 days for Shiro, and 58 days for Mamy) were attached at the base of the dorsal fin; however, there was a tradeoff between duration and accuracy of positions as the tags attached higher on the dorsal fin yielded more positions of higher quality despite the shorter duration.

Table 2. Summary statistics of telemetry data from four satellite tagged Omura's whales. Indicated for each individual are the start and end day and duration of transmissions (Trans), the total raw positions received from the ARGOS satellite system, the number of useful positions after being filtered for accuracy, the total track (summation of all legs between positions), the range along the coast covered during the tag period, and the average speed of all legs.

Individual	Deploy Date	End Date	Days of Trans	Total Positions	Filtered Positions	Total Track (km)	Coastal Range (km)	Ave. Speed (km/hr)
Tadasu	5-Nov-16	5-Dec-16	30	451	419	2,148	250	4.27
Shiro	22-Nov-16	9-Jan-17	48	463	402	2,366	230	3.30
Mamy	30-Nov-16	27-Jan-17	58	493	446	3,181	405	3.64
BB	30-Nov-16	1-Jan-17	32	539	506	2,426	240	4.37
Average			42	487	443	2,530	283	3.92
Total			210	1,946	1,773	10,121	405	

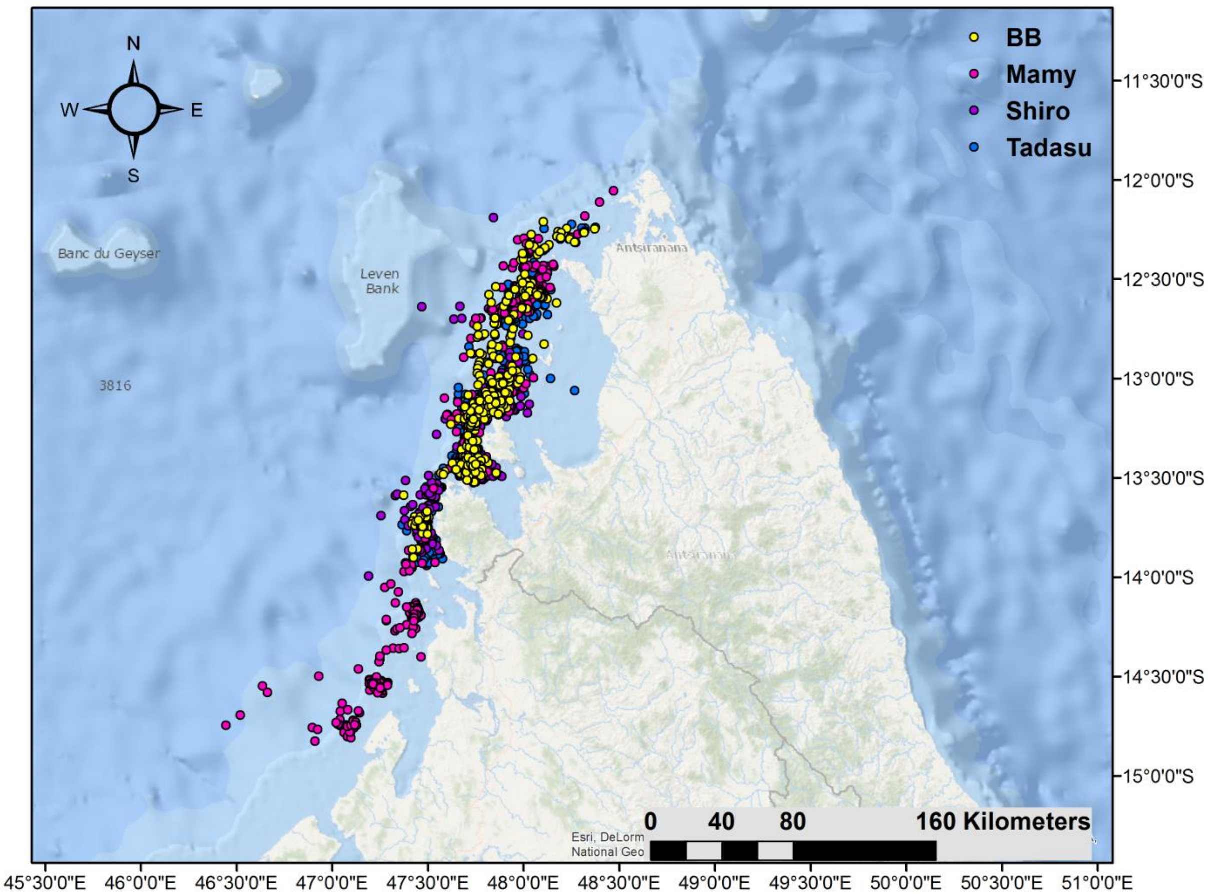

Figure 9. Map showing filtered positions of all four satellite tagged Omura's whales, color-coded for each individual.

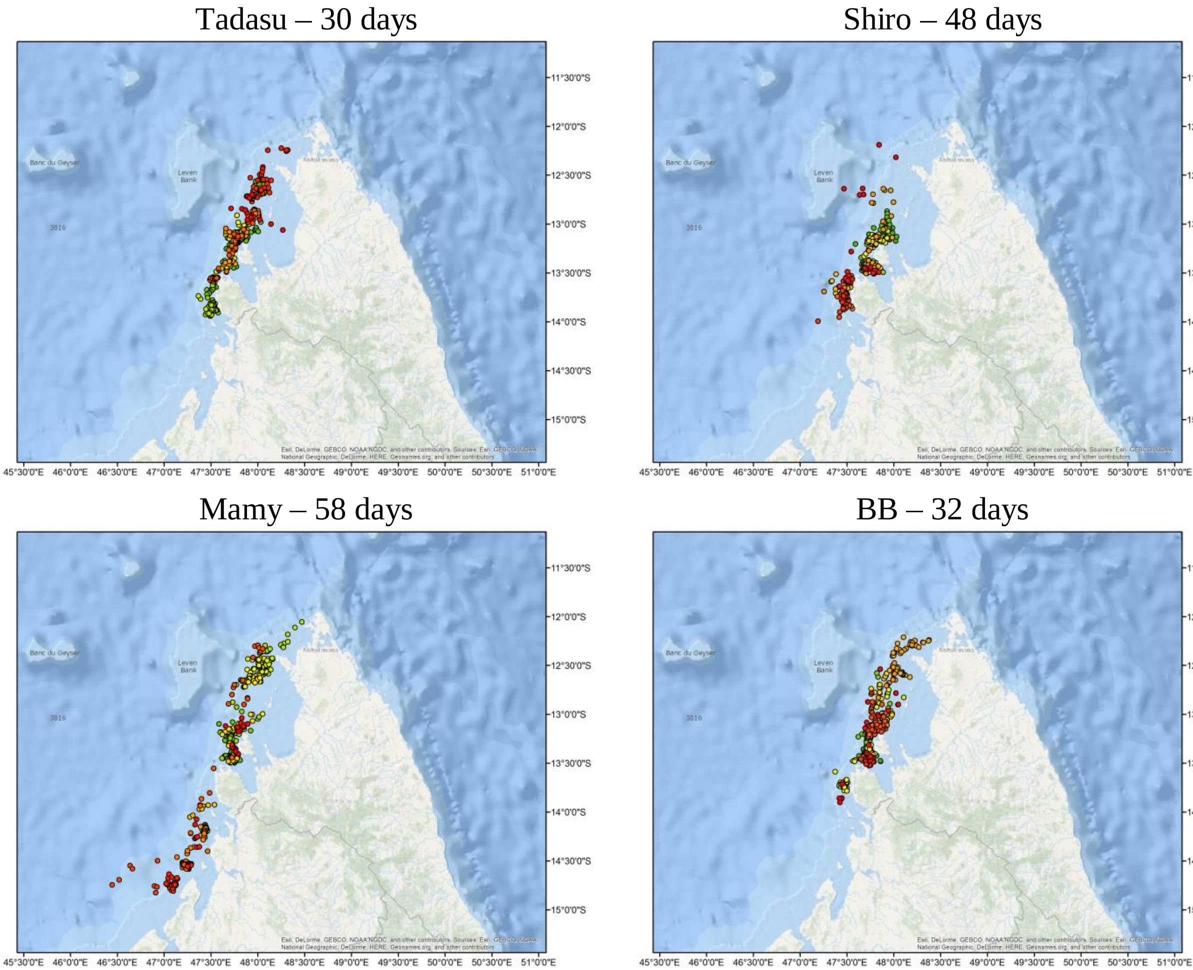

Figure 10. Maps showing filtered positions of each tagged individual displayed separately, color-coded for time of position ranging from start of tagging period (green) to last transmission of tag (red).

Probably the most striking result of the satellite tracking was that all tagged individuals remained in a relatively restricted range along the northwest coast of Madagascar. Total track length (summation of all legs between locations) ranged from 2,150km to 3,180km; however, all movement was in close proximity to the tagging site, covering a range of no more than 405km of coastline (mean among individuals of 283km; Table 4, Figure 10). Only the longest duration tagged animal, Mamy, exceeded a coastal range of 250km; the second longest duration tagged whale, Shiro, had the smallest range (230km), so range was not obviously related to tag duration. Moreover, all tagged individuals moved multiple times throughout their individual ranges during the duration of the tag (Figure 10); for example, Mamy spanned its entire range of ca. 400km four times from 12/14/2016 to 1/23/207, and three times during 19 days from 1/4/2017 to 1/23/2017; similarly, BB spanned its entire range of ca. 240km four times during 17 days from 12/15/2016 to 1/1/2017. This indicates highly localized behavior, particularly for a baleen whale, at least during the duration of this two month monitored period.

To put this in perspective, in a study of humpback whale movements around Madagascar (Cerchio et al. 2016), tagged individuals covered 1,000s of kilometers in comparable time frames, with two females covering ca. 1000km along coastal Madagascar in 15 and 21 days. Individual humpback whales commonly traveled >100km of coastline in a day, with one female covering 500km in 3 days. These figures refer only to movements around the shallow waters of coastal Madagascar to maintain comparability to the Omura's whale movement; open ocean movements of the humpback whales tagged off Madagascar included long transits to the east African coast of 2100km in 25 days, and 2800km in 32 days (Cerchio et al. 2016). Such long range movements of migratory baleen whales are commonly reported in satellite telemetry studies (Zerbini et al 2006, 2011, Bailey et al. 2009, Olsen et al. 2009). Therefore, the small and restricted ranges displayed by the Omura's whales tagged in this study represent highly unusual and unique behavior in context of baleen whales, and is likely due to a non-migratory and local resident life history pattern.

Assessment of Movement Behavior

Assessment of movement behavior based upon SSSM results indicated a strong skew towards localized movements throughout the documented ranges (Table 3, Figure 11). Mean b-mode ranged from 1.78 to 1.88 among all individuals, and 74% of all estimated positions were classified as localized movement, compared to only 9% as transiting. Travel speed and leg length was substantially lower for localized movements (mean of 1.30km/hr and 3.9km) than for transiting movements (mean of 4.69km/hr and 14.1km). The typical pattern displayed by all individuals was short periods of transiting (or undetermined) movement between specific areas where the whales would then linger for several days displaying primarily localized movements; this is particularly evident when examining the temporal series of b-mode simultaneously with latitude, which shows correlated periods of localized movements (b-mode → 2.0) while remaining at specific latitudes, and transiting movement (b-mode → 1.0) during periods of steadily changing latitude, moving up or down the coast (Figure 12).

Table 3. Results of behavioral switching space-state model (SSSM) of satellite telemetry data. Mean b-mode is shown for each individual, and the characteristics of movement during three different b-modes categories is shown: Transiting Movement for b-mode<1.25, Undetermined Movement for 1.25<b-mode<1.75, and Localized Movement for b-mode>1.75.

		Transiting Movement			**Undetermined**			**Localized Movement**		
	Mean B-mode	% of Positions	Ave Speed (km/hr)	Ave Leg (km)	% of Positions	Ave Speed (km/hr)	Ave Leg (km)	% of Positions	Ave Speed (km/hr)	Ave Leg (km)
Tadasu	1.78	8%	4.90	14.7	21%	3.01	9.0	71%	1.50	4.5
Shiro	1.88	2%	4.06	12.2	13%	2.68	8.0	85%	1.19	3.6
Mamy	1.80	11%	4.63	13.9	13%	2.31	6.9	77%	1.27	3.8
BB	1.70	16%	4.76	14.3	26%	2.63	7.9	58%	1.37	4.1
Total	1.80	**9%**	**4.69**	**14.1**	17%	2.65	7.9	**74%**	**1.30**	**3.9**

There were several general areas where whales repeatedly returned and spent days exhibiting localized movement (labeled A-G in Figure 11). Two of these were already recognized as distinct aggregation areas from boat-based surveys, near Banc de Rosario (Figure 2; label C in Figure 11; 13.4-13.5°S in Figure 12) and near Banc du Goliath (Figure 2; label B in Figure 11; 13.1-13.2°S in Figure 12); these were also sites of long term acoustic monitoring. All tagged whales spent time in these two areas where feeding was regularly observed; between 30 November and 5 December Shiro, Mamy and BB were all in area C simultaneously, during the 5 days following the tagging of the latter two while feeding (Figure 12). Boat-based observations indicated that these two areas were quite distinct, with no sightings in the ca. 20km stretch between them; satellite telemetry data indicated a more diffuse pattern, with a spread of positions between the two areas, and only moderate clustering of localized movements in each area (see Shiro and BB, Figure 23). Also area B is relatively large stretching ca. 40km from the north of Nosy Be to the small island group of Nosy Mitsio (13°0'S 48°35'E); at least Tadasu indicated movement that subdivided the area into two clusters, north of Nosy Be and southwest of Nosy Mitsio (Figure 11). In addition to these areas, the satellite data indicated other favored areas that were not previously recognized. Tadasu, Mamy and BB all traveled ca. 80km northeast of Nosy Be to spend periods of days exhibiting localized movement south of Cap Sainte Sebastian (label A in Figure 11; 12.3-12.6°S in Figure 12). Tadasu and Mamy made short excursions ca. 70km further north but did not linger there. To the south, Tadasu and Shiro exhibited several days of localized movement south of Nosy Iranja, ca. 70km south of Nosy Be (label D in Figure 11; 13.7-13.9°S in Figure 12) and BB made a short excursion there of undetermined movement. Only Mamy moved further south than this, traveling ca. 200km south of Nosy Be with clustered localized movement at three distinct areas (labels E, F and G in Figure 11; 14.2°, 14.5° and 14.7° in Figure 12). As noted above, after spending 11 days in areas E and F Mamy made a dramatic movement ca. 280km to area A and then back ca. 325km to area G in 6 days (Figure 12).

These movement data suggest a pattern of continual search throughout a restricted range for a patchy food resource, in which animals prospect through areas that are well known to them and linger to feed for days when prey patches are found. This is apparent from a combination of boat-based observed behavior, the distribution of satellite telemetry positions, the pattern of movements throughout the habitat, and the utilization of specific areas as indicated by localized movement. Some of these areas may represent aggregations for social or breeding behaviors, as indicated by choruses of song off Banc du Goliath and Banc de Rosario, or singing and feeding may be synonymous throughout the habitat. It was also clear that the vast majority of movement was in shallow shelf waters, with only brief excursions of transiting and undetermined movements made into deep water by Shiro in the far north and Mamy in the far south (Figure 11). An important caveat is that these data only represent the behavior of these four individuals, during the two month period in which the tags transmitted, and it is unknown if the described behavior persists throughout the year. Presence of song off Banc du Goliath throughout the year suggests that the population remains local, but it is possible that movements may be more extensive, traveling further distances away from Nosy Be, or further/more frequently offshore during other times of year. This can be assessed only through additional satellite tagging during other periods of the year, or with longer duration tags (such as implantable tags modified to a small baleen whale and thinner blubber layer).

Habitat Suitability Modelling

All boat-based sightings were used in the MAXENT habitat suitability model, including all Nosy Be data (331 GPS logged positions), along with four opportunistic sightings outside of our range. The latter were provided to our team by known operators that encountered Omura's whales while on long range expeditions and had positive photographic documentation and GPS coordinates; two of these were ca. 900km (19.396°S) and ca. 550km (16.325°S) to the south of Nosy Be, extending documentation of Omura's whales presence off Madagascar significantly further south than our study range. Satellite telemetry positions were limited to raw Argos positions that had an error of <500m, amounting to 101 positions from the four tagged individuals with a mean error radius of 216m.

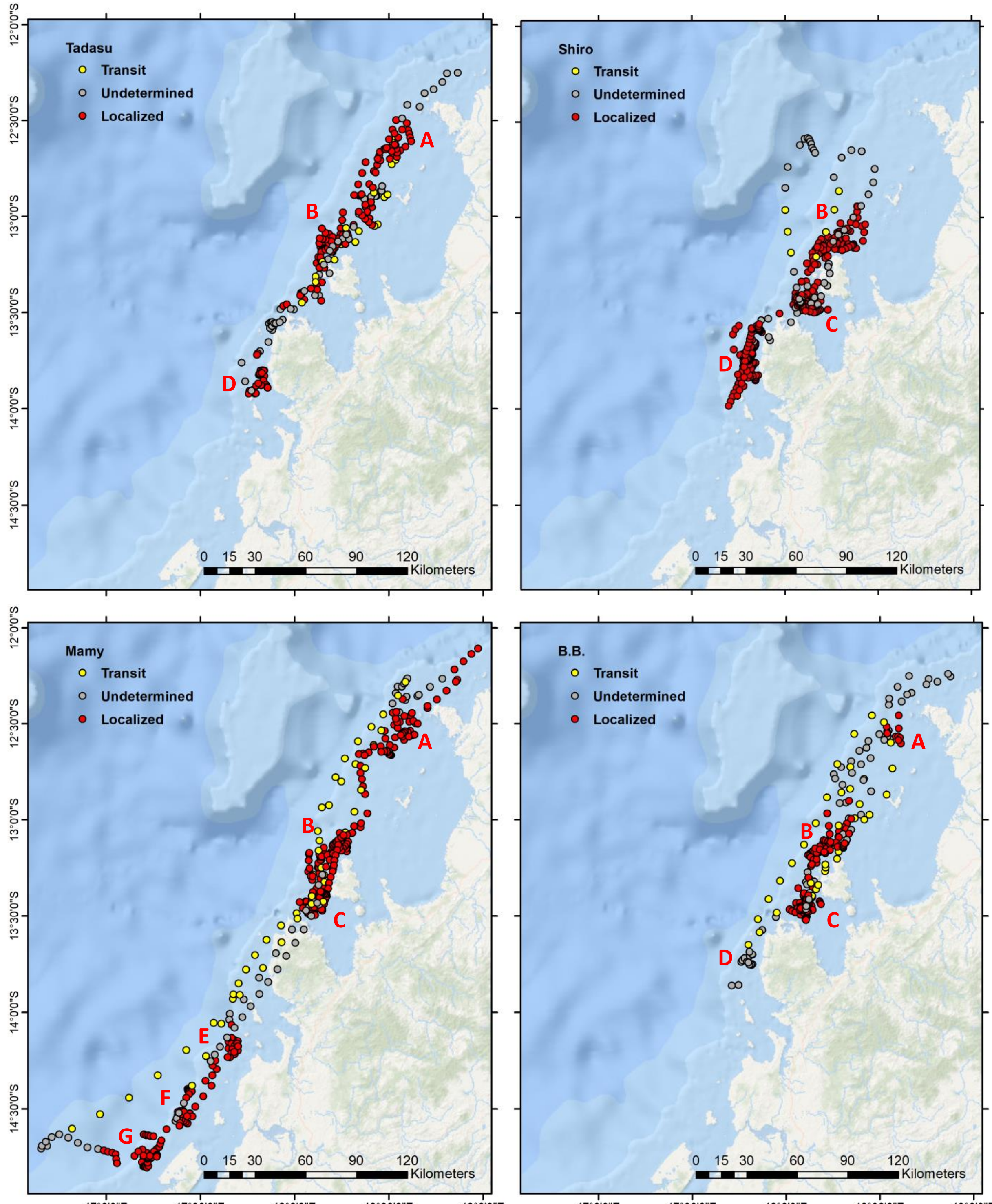

Figure 11. Plots of SSSM b-modes for each tagged individual indicating movement behavior.
For each estimated position for the SSSM, the b-mode value is indicated as transiting movement for b-mode<1.25, undetermined movement for 1.25<b-mode<1.75, and localized movement for b-mode>1.75. Letter labels in red indicate general areas in which clustered positions of localized movement occurs, and referenced in the text.

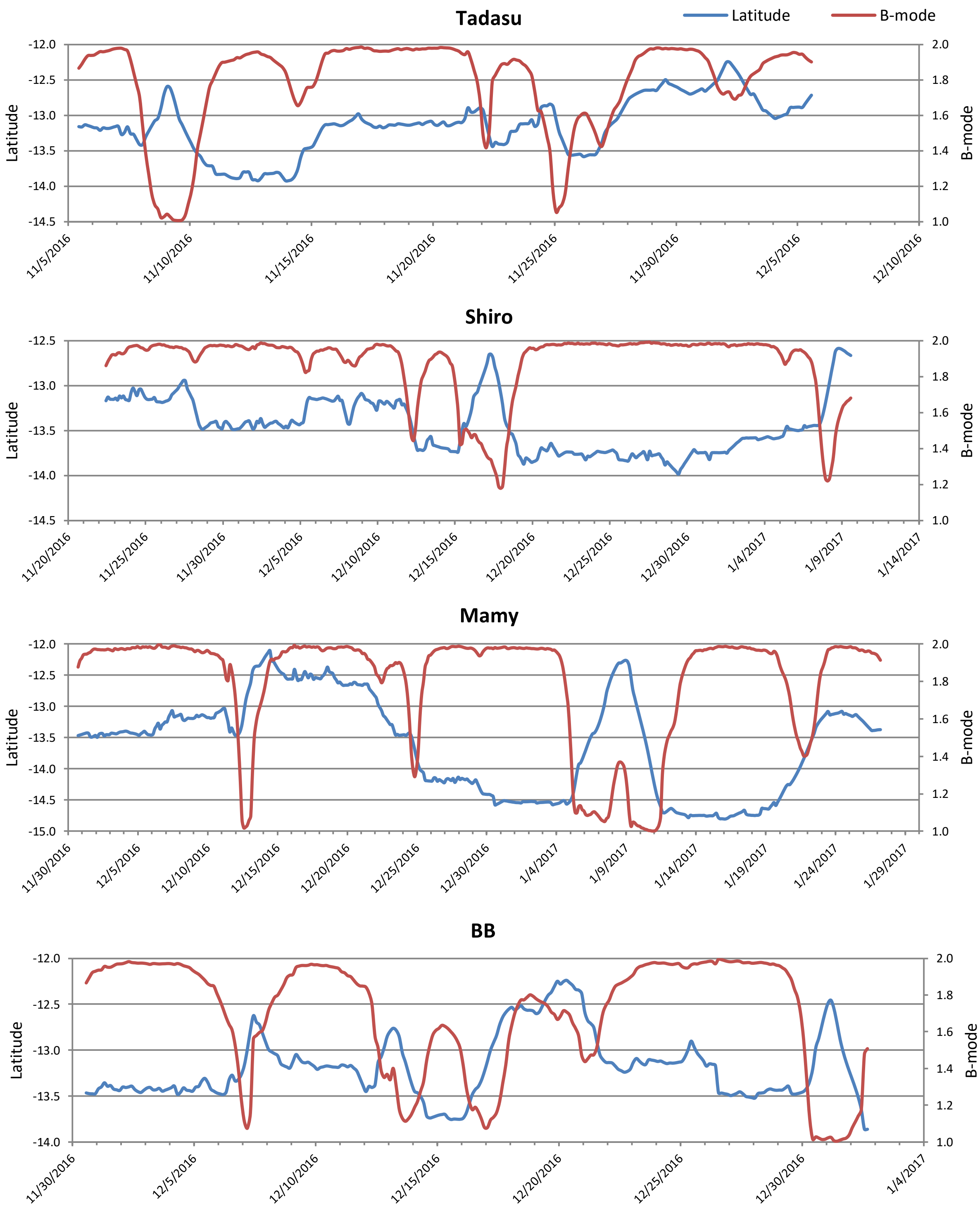

Figure 12. Plots of latitude (blue) and b-mode (red) over time for each tagged Omura's whale, showing correlated periods of localized movements (b-mode → 2.0) while remaining at specific areas, and transiting movement (b-mode → 1.0) during periods of steadily changing latitude, moving up or down the coast.

The physical variable bathymetry provided the greatest predictive value as indicated by highest contribution to model fit (64.2-82.7%; Table 4). This is not unexpected given the observed shallow water distribution on shelf habitat from boat-based surveys and satellite telemetry data. The second greatest contribution came from the variable Photosynthetically Active Radiation (PAR; 11.7-25.3%; Table 4). PAR is defined as the amount of light of the proper wavelength available for photosynthesis. Since PAR is a requirement for photosynthesis, the importance of this variable in the model may reflect the importance of primary productivity, however it is difficult to confidently interpret. It is noted that the variable Chlorophyll, which we might expect to be a more direct measure of productivity, had very little contribution. Primary productivity likely varies substantially on a fine scale both spatially and temporally. It is equally likely that movements of Omura's whales within their preferred habitat may reflect variations in productivity as they search for and exploit food resources. We would expect the distribution of whales relative to resources to have an associated temporal lag between primary productivity events and availability of targeted zooplanktonic prey; this was directly observed in 2016 as described above, with growth of cyanobacterial mats, followed by blooms of euphausiids which in turn determined distribution of feeding Omura's whales. It is possible that in a more fine scale analysis accounting for temporal variation, a more direct measure of productivity (i.e., chlorophyll) would have greater importance in the model, at least locally. In the current model, since the variable values are averages measured over an extended period of time, PAR may predict at a gross level where productivity occurs on average.

Table 4. Estimated contributions of environmental variables in Maxent habitat suitability model. Seven environmental variables were assessed by remote sensing on a 1km^2 grid resolution. Relative contribution of each variable was estimated in two manners, by directly estimating the increase in model fit with contribution of each variable (Percent Contribution), and by evaluating the effect on model fit of randomly permuting the values of each variable in turn (Permutation Importance).

Physical Environmental Variable	Percent Contribution	Permutation Importance
Bathymetry	64.2	82.7
Photosynthetically Active Radiation	25.3	11.7
Salinity	7.9	0.7
Wind	2.4	2.6
Chlorophyll	0.2	2.3
UV Radiation	0	0
Sea Surface Temperature	0	0

The predicted distribution map indicates favorable conditions for Omura's whale along the west coast of Madagascar, and particularly in the northwest, with little other predicted suitable habitat throughout the Southwest Indian Ocean (Figure 13). Some caution should be used in interpretation of these modelling results, since this model utilizes a regionally-limited dataset, does not consider absence or effort data and uses a relatively basic algorithm. Recognizing this caveat, the output corroborates existing data from Madagascar. Our surveys around Nosy Be, and the results of satellite tagging confirm the high suitability of habitat indicated along the coast between 12°S and 14°S, which is not necessarily surprising since these were the input data for the model; in addition, a new area of predicted distribution is indicated between 15°S and 16°S (Figure 13). The absence of suitable habitat around most of the remainder of Madagascar is in part corroborated by extensive multi-year survey effort off the southwest coast (Anakao at 23.7°S) and northeast coast (Antongil Bay at 16.5°S, and Ile Sainte Marie at 17°), in which no evidence of Omura's whales has been found. Eventual inclusion of this effort and absence data is presumed to only strengthen the outcome of the current model. Of particular interest is the absence of predicted suitable habitat throughout the larger Southwest Indian Ocean region outside of northwest Madagascar. To date, Omura's whales have only been identified regionally off northwest Madagascar, despite cetacean survey effort, albeit patchy, throughout the region, in particular off South Africa, Tanzania, Kenya, Reunion and Mauritius. If further model development supports this hypothesis, then the Omura's whales off northwest Madagascar may represent a local isolated population.

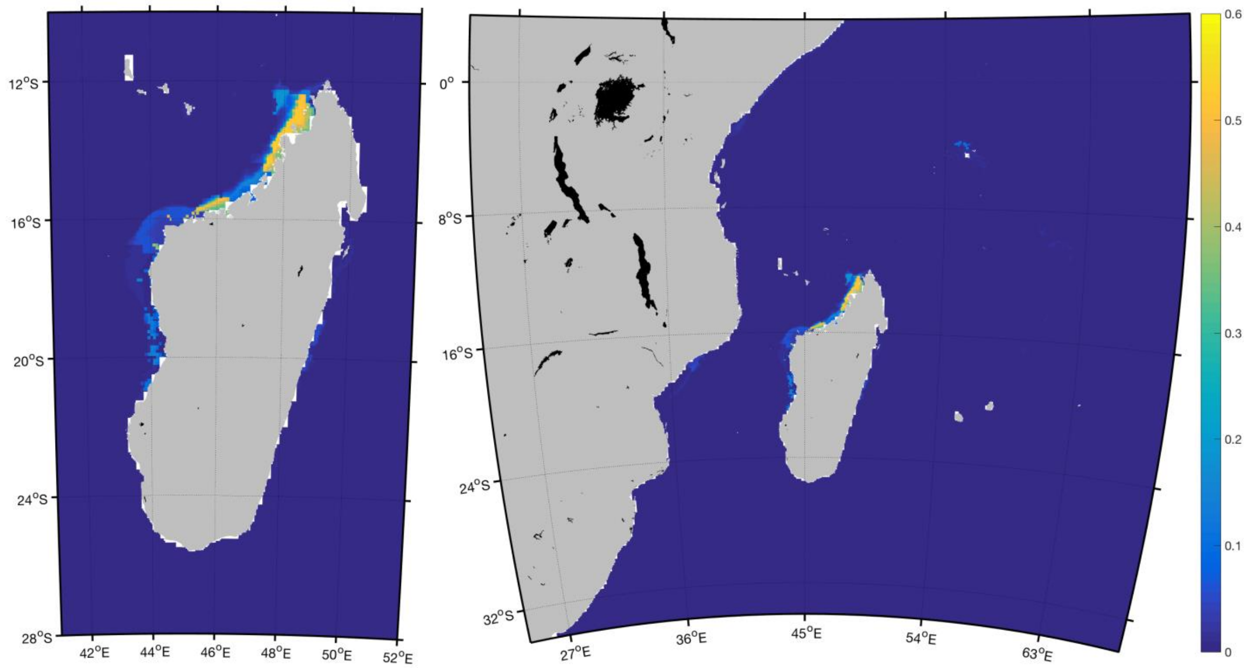

Figure 13. MAXENT habitat suitability maps showing Omura's whale predicted distribution. Detail of Madagascar, left, and general Southwest Indian Ocean region, right, are shown; warmer colors represent areas with better predicted conditions.

This initial application of SDM, along with the satellite telemetry results and direct observations on feeding ecology, suggest that Omura's whale distribution may largely be determined by ecological processes that are restricted to shallow water shelf environments. Distribution within this habit is likely strongly influenced by the distribution of patchy and ephemeral prey resources. Furthermore, our initial attempt at habitat suitability predictive modeling suggests that the appropriate habitat may not be common in the Southwest Indian Ocean, and thus the Northwest Madagascar population of Omura's whale may be isolated within a fragmented oceanic/global range for the species. In partnership with Daniel Pendleton of New England Aquarium, we plan to refine and develop habitat suitability models using time-varying environmental predictors to fit species distribution models with fine spatio-temporal resolution, e.g., 8-day, monthly and seasonal timescales (Pendleton et al. 2012).

SIGNIFICANCE AND CONSERVATION CONCERNS

The results and analyses reported herein have advanced our understanding, both of Omura's whales as a species, and of the local population. It was previously predicted that Omura's whales are non-migratory with resident populations, and the data gathered in this project support that expectation. The acoustic data presented here have conclusively shown year-round presence in the Nosy Be region with singing activity occurring in nearly all weeks of the year. The satellite telemetry data indicated highly localized movement of four individuals in a restricted range around the research site; such movement patterns are highly unusual for a baleen whale species and not compatible with a migratory species' typical behavior. Habitat suitability modelling corroborates the findings of the satellite telemetry and boat-based observations, indicating the presence of suitable habitat in a highly restricted range in the Southwest Indian Ocean. These results suggest that the population is non-migratory and resident in the northwest Madagascar region and potentially isolated on a regional/oceanic scale. Regarding ecology of the species, prey items for Omura's whales were documented and an ecological trophic cascade observed for the first time, providing insights into the important ecological relationships in this habitat. These observations will guide future work on the feeding ecology of this species and the trophic dynamics in this habitat, leading to a better understanding of what drives primary productivity and how it may be vulnerable to anthropogenic impacts. The combination of boat-based observed behavior, the distribution of satellite telemetry positions, and the pattern of movements throughout the habitat with repeated utilization of specific areas, together suggest that Omura's whale distribution is largely determined by local ecological processes that are restricted to shallow water shelf environments. Distribution within this habitat is likely strongly influenced by the distribution of patchy and ephemeral prey resources, such that animals continually prospect through areas that are well known to them, searching throughout a restricted range for a patchy food resource, and linger to feed for days when prey patches are found.

Thomas et al. (2015) provided an overall review of the threats to baleen whales, specifically identifying the following: entanglement/ entrapment, ship strike, whaling, pollution, disease, habitat degradation from oil spills, the cumulative impacts of anthropogenic noise and other stressors, and the short- and long-term effects of climate change and ocean acidification on marine ecosystems. Given the primarily coastal and shallow water distribution of Omura's whale, the species is in particular risk of anthropogenic interactions and threats relative to oceanic balaenopterids. Thus we expect that Omura's whale populations have a relatively high probability of impact from entanglement and bycatch in local fisheries, ship strikes, coastal development and coastal industry. Furthermore, if results from our population studies in Madagascar bear out to apply range-wide, and the species is characterized by small, localized populations with low range-wide genetic diversity (Wada et al. 2003, Cerchio et al. 2015, Cypriano-Souza et al. 2016), then they may be particularly vulnerable to such anthropogenic impacts that could cause small populations to decline. Moreover, since there appear to be many isolated populations spread disparately throughout its range, the conservation status of each population must be determined at each location where they occur. The distribution of the species in typically remote and poorly surveyed regions exacerbates the problem, in that both occurrence of interactions and magnitude of impacts is difficult to impossible to document. Lastly, the occurrence of this tropical whale in range states such as Madagascar that are underdeveloped and stricken with chronic poverty and political instability, typically implies poor regulation and management, and vulnerability to corruption and unsustainable/destructive resource exploitation.

Although bycatch and entanglement of Omura's whales has not been observed in Madagascar, bycatch in local fisheries has been documented in several other regions including Japan, Thailand and Sri Lanka (Cerchio et al. 2017). It is possible that entanglement occurs in Madagascar but has gone undetected, since the remoteness and lack of development makes detection and monitoring of bycatch challenging. Bycatch of coastal dolphins has been reported widely along the west coast of Madagascar (Cerchio et al. 2014a). Seismic exploration has occurred extensively off the west and northwest coast of Madagascar, and was commonly recorded in late 2017 during acoustic monitoring in the deep water off Nosy Be (Cerchio, unpublished data). Therefore, the population has definitely been exposed to seismic surveys potentially at close range in shallow water. There is potential for disturbance of breeding and resting behavior, masking of communication, and even physiological damage (i.e. to hearing) if in close proximity or with long exposures to loud noises such as seismic airguns (Gordon et al 2003). Numerous studies globally have documented behavioral responses of baleen whales to seismic airguns, such as changes in travel routes and distribution (Richardson et al 1986, 1999, Gailey et al. 2007, Weir 2008), and most recently more subtle responses such as shifts in vocal behavior (Di Iorio and Clark 2010, Castellote et al. 2012, Blackwell et al. 2013, Cerchio et al. 2014b). It has also been shown that noise from hydrocarbon E&P activities and vessel traffic contributes significantly to ambient noise within the communication bandwidth of baleen whales, likely acting to mask communication and breeding displays (Clark et al. 2009).

Probably of greatest current concern in northwest Madagascar, is a mining project underway for Rare Earth Elements (REE) on the Ampasindava Peninsula, adjacent to the primary habitat identified for the Omura's whale population. REE mining, using *in-situ* leaching methods, is among the most environmentally damaging types of extraction (Yang et al. 2013), and the planned scale of the Madagascar project poses grave long-term concern to the local marine environment from groundwater contamination and mining effluent into coastal waters. As observed during 2016, the ecology of this region appears to be driven by local ecological processes, which provide the primary productivity for a diverse assemblage of marine megafauna from schools of bonito, mobulid rays, and whale sharks to coastal dolphins and Omura's whales. It is likely that these processes are sensitive and vulnerable to local industrial pollution sources, particularly if unregulated. The fact that the coasts adjacent to the mining project are encompassed by one of the largest Marine Protected Areas in Madagascar (the Ankivonjy MPA), underscores the challenges of protecting habitat along the coasts of developing nations, where much of the Omura's whale range is found.

DATA GAPS

Despite the progress we have made in advancing our understanding of this population, it is important to recognize that ecological study of this species has only commenced in the past five years. As with any newly described species, a multidisciplinary approach is necessary to gather the fundamental baseline information on its ecology, behavior and status. As such, we are only beginning to develop an understanding within each discipline, and to take advantage of the opportunity for research presented by the unique situation off Nosy Be, Madagascar. Extensive targeted studies are possible and warranted, both due to the nascent understanding of the species and the potential for detailed studies with this accessible resident population.

Future work should include a long-term (10 years+) latitudinal study as has been done on numerous populations of humpback whales, killer whales, bottlenose dolphins, etc. (i.e., species for which populations exist that are accessible, resident or seasonally resident, and for which repeated observations of individuals over many years are possible). Long-term individual photo-identification is necessary to understand site fidelity, residence patterns, life history parameters and social structure. Genetic analyses are needed to assess population genetic structure and diversity, relatedness among individuals, and mating behavior. Stable isotope analysis in combination with prey sampling and genetic determination of prey species from fecal samples should be used to better understand feeding ecology. Broad-scale ecological studies of the habitat and locale should be conducted to understand the processes driving temporal and spatial distribution of the planktivorous megafauna community of which Omura's whales are one component.

Questions remain regarding the long-term spatiotemporal distribution of Omura's whales throughout the currently identified habitat and potential new habitats. Continued passive acoustic monitoring can inform our understanding of habitat use, as well as more detailed questions regarding breeding behavior. Additionally, expanded satellite tagging will provide further information to better understand year-round residency patterns and shifts in distribution. Finally, given the concerns regarding the development of mining operations in the coastal areas of this population's habitat, blubber analyses of contaminant loads could be critical for understanding exposure to contaminants.

A limiting factor in conducting many of these studies is the development of a reliable funding stream, which has remained challenging. This is not atypical with Data Deficient species, for which there exists no specific mandate for conservation or action plans. The remote nature of the range and habitat of the species, such as off Madagascar and other underdeveloped tropical countries, means that the species is largely not a priority for research and conservation initiatives, and not a focus for many research groups due to inherent logistical challenges. This combination of factors makes populations more vulnerable to anthropogenic influences, and presents additional challenges for documenting anthropogentic impacts and potential population effects.

ACKNOWLEDGEMENTS

Many individuals and institutions contributed to the success of this project. Logistical support for field activities came from Tanguy and Arthur Guillemain d'Echon, Elina Sourisseau and associates of the MadaMegafauna Association, and Sylvia Trélanche of Forever Dive. Assistance in field surveys and data collation in 2016 was provided by Giovanni André, Robert L. Brownell, Jr., Robert Pitman, Lisa Ballance, Alessandro Bocconcelli, and Leigh S. Hickmott. Les Kaufman donated equipment for plankton collection, and species identification was done by Nancy Copley and Peter Wiebe. Recorders were made available by generous loans from Mark Johnson in 2014 and Sofie van Parijs in 2015, and Sandra Dorning and Bridget Mueller-Brennan were acoustic analysts under the NOAA Hollings Fellowship Program. Assistance with satellite tagging effort was provided Robert Pitman, Alex Zerbini, Greg Schorr, and staff of Wildlife Computers. Satellite telemetry SSSM analysis was conducted by Alex Zerbini, and habitat suitability modeling by Daniel Pendleton. Research authorization was obtained from our Madagascar national partner Centre National de Recherches Océanographiques, Nosy Be. Funding was provided by generous grants from the U.S. Marine Mammal Commission, the National Geographic Society Committee for Research and Exploration, the New England Aquarium Marine Conservation Action Fund, and the Woods Hole Oceanographic Institution (through the Dalio Foundation).

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