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Humpback Whales in the Western Indian Ocean

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Editorial Note

Humpback whales are well known especially for their very long migration routes and also because of the songs that males emit during the breeding season. In 1971, in their famous article published in the journal 'Science', Payne and McVay describe these songs as "a series of surprisingly beautiful sounds"! Since 1971, more acoustic data have been collected and more knowledge generated; we now know that the song 'leitmotiv' is different from one geographic area to another, and from one year to the next. We also now know how they produce these sounds from their respiratory system.

In the last two decades, different techniques have been deployed to observe humpback whales in all the oceans. Not only have passive acoustic monitoring techniques been used, but also visual observations, electronic devices, and genetics. The objectives of these studies have been to better understand whale activities, behaviors, and also the underwater environment in which they live, and the potential effects of anthropogenic activities on their societies. This has involved many different research teams, with their own skills, methods and programmes. Results have been published in the scientific literature and presented at different international conferences.

However, three things have recently become apparent: Firstly, the study of humpback whales is a wide subject requiring people with complementary skills. It was apparent that it was necessary to bring these people together to discuss this species of whale for several reasons: a) because it would highlight the major results obtained thus far; b) because it would be interesting to share experiences (especially on the data and methods used, but also on common challenges); c) to co-design future projects and identify priorities; and d) because it would provide an opportunity to start new collaborations.

Secondly, before 2015, no international scientific conference or workshop existed with regular annual sessions especially dedicated to this species of Mysticeti whales. In order to address this, we initiated the creation of the Humpback Whale World Congress (HWWC, http://www.hwwc.mg/). The first session was held in Madagascar in 2015 and the second in La Réunion Island in 2017. Our idea was to bring together researchers and technicians from universities, research institutes, government organizations, and industry, dealing with all aspects of the biology, ethology, genetics, ecology, acoustics, signal processing, pattern recognition, mathematics, and computer sciences applied to the study of the humpback whales and their environment, and the potential effects of anthropogenic activities on the species. The goal of the HWWC is to provide a forum for exchange of new results obtained from the latest advances in instrumentation and methods.

Thirdly, during the BaoBaB project I led from 2012 to 2014, it became apparent that the extensive movement of humpback whales, even during the breeding season (with more than 100 km being covered per day), resulted in the same individuals being observed from the east coast of Africa to the Mascarene Islands. Because of this remarkable characteristic of this baleen whale species, it was obvious that we needed to encourage collaboration at a regional level, and we envisaged a consortium of people who work collaboratively on the Southwestern Indian Ocean humpback whale population.

During the international HWWC we were very pleased by the quality of the work shared by different teams, and the strong motivation to exchange information and work together. For this reason, we requested some colleagues to describe their projects in full papers, to put them together, and publish this unique special issue.

I would like to thank all the authors and co-authors, all the persons who contributed to this special issue, and more strongly the Cetamada Team who currently does such amazing work on these humpback whales!

Enjoy reading!

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Using passive acoustic monitoring to assess humpback whale occurrence and breeding activity around La Réunion Island

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Abstract

Humpback whales use the coastal waters of La Réunion Island seasonally from June to October. Their distribution is relatively well-known on the west coast, which provides suitable breeding habitat, however little is known about their use and movement along the south and east coast of the island. Three autonomous acoustic recorders were deployed during the breeding season of 2016 off the west, south and east coasts to investigate spatial and temporal variations in humpback whale occurrence around the island. The dataset consisted of 10 minute acoustic recordings every hour, continuously from mid-June to early September from these three locations. Song and social call events were discriminated and their total durations were calculated and expressed as a percentage of the total recording duration per day. Off the west and south coast, social calls were distributed fairly homogenously over the season, while songs occurred over a shorter time period, with two significant peaks observed in mid-July and early-August. Off the east coast very few vocalizations were detected. These results demonstrated that humpback whales preferentially use the west coast of the island for breeding. In this area, daily variations in singing activity were observed. Singers appeared to be more active at night and during the morning, when less boat traffic was detected.

Keywords: humpback whale, song, passive acoustic monitoring, Indian Ocean, breeding activity, occurrence.

Introduction

Humpback whales (*Megaptera novaeangliae*) typically undertake latitudinal migrations, resulting in a strong and constrained annual cycle, where feeding and breeding activities are spatially and temporally segregated (Dawbin, 1966). In the south-western Indian Ocean (SWIO), humpback whales breed along the east coast of Africa, Madagascar and around small oceanic islands, and feed almost exclusively off Antarctica during the austral summer (Best *et al*., 1998).

La Réunion Island is a small (72 km long and 207 km of coastline) oceanic island, located 700 km east of Madagascar and 250 km west of Mauritius. The island shelf is very narrow (200 m depth contour which lies on average 3 km from the coast) and bottom depth increases rapidly from close to the shore, down to 3,000 m deep. This topography could restrict humpback whale breeding habitat to within 2km from the coast, except off Saint-Gilles where the 100 m contour lies 7 km from the coast (Dulau-Drouot *et al*., 2008). The humpback whale appears to be the most common species showing a clear seasonal pattern at La Réunion Island, and are present in coastal waters from early June to late October, with a peak in July-September. The consistent occurrence of newborn calves, competitive groups and typical humpback whale songs confirm that La Réunion Island represents a breeding area for the species in the south-western Indian Ocean (Dulau-Drouot *et al.,* 2008; 2012). Survey effort around La Réunion mostly covers the west coast and little is known about the occurrence of the species on the east coast of the island, leeward and where the shelf is very narrow (Dulau-Drouot *et al*., 2017).

Male humpback whales are well known for producing stereotypical sound pattern known as songs, composed of units, phrases and themes (Payne and McVay, 1971). Songs are associated with breeding areas although they have been recorded, to a lesser extent, during migration (Clapham and Mattila, 1990; Noad *et al*., 2000) and in feeding areas (Mattila *et al*., 1987; McSweeny *et al*., 1989; Clark and Clapham, 2004). Humpback whales are also known to produce social calls, which are emitted in bouts but are not structured, and produced in shorter events than songs (Payne and McVay, 1971). Social sounds are believed to be produced by both males and females (Dunlop *et al.,* 2007).

Passive acoustic monitoring can be a useful tool to detect the presence of cetaceans, particularly species that are acoustically very active, such as humpback whales on breeding grounds. It can provide valuable and quantitative information on timing of migration, occurrence patterns, and breeding activity, on a continuous time scale that is not dependent on weather conditions (Lammers *et al.,* 2011; Munger *et al*., 2012; Cerchio *et al.,* 2015).

The main objective of this study was to use passive acoustic methods to monitor the presence of humpback whales off the west, east and south coast of La Réunion Island over the breeding season, to assess spatio-temporal patterns of occurrence around the island. Daily patterns in song production and boat traffic were also investigated to provide further insight into humpback whale breeding activity and habitat use in coastal areas, where most human activity occurs.

Materials and methods

Data collection

Passive acoustic monitoring was conducted off La Réunion Island using 3 SoundTrap 300 STD autonomous recorders (manufactured by Ocean Instruments, New Zealand) deployed on the west (Saint Gilles), south (Saint Louis) and east coast (Saint Benoit), in water depth of around 30 m (Fig. 1, Table 1). The three recorders were located 70 to 80 km apart, therefore singers could not be recorded simultaneously at the three stations. The SoundTrap units were configured with a bandwidth of 20 Hz – 60 kHz and recorded at a sampling rate of 48 kHz which is adequate for humpback whale vocalizations, as the main frequency range is below 24 kHz (Thomson *et al*., 1979; Payne *et al*., 1983; Silber *et al*., 1986). The gain of the preamplifier was set to "high" to increase sensitivity, resulting in a maximum Sound Pressure Level (SPL) of approximately 172 dB re 1 µPa (SoundTrap user guide).

The recorder units deployed off the south and east coasts were duty-cycled to record 10 minutes every hour, and had a lifespan of a minimum of 57 days. The hydrophone deployed off the west coast was equipped with an external battery pack and was set to record continuously, resulting in a lifespan of around 33 days. Recorders were thus deployed several times during the study period. For comparison purpose, only the first 10 minutes of each hour of recording from Saint Gilles were taken into account in this study.

Vocalization detection

The occurrence of humpback whale sounds was assessed from the 15th of June to the 1st of September 2016. The "whistles and moans detector" module of Pamguard V.1.15.10 was used to detect humpback whale vocalizations from the recordings (Gillespie *et al*., 2008). A bandpass filter of 0-8000 Hz was applied to select frequencies corresponding to humpback whale sounds (Thomson *et al*., 1979; Payne *et al*., 1983; Silber *et al*., 1986; Clark *et al*., 1990). The detector extracts the contour of tonal sounds from the spectrogram display (Fast Fourier Transform (FFT) data). It was configured by testing different parameters: minimum frequency; maximum frequency; detection sensitivity; and numbers of connections for contour detection. Contour detections were visualized in real-time on the FFT spectrogram (FFT length 1024; FFT hop size 512 and Hann window). Each detection (contour and sound file) was saved into a database as both a binary (SQLite) and audio file (wav format). The "clip generator" module of Pamguard was used to visualize and play back all automatically-detected vocalizations. Each vocalization was validated by an acoustic operator and classified either as a humpback whale vocalization or as a false detection (Fig. 2). Only vocalizations with a good signal-to-noise ratio (vocalizations in which the signal was at least 10 dB higher than the background noise) were considered for analysis. Boats were also detected and categorized as "boat traffic". Motor boat signatures were characterized by broadband noise and harmonically related tones that correspond to engine and propeller specifications (Ogden *et al.,* 2011; Sorensen *et al.,* 2010).

Spatial and Temporal Occurrence

The duration of each event of successive vocalizations was measured by taking the time interval (in

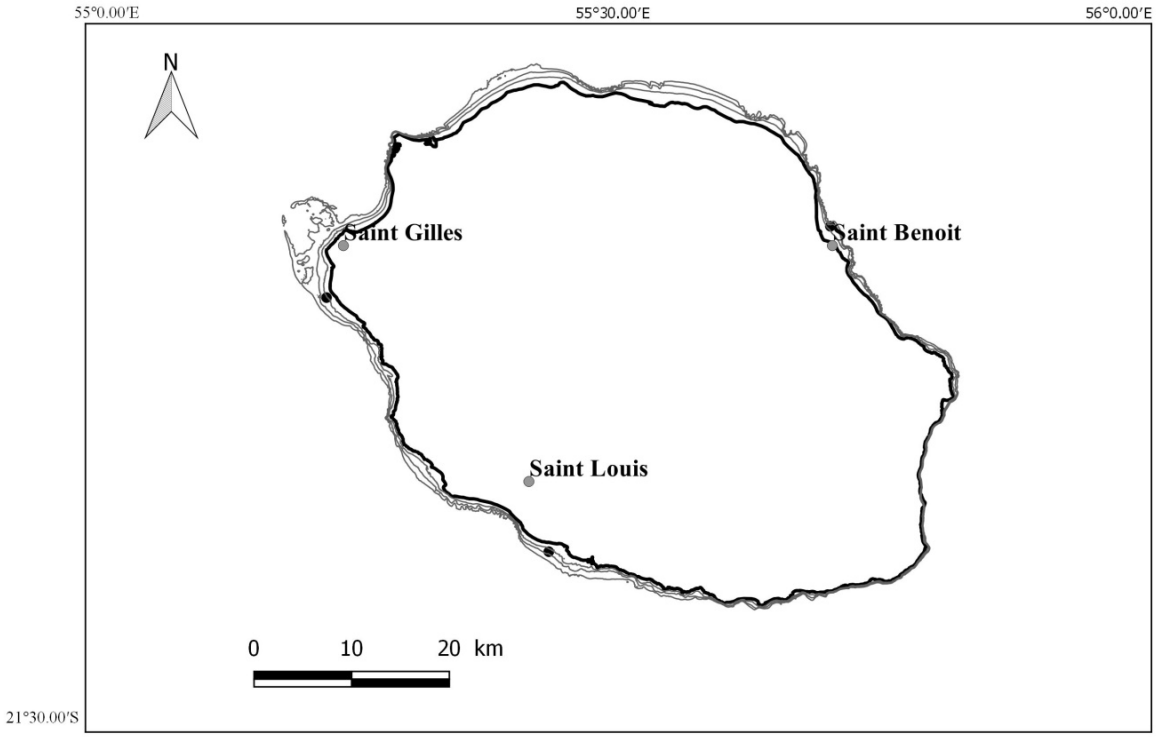

Figure 1. Map of La Réunion Island showing the position of the three hydrophones (black points) deployed around the Island.

mins) between the first and the last vocalization. Two events were considered as different after a lag time of more than 10 seconds between the last vocalization of the first event, and the first vocalization of the next event. This lag time was chosen because the time interval between two successive song units varied from 1 to 5 seconds. It was therefore considered that 10 s was a reasonable timeframe to consider two events as independent. Events were then classified into song or social call events, based on their structure and frequency. Song events were characterized by continuous, highly structured phrases and themes that contain sets of repetitive units above 4 kHz and generally showed harmonics (Payne and McVay, 1971; Darling, 1983; Helweg *et al*., 1992; Au *et al.,* 2000; Fristrup *et al*., 2003). In contrast, social call events were characterized by sounds ranging from 50 Hz to 3 kHz, which were produced erratically, in an unpredictable manner, without any rhythm and consistency (Tyack, 1981; Silber, 1986). The total duration of song and social call events were computed per day for each location (Saint Gilles, Saint Louis and Saint Benoît) and expressed as a percentage of the daily recording duration (240 minutes).

Table 1. Hydrophone stations used for temporal distribution and occurrence in 2016.
Days = number of days data were collected.

Site	Location (DMS)	Hydrophone depth (m)	Recording dates	Duration (Days)
Saint Gilles hydrophone	21° 5' 4.9999'' S, 55° 12' 59.9976'' E	33	29/06/2016-30/07/2016 02/08/2016-01/09/2016	61
Saint Louis hydrophone	21° 20' 10'' S, 55° 26' 10.9968'' E	33	17/06/2016-25/08/2016 26/08/2016-01/09/2016	76
Saint Benoit hydrophone	21° 0' 50.9998'' S, 55° 42' 52.9999'' E	33	15/06/2016-01/09/2016	78

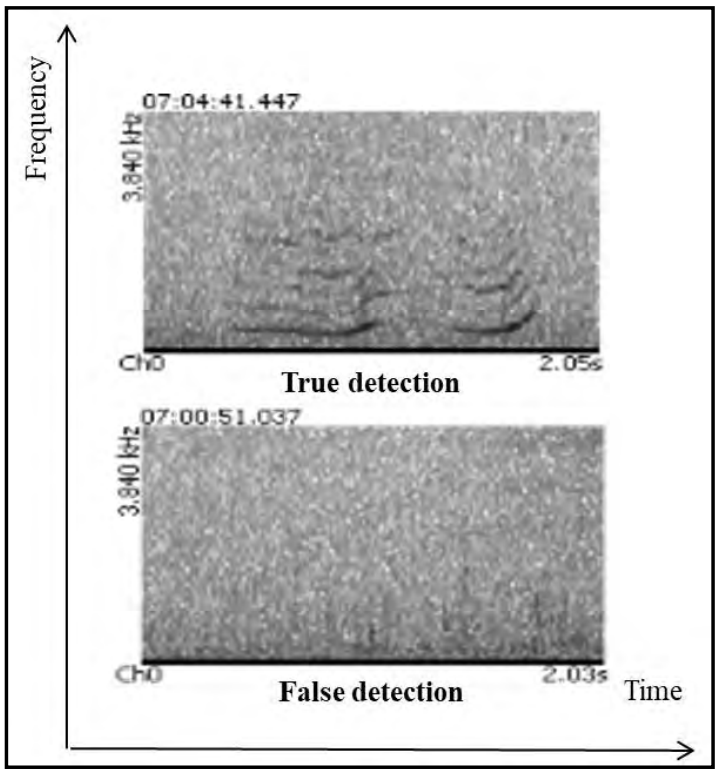

Figure 2. Examples of true (humpback whale vocalization) and false detections (noise).

Daily patterns in humpback whale singing activity and vessel traffic

Daily pattern of singing activity was investigated during the peak of the season, when songs were more frequently recorded (from the 29th of June to the 1st of September). For each location, a detection rate was computed for each hour of the day, by taking the proportion of recordings that included at least one song event, over the total number of 10 min recordings made at that hour, over the study period. Similarly, the detection rate of marine traffic (presence/absence of boat), was determined acoustically at the three sites.

Results

The hydrophone deployed off Saint Benoît (east coast) recorded for 78 days in a row. The hydrophones deployed off Saint Louis (south coast) and Saint Gilles (west coast) recorded for 76 and 61 days respectively, with 1 or 2 days of missing data (Table 1). Gaps in the recording occurred during recovery and re-deployment of the Sound Trap unit (for downloading data and recharging the batteries), which could not be undertaken on the same day.

A total of 860 hours of recording were analyzed: 244 hours from Saint Gilles; 304 hours from Saint Louis; and 312 hours from Saint Benoît. Humpback whale vocalizations were detected from all three recording locations, with some variability observed between sites (Fig. 3). Overall, humpback whale vocalizations were detected more often off the west coast (Saint Gilles) and the south coast (Saint Louis) compared to the east coast (Saint Benoît).

Temporal pattern of occurrence

For all sites, social calls were detected throughout the season, from July to early September, while songs were detected over a shorter period.

Songs were detected from the 14th of July to the 1st of September off the west coast, with two peaks observed in late July (song representing 100% of the recording duration) and in early August (87% of the recording duration) (Fig. 3). Off the south coast, songs were detected from the 15th of July only until the 14th of August. Two peaks were observed around the 16th of July and around the 2nd of August with song representing 70% and 81% of the recording duration, respectively (Fig. 3). Off the east coast, songs were detected from the 23th of July, and to a lower extent (35%), compared to the other sites. No peak was observed (Fig. 3). Very few humpback whale vocalizations were detected in general off this part of the island.

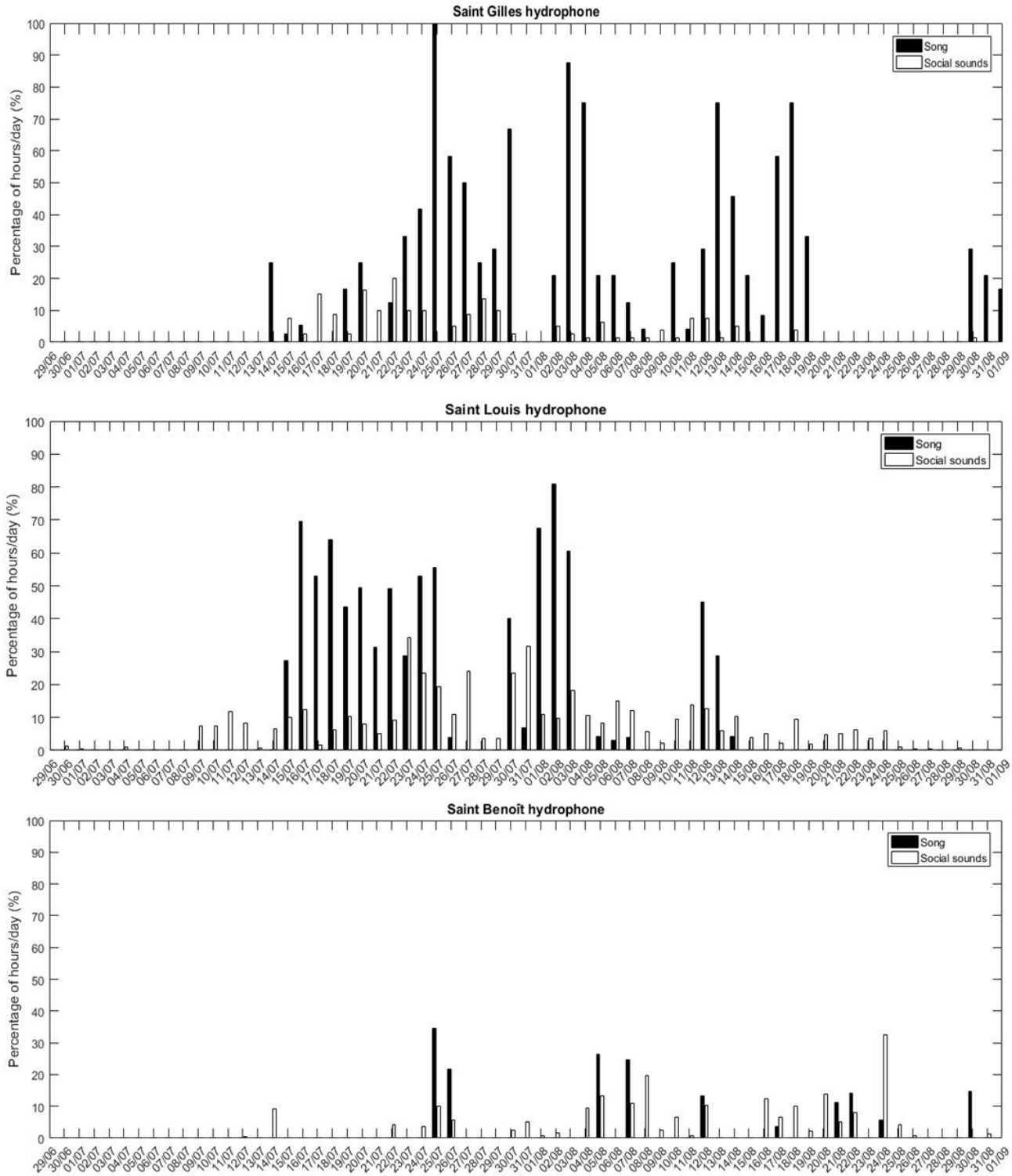

Figure 3. Percentage of hours of recording including humpback whale song (black bars) and social call (whites bars) over the breeding season of 2016 (late June to early September) at Saint Gilles (West), Saint Louis (South) and Saint Benoît (East).

Diel pattern in song activity

Songs were detected over the entire 24h period, but tended to increase at night off the west coast (Saint Gilles), more specifically between 7pm and 1am. The maximum detection rate (0.4) was observed in the evening, at 9pm and 10pm, and the minimum detection rate (0.2) was observed early in the afternoon, between 1pm and 3pm (Fig. 4). Off the south coast, songs were detected consistently throughout the day, and no clear daily pattern was observed. The detection

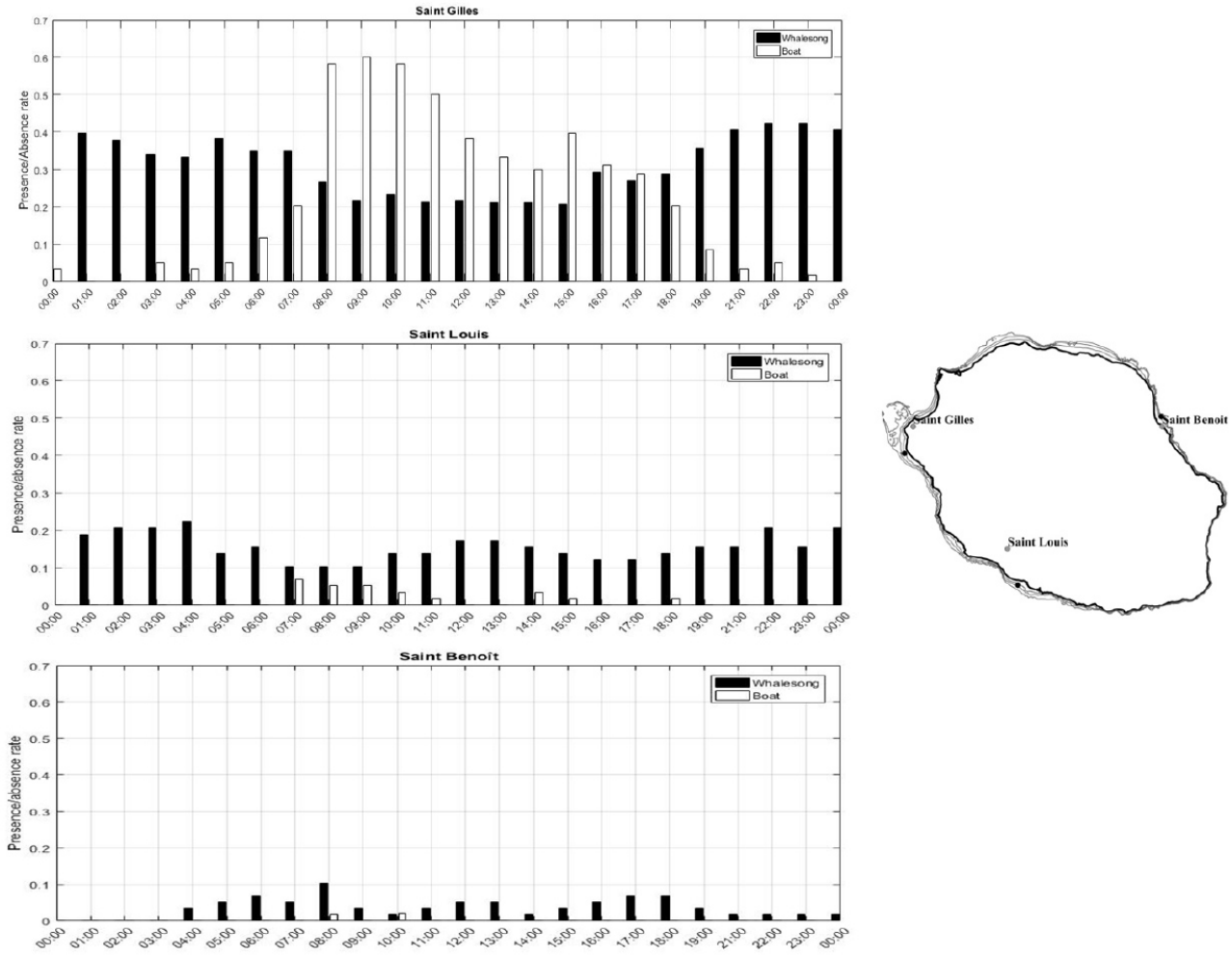

Figure 4. Detection rate of humpback whale songs (black bars) and boats (white bars) per hours, at each location, during the peak of singing activity (29th of June to the 1st of September 2016).

rate was lower than on the west coast, ranging from 0.1 to 0.2. Off the east coast, song detection rates were low (<0.1) and no diel pattern was observed (Fig. 4).

Diel pattern in vessel traffic

Vessel traffic was detected during daylight, from 7am to 6pm, with a peak (0.6) at 9am off Saint Gilles. On the south and east coast, marine traffic was less important, being almost absent. The maximum rate off Saint Louis (0.07) was at 7am, and only two boats were detected in Saint Benoit during the entire breeding season (Fig. 4).

Discussion

The results showed that humpback whales used the three study sites during the breeding season, with the west coast being used more extensively. Although the detection range of the hydrophone was unknown, the acoustic intensity of the sound received by the recorders was generally high compared to the background noise, and only good quality recordings were used, suggesting that the whales were detected within a few kilometers (up to a few tens of km maximum) from the recorders. Detection range might also have varied between sites, as sound propagation is largely influenced by local environmental characteristics. Due to a gentler slope, the recorder located on the west coast might have had a smaller detection range compared to those deployed on the east and south coast, although other factors might also have influenced sound propagation (e.g. type of substrate, topography, ambient noise). Assessing the detection range of the hydrophones at each location would require acoustic modelling based on oceanographic and environmental data, and could not be conducted in this study. Despite these uncertainties regarding the range of the hydrophones, the considerably higher detection rate recorded off Saint Gilles tends to indicate that the west coast of La Réunion represents a more suitable breeding habitat for the species, compared to the east coast

that had been only poorly surveyed so far. This might be a result of lower habitat suitability in these areas, where underwater relief is very steep and the insular shelf is very narrow. Conversely, the west coast offers a larger shelf, particularly off Saint Gilles, where the 100m contour lies up to 7 km from the coast, offering an extended shallow water area, consistent with preferred humpback whale breeding habitat (Dulau-Drouot *et al*., 2008; 2012).

Social calls were detected at all three survey sites throughout the breeding season, from July to September, with no clear peak detected. Conversely, peaks in song production was observed from mid-July to early August off the south coast, and from mid-July to mid-August on the west coast, corresponding with the peak in breeding activity (increased sighting rate and presence of competitive groups) observed in La Réunion (Dulau-Drouot *et al*., 2008).

Furthermore, off the west coast, a diel pattern in song production was observed, with detection rates tending to increase during the night and decrease at around 8am. The rate of song detection was lowest during the day (between 9am to 3pm) and began to increase at around 4pm. These results suggest that, in breeding habitats, males spend more time singing at night, which is consistent with acoustic monitoring conducted in Maui, Hawaii (Au *et al*., 2000; Payne and Payne, 1985). Males might be less acoustically active during the day when they can engage in direct competition for females, within active groups, and may switch to other mating tactics such as song production at night, when visual cues are not possible (Au *et al*., 2000).

Interestingly, such a daily pattern in song production was not detected off the south and east coasts of La Réunion, which were used to a lesser extend compared to the west coast. Differences in song production between night and day might be less pronounced in areas providing less suitable breeding habitat, or when whale density is lower, as males might have less opportunity to switch between different mating tactics. Previous studies in Kauai, Hawaii (Helweg and Herman, 1994) and in the West Indies (Winn and Winn, 1978) also reported a lack of diel pattern in the number of singers. In Kauai, data were obtained at depth (700 meters) about 10-14 miles offshore, away from the breeding habitat (Helweg and Herman, 1994), and in the West Indies, the results were obtained from a large survey area from the Bahamas to Venezuela (Winn and Winn, 1978). The results from the present study may suggest that the detection of a daily pattern in song production could be representative of prime humpback whale breeding sites, providing suitable opportunities for males to engage in different mating behavior to maximize mating opportunities.
Alternatively, the daily pattern observed off the west coast could be linked to the increased number of boats using the area. As expected from visual observations and the location of the main harbours and recreational areas, boats were mainly present on the west coast, during daytime, from 6am to 6pm and with a peak in the morning. The increase in boat traffic corresponded to the time of the day when singing activity was lower off the west coast. The daily pattern observed off the west coast might be an artifact of the increased number of boats observed in this area during daytime, which could have masked part of the songs and thus decreased the detection range of the recorder. The question as to whether the decrease in song detection during the day resulted, in part, from an increase in disturbance from boat traffic might be asked, as engine noise may affect the acoustic environment of singers (Watkins, 1986; Norris, 1995; Sousa-Lima and Clark, 2008).

These preliminary results were based on a single breeding season (2016), during which a relatively low number of whales were observed compared to previous years (GLOBICE, unpub. data). Additional data should be collected over the coming years to confirm trends and further examine spatio-temporal variations in whale occurrence and song production in La Réunion. In particular, variation in humpback whale abundance between years might also have an impact on the breeding/singing behavior and the distribution of the species around the island, and would be worth investigating further.

Acknowledgements

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References

Au WWI, Mobley J, Burgess WC, Lammers MO (2000) Seasonal and diurnal trends of chorusing humpback whales wintering in water off western Maui. Marine Mammal Science 16: 530-544

Best PB, Findlay KP, Sekiguchi K, Peddemors VM, Rakotonirina B, Rossouw A, Gove D (1998) Winter distribution and possible migration routes of humpback whales, *Megaptera novaeangliae*, in the southwest Indian Ocean. Marine Ecology Progress Series 48: 53-118

Cerchio S, Willson A, Muirhead C, Minton G, Collins T, Baldwin R, Willson MS, Harthi SA (2015) Preliminary Report on Long-term Detection of Arabian Sea Humpback Whale Vocalizations off Oman. International Whaling Commission

Clapham PJ, Mattila DK (1990) Humpback whale songs as indicators of migration routes. Marine Mammal Science 6: 155-160

Clark EW (1990) Acoustic behavior of mysticete whales. In: Thomas A, Kastelein RA (eds) Sensory Abilities of Cetaceans: Laboratory and Field Evidence. Plenum, New York, pp 571-584

Clark CW, Clapham PJ (2004) Acoustic monitoring on a humpback whale (*Megaptera novaeangliae*) feeding ground shows continual singing into late spring. Proceeding of the Royal Society of London 271: 1051-1057

Darling JD (1983) Migrations, abundance and behavior of Hawaiian humpback whales (*Megaptera novaeangliae)* (Borowski). PhD dissertation, University of California at Santa Cruz, Santa Cruz, CA, 147 pp

Dawbin WH (1966) The seasonal migratory cycle of humpback whales. In: Norris KS (eds) Whales, Dolphins and Porpoises. University of California Press: Berkeley and Los Angeles, pp 145-70

Dulau-Drouot V, Boucaud V, Rota B (2008) Cetacean diversity off La Réunion Island (France). Journal of the Marine Biological Association of the UK 88 (6): 1263-72

Dulau-Drouot V, Fayan J, Mouysset L, Boucaud V (2012) Occurrence and residency patterns of humpback whales off Réunion Island during 2004-10. Journal of Cetacean Research and Management 12 (2): 255-263

Dulau-Drouot V, Pinet P, Geyer Y, Fayan J, Mongin P, Cottarel G, Zerbini A, Cerchio S (2017) Continuous movement behavior of humpback whales during the breeding season in the southwest Indian Ocean: on the road again! Movement Ecology 5: 11. doi: 10.1186/s40462-017-0101-5

Dunlop RA, Noad MJ, Cato DH, Stokes D (2007) The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*). Acoustic Society of America 122 (5): 2893-2905. doi:10.1121/1.2783115

Fristrup KM, Hatch LT and Clark CW (2003) Variation in humpback whale (*Megaptera novaeangliae*) song length in relation to low frequency sound broadcasts. Acoustic Society of America 113: 3411–3424

Helweg DA, Frankel AS, Mobley JR Jr, Herman LM (1992) Humpback whale song: Our current understanding. In: Thomas JA, Kastelein RA (eds) Marine Mammal Sensory Systems. Plenum AY, New York, pp. 459–483

Lammers OM, Munger L, Fisher-Pool P, Wong K, Au W, Brainard RE (2011) Long-term passive acoustic monitoring of nearshore ecosystems in the Northwestern Hawaiian Island. Journal of the Acoustical Society of America 130 (4): 2536

Matilla DK, Guinee LN, Mayo CA (1987) Humpback whale songs on a North Atlantic feeding ground. Journal of Mammalogy 68: 880-883

McSweeney DJ, Chu KC, Dolphin WF, Guinee LN (1989) North Pacific humpback whale songs: a comparison of southeast Alaskan feeding ground songs and Hawaiian wintering ground songs. Marine Mammal Science 5: 116-138

Munger LM, Lammers MO, Fisher-Pool P, Wong K (2012) Humpback whale (*Megaptera novaeangliae*) song occurrence at American Samoa in long-term passive acoustic recordings, 2008-2009. Journal of the Acoustic Society of America 132 (4): 2265-2272

Noad MJ, Cato DH, Bryden MM, Jenner M-N, Jenner K, Jenner CS. (2000) Cultural revolution in whale songs. Nature 408: 537

Norris TF (1995) Effects of boat noise on the singing behavior of humpback whales (*Megaptera novaeangliae*). MSc thesis, Faculty of Moss Landing Marine Laboratories, San Jose State University

Ogden GL, Zurk LM, Jines ME, Perterson ME (2011) Extraction of small boat harmonic signatures from passive sonar. Acoustical Society of America 129 (6): 3768-3776. doi: 10.1121/1.3583500

Payne R, McVay S (1971) Songs of humpback whales. Science 173: 585-597

Payne KB, Tyack P, Payne RS (1983) Progressive changes in the songs of humpback whales (*Megaptera novaeangliae*). In: Payne R (ed) Communication and Behavior of Whales. AaaS Selected Symposium 76, Westview Press, Boulder, Co, pp 9-57

Payne K, Payne R (1985) Large Scale Changes over 19 Years in Songs of Humpback Whales in Bermuda. Ethology international journal of behavioral biology 68: 89-114

Silber GK (1986) The relationships of social vocalizations to surface behavior and aggression in the Hawaiian humpback whale (*Megaptera novaeangliae*). Canadian Journal of Zoology 64: 2075-2080

Sorensen E, Ou HH, Zurk LM, Siderius M (2011) Passive Acoustic Sensing for Detection of Small Vessels. Source IEEE Xplore Conference OCEANS 2010. doi: 10.1109/OCEANS.2010.5664542

Sousa-Lima RS, Clark WC (2008) Modeling the effect of boat traffic on the fluctuation of humpback whale singing activity in the Abrolhos national marine park, Brazil. Canadian Acoustics 36 (1): 174-181

Thompson T, Winn HE, Perkins P (1979) Mysticete sounds. In: Winn HE, Olla BL (eds) Behavior of Marine Animals. Current Perspectives in Research, Vol. 3: Cetaceans, Plenum, New York, pp 403-431

Tyack P (1981) Interactions between singing Hawaiian humpback whales and conspecifics nearby. Behavioral Ecology and Sociobiology 8: 105–116

Watkins WW (1986) Whale reactions to human activities in Cape Code waters. Marine Mammal Science 2 (4): 251-262

Winn HE, Winn LK (1978) The song of the humpback whale, *Megaptera novaeangliae*, in the West Indies. Marine Biology 47: 97-114