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Assessment of Southern Right whale (*Eubalaena australis*) acoustic presence off northwestern Chiloé Island and Arauco Gulf, Chile

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ABSTRACT

The southern right whale from the Southeast Pacific population (*Eubalaena australis*) is a currently Critically Endangered sub-population according to the IUCN. In 2012, the International Whaling Commission adopted a Conservation Management Plan for this stock and since 2016 the Scientific Committee has supported a Passive Acoustic Monitoring (PAM) project with the aim of identifying possible breeding areas along the coast of Chile-Peru. Within the framework of this project, one year of continuous acoustic data was collected from the northwestern of Chiloé Island (2018-2019), and 5 months of recordings from the Arauco Gulf (2019-2020). These recordings were analyzed using an automatic detector specially developed under this project for right whale upcall vocalizations in the LFDCS software. The detections were reviewed and validated by an analyst. Off Chiloé, we found 189 true positive detections in the 2018-2019 period, with calls present during the austral summer, autumn and winter with no clear seasonal trend. While in the Arauco Gulf, no true positive detections were found. There were two peaks of detections off Chiloé, one in December 2018 with high vocalization rates during 2 days, and the second in March 2019 with 8 days of acoustic presence. Gunshots were found along with upcalls during March 2019. The presence of gunshots is of relevance, because they have been associated with mating or agonistic behavior between males in other populations. These presence of upcalls in almost all seasons suggest that northwestern Chiloé Island is potentially used by individuals as a non-migratory habitat or could be the reflection of a population so small that seasonality cannot be detected. On the other hand, the short recording period in the Arauco Gulf means that southern right whales may have been missed so better temporal coverage at this site is necessary. Future data collection efforts will focus on study sites off Northern Chile and Peru.

INTRODUCTION

The Southeast Pacific subpopulation of the southern right whales (*Eubalaena australis*) along the coast of Chile-Peru, is too rare to determine whether there is a trend in abundance and it is reasonable to infer that there are fewer than 50 mature individuals. , therefore since 2008 it has been classified by the Union for the Conservation of Nature (IUCN) Red Lista as "Critically Endangered" (Cooke, 2018). Given this, in 2012 the International Whaling Commission adopted a Conservation Management Plan (Galletti Vernazzani *et al.*, 2012). In 2016, the scientific committee of the International Whaling Commission decided to support the project "Acoustic Monitoring of the Eastern South Pacific population of southern right whales, a key to increase the results of the CMP" ", with the aim of acoustically identifying potential breeding areas off the

coasts of Chile-Peru to better inform the conservation management plan for this species (IWC, 2017). This study is carried out within the framework of this project.

Between 1964 and 2011, there have been 108 opportunistic sightings of 179 southern right whale individuals off the coast of Chile-Peru, including 39 calves. According to the geographical trend of the sightings, there could be aggregations in the north (23°-25°S) and central-south and south of Chile (33°-42°S) (Galletti Vernazzani *et al.*, 2014). From these sightings, 6% were off the northwestern of Chiloé Island, including the observation of reproductive behaviors of surface-active groups (SAG), and mothers with calves (Galletti Vernazzani *et al.*, 2014). Thus, the northwestern of Chiloé Island could be a potential breeding and/or calving area. Moreover, the Arauco Gulf could also be a potential habitat for the southern right whale (Galletti Vernazzani *et al.*, 2012), which is an area where twentieth-century whaling operations captured various species of cetacean, including the southern right whale (Espinoza, 2011). From the sightings up until 2011 off the coast of Chile, 88% were between June and September, which coincides with the breeding season of this species (Best, 1993; Galletti Vernazzani *et al.*, 2014).

In April 2012, southern right whale upcalls were recorded in the Corcovado Gulf (southeast of Chiloé Island), which was the first report of vocalizations of the southeastern Pacific southern right whale (Jacobs *et al.*, 2019). Southern right whales produce species-specific calls that help to identify them amongst other marine sounds. The most well-known vocalization of southern right whale is the ‘upcall’; a stereotypical call thought to be a contact call produced by both males and females of all ages-groups in close proximity (Clark *et al.*, 1982). “Gunshot” calls have also been described, initially linked to reproductive behaviour (Parks and Tyack, 2005), but new evidence shows that they are produced by males and females in a range of behavioural contexts (e.g. Crance *et al.*, 2017).

This study aims to 1) determine the seasonal presence of southern right whale vocalizations in one year of recordings from Puñihuil, Isla Chiloé (southern Chile), and 2) to determine the presence of southern right whale vocalizations from five months of recordings in the Arauco Gulf (central-southern Chile).

MATERIALS AND METHODS

1. Hydrophone installation and data collection.

To evaluate the acoustic presence of the southern right whale in central-south and southern Chile, continuous passive acoustic monitoring data were collected over 12 months (2018-2019) off the northwestern of Chiloé Island, and during 5 months (2019-2020) in the Arauco Gulf (Figure 1). Recordings in the Arauco Gulf were prematurely ended due to the loss of the hydrophone and mooring, possibly due to bottom-trawl fishing in the area.

Passive acoustic monitoring was carried out with Soundtrap (300 STD) hydrophones (<http://www.oceaninstruments.co.nz/>) recording continuously at a 24kHz sampling rate at both study sites. The hydrophone mooring line consisted of 1) hydrophone and external battery pack mounted inside a steel frame for protection, 2) system of 3 buoys to give buoyancy to the line, 3) two 50 kg dead weights and 4) an acoustic release (iXBlue OCEANO 500).

The first recording period was carried out off Puñihuil, northwestern of Chiloé Island, between July 2018 and July 2019. To cover the 12 months of recording, the instruments were maintained every 2 months. The second recording period was carried off Chome, in the Arauco Gulf between September 2019 and January 2020. More details about the acoustic deployment are resumed in Table 1.

Table 1. Details of Soundtrap hydrophone deployments

Site	Start date / hour	End date	Latitude - Longitude	Deployment Depth (m)	Water column Depth (m)
Puñihuil, Isla de Chiloe, southern Chile	02 July 2018 / 12:04	08 September 2018	41°56'09.4''S-74°07'31.5''W	60 m	70 m
	09 September 2018 / 09:17	15 November 2018	41°56'12.2''S-74°07'34.3''W	65 m	75 m
	16 November 2018 / 08:41	18 January 2019	41°56'11.3''S-74°07'37.3''W	62 m	72 m
	20 January 2019 / 08:10	15 March 2019	41°56'13.6''S-74°07'35.5''W	66 m	76 m
	16 March 2019 / 09:53	19 May 2019	41°56'13.3''S-74°07'35.6''W	68 m	78 m
	20 May 2019 / 10:34	23 July 2019	41°56'11.5''S-74°07'36.0''W	61 m	71 m
Chome, Arauco Gulf, central Chile	07 September 2019 / 09:54	17 November 2019	36°45'29.5''S-73°19'20.4''W	130 m	140 m
	18 November 2019 / 08:00	31 January 2020	36°45'21.9''S-73°19'33.4''W	132 m	142 m
	01 February 2020 / 11:10	Not recovered	36°45'21.9''S-73°19'34.2''W	135 m	145 m

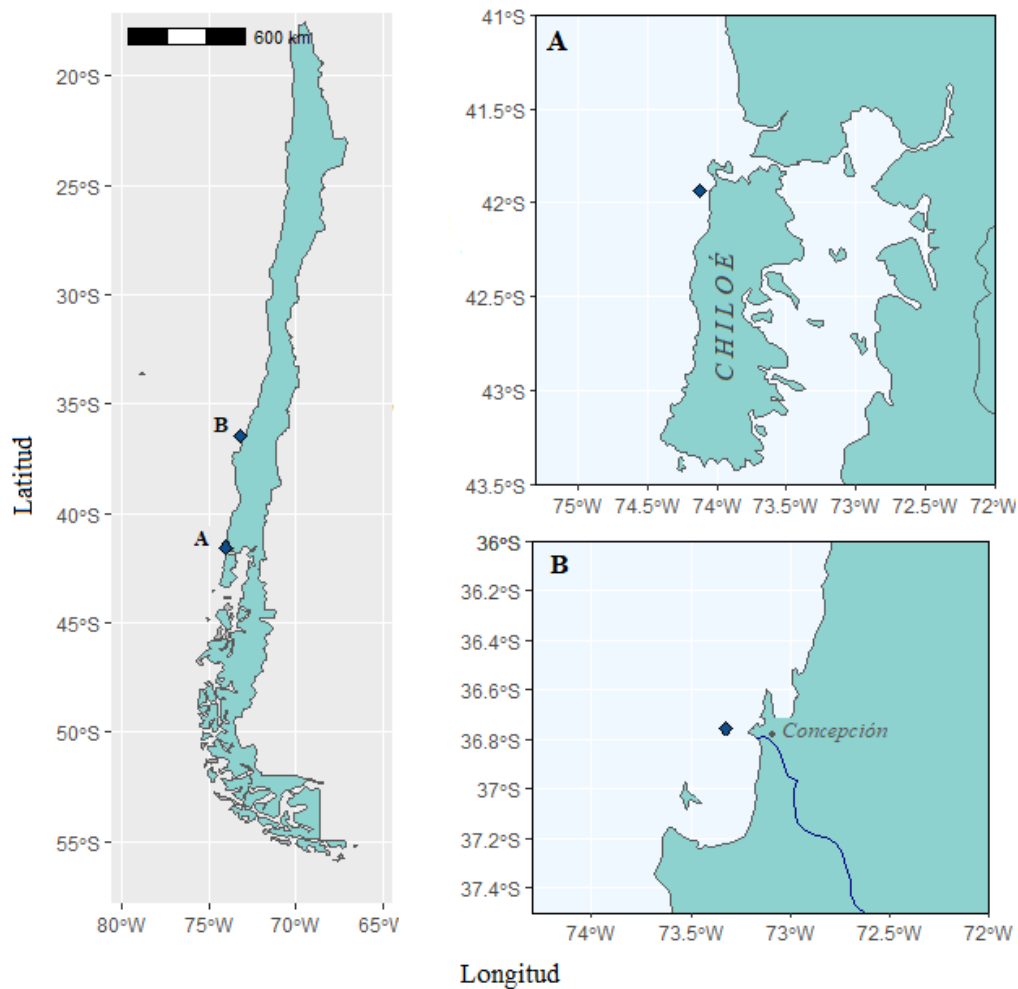


Figure 1. Study sites at the center and south of Chile. Blue dots represent the hydrophone deployments: A) Puñihuil, Chiloé Island (41°56' S - 74°07' W, July 2018 – July 2019) and B) Chome, Arauco Gulf (36°45' S - 73°19' W, September 2019 – January 2020).

2. Analysis of recordings with automatic detector in LFDCS

To evaluate the acoustic presence of the southern right whale in the recordings, two types of vocalizations were identified: upcalls and gunshot calls. To identify upcalls, an automatic detector was developed in the Low Frequency Detection and Classification System (LFDCS) software (Baumgartner and Mussoline, 2011). The LFDCS allows the creation of automatic detectors (or “call types”) for each type of vocalization based on its attributes and compile them into “call libraries”. To do this, the program 1) represents the sound and eliminates persistent and transient noise, 2) recognizes sounds by a simple amplitude threshold and tracks the frequency contour of the signal over time, generating a “pitch-track” and 3) classifies the signal into a type of vocalization from the call library according to 7 attributes of the “pitch-track”, by means of a quadratic discriminant function analysis. In the analysis, the Mahalanobis distance (mDist) represents the distance between the attributes of the unknown signal, and the average of attributes of a “call-type” in the call library, thus being the mDist a metric used as threshold for automatic detection.

Thus, the automatic detector was built with a total of $n = 193$ exemplars. In the same call library, detectors for humpback whale upsweeps were also included, to reduce potential errors due to detector confusion between right whale upcalls and humpback whale calls. The upcall detector was applied to the datasets from Puñihuil and Chome, using an MDist threshold of 3.5. Then, all detections were visually checked and classified as false or true positives in order to estimate the error rates of the detector, by means of the true and false positives percentages. Subsequently, with the true (validated) automatic detections two counts and graphs were made: 1) monthly average of automatic detections per hour (call rate) and 2) number of days with acoustic presence per month.

For gunshot calls there are currently no automatic detectors available, these signals are hard to detect automatically given their broadband nature. However, gunshots are generally associated with upcalls (G. Davis, Com. Pers.), so when upcall detections were reviewed by the analyst, the presence of gunshots was also checked for.

3. Calculation of false negative rate for the automatic detectors

To evaluate the upcall's automatic detector, we calculated the false negative rate by making manual annotations of a subset of the data from Puñihuil in Raven Pro 1.5. The subset analyzed included all the days with true detections and the two adjacent days before and after, adding up 50 days in total, considering some days with true detections were consecutive. Additionally, the same number ($N=50$) of aleatory days without true detections was included. The false negative rate was calculated considering the manual annotations and the true detections of the automatic detector.

RESULTS

In the Puñihuil dataset, 252 events were detected, of which 189 were true positives (75%) (Table 1) in 16 days with acoustic presence. No clear seasonal pattern was found; calls occurred in August and December 2018, and January, March and July 2019, as seen in Figures 2 and 3. Call rates were highest in December 2018 where upcalls were detected during several hours on the 6th of December. Acoustic presence only occurred on 2 days during all months where detections occurred, with the exception of March 2019 when upcalls were detected on 8 days between the 19th and the 29th of March (Figure 4). During this same period, gunshot calls were identified on the 19th and 20th of March 2019. In the Chome dataset, 5 detections were made, and all were false positives, so we found no right whale acoustic presence in this dataset.

False negative rate was calculated by manual annotation of 100 days selected from the Puñihuil dataset, finding 598 upcall signals and 19 days with acoustic presence. The false negatives were of 409 (68%), and all omitted signals were present in between, before and/or after the bouts of true detections. The days with acoustic presence that were omitted (3 days) corresponded to signals from adjacent days, some at few hours from the true detections. None of the 50 aleatory days without true detections that were analyzed presented upcalls presence, therefore the omission rate of the detector is likely due to the variation in frequency and intensity within bouts of calls.

Table 2. Summary of automatic detections of right whale upcalls off Puñihuil and Chome, presenting false and true positive percentages (%). NA= non-applicable.

Study area	Period	Detection	N	%
Puñihuil, Chiloé Island	31 July 2018 - 27 July 2019	False positives	63	25
		True positives	189	75
		Total detections	252	NA
		Manual annotations	598	NA
		False negatives	409	68
Chome, Gulf	5 September 2019 - 10 January 2020	False positives	5	100
		Total detections	5	NA

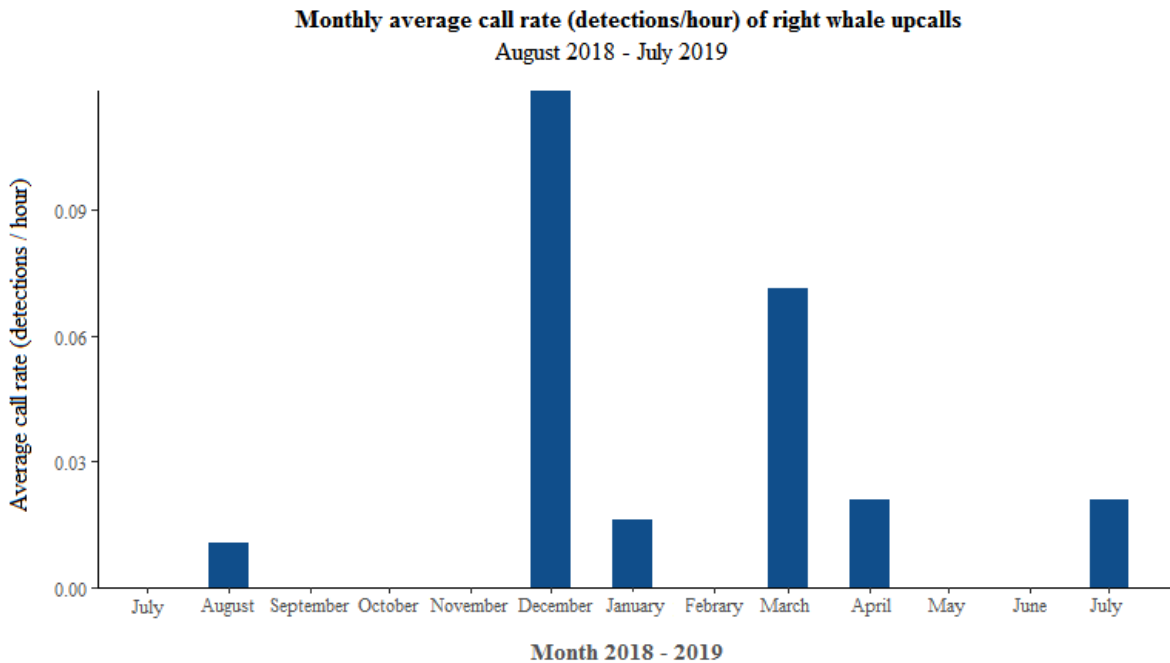


Figure 2. Monthly average of true positive detections (average number of detections per hour) of right whale upcalls off Puñihuil, Chiloé Island, between the 31st of July 2018 and the 27th July 2019.

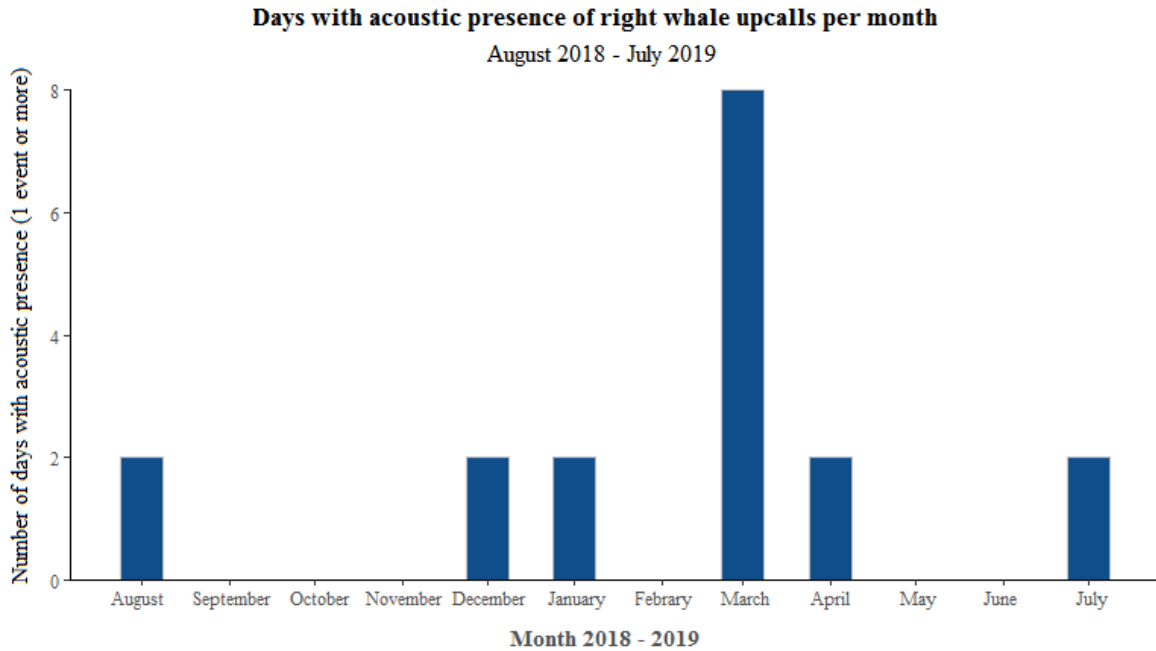


Figure 3. Days with acoustic presence (1 or more calls) per month of right whale upcalls off Puñihuil, Chiloé Island, between the 31st of July 2018 and the 27th July 2019.

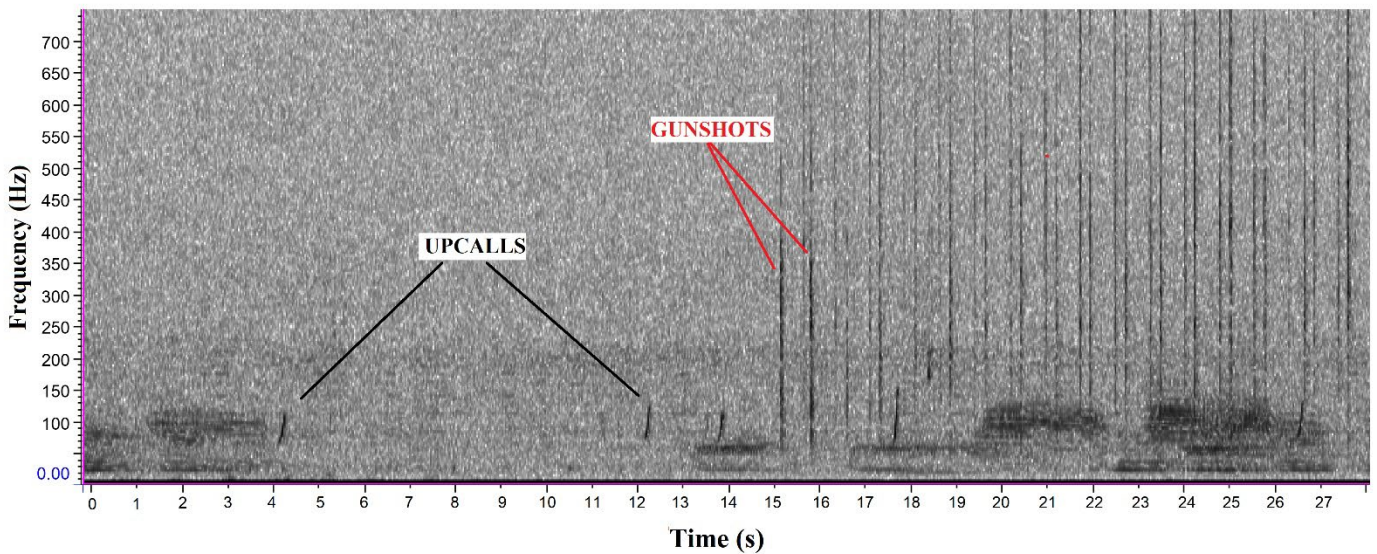


Figure 4. Spectrogram showing upcalls and gunshots recorded off Puñihuil, Chiloé Island, during the 19th of March 2019. Spectrogram parameters: Hamming window, 80% overlap, 4096 FFT.

DISCUSSION

Breeding season in southern hemisphere is expected to occur mostly during springtime (Best, 1993). Chiloé Island and Arauco Gulf, suspected to be a possible breeding area, were expected to reveal the presence of southern right whales mostly during this period. However, in Puñihuil the acoustic presence of southern right whales was occasionally detected in autumn, summer and winter, showing no clear seasonal trend, while in Arauco Gulf, right whales were not acoustically detected.

Uppcall vocalizations were present during austral summer, autumn and winter in the 2018-2019 period. Although there wasn't a clear seasonality, these acoustic detections reveal that this species is occasionally present in this habitat during almost all seasons. The presence of gunshots in these data is relevant, since for the North Atlantic right whale gunshot calls have been associated with reproductive activity in surface active groups (SAG) and agonistic interactions between males (Parks and Tyack, 2005; Parks *et al.*, 2005), but also in other social behaviors, including song production by males and females (Gerstein *et al.*, 2014; Crance *et al.*, 2019, Shabangu *et al.*, 2020). These results suggest the site off northwest Chiloé as a potential non-migratory habitat, but also could be reflection of a population so small that seasonality cannot be detected. For the north Atlantic right whale (*Eubalaena glacialis*) population, acoustic presence has been observed throughout the year in its coastal distribution range (Davis *et al.*, 2017), including non-migratory habitats, where the expected acoustic presence peaks at the beginning and the end of the reproductive/feeding season that occur at the migratory corridors are not present (Hodge *et al.*, 2015; Davis *et al.*, 2017).

It is important to bear in mind that the southern right whale reproduction cycles are, on average, every 3 years (Carroll *et al.*, 2013), and the recording period could coincide with a one-year break. Therefore, the possible existence of a breeding area near the northwestern of Chiloé Island cannot be ruled out. These acoustic findings and behavioral observations of likely reproductive behavior such as SAG and mother-calf pairs (Galletti Vernazzani *et al.*, 2014), highlight the importance of the southern Chile area. Moreover, recent sightings of mother-calf pairs at Golfo de Penas (approx. 500km south of northwestern Chiloe Island) may suggest this remote area could also be part of a larger southern Chile breeding area, so more directed survey efforts should be concentrated.

Jacobs *et al.* (2019) used acoustic data collected off southern Chiloe Island (about 180km south of Puñihuil) from 29 January to 17 June 2012 to visually detect southern right whales upsweep calls. A subsample of 46 days out of 139 days (6 in February, 15 in March, 17 in April, 7 in May, and 1 in June) were analyzed. They found 4,313 right whales upsweep calls and reported their acoustic presence in at least 28 days in April. This represents a much higher detection rate and days with presence than what we found under the 2018-2019 monitoring even considering the manual annotations of data, and may be explained by several reasons including: 1) the reproduction cycles if considered every three years would have coincide with summer/autumn months of 2018 and not 2019; 2) a considerable higher presence of southern right whales in southern Chiloe Island than northern Chiloe Island; 3) a methodological difference between visual and automatic detection of calls. The less likely hypothesis is a different presence between northern and southern Chiloe Island, as these two sites are close in distance and several sightings have been reported around the Island. The reproductive cycle may have play an important role and can't be ruled out. The most likely cause of difference in detection rates is the methodological approach. In spite of the differences in detection rates found on both datasets and analysis, it has to be noted that both results provide evidence for a higher presence of right whales around March/April.

The false negative rate of the automatic detector was 68%, although the detector was effective in detecting days with acoustic presence (16 of 19 days). Therefore, the false negative rate is likely due to the variation in the signals within the bouts of upcall, so the relative abundance of signals is underestimated by the automatic detector.

Surprisingly, no detections were made during spring months for Arauco Gulf or Chiloe Island. However, this dataset is much shorter than the Puñihuil dataset. It is possible that a longer dataset would have registered acoustic presence at other times of year, so further monitoring is desirable to cover a full annual cycle. Although in Puñihuil dataset the automatic detector was effective for detecting days with acoustic presence, omitted signals in Chome is possible if they were scarce. Most of sighting data from 1964-2011 for areas near Arauco Gulfs (36-37oS) are reported between August to November (85%) and for areas near Chiloe Island (41-43oS) between September-October (80%) (Galletti Vernazzani *et al.* 2014). In the case of Chiloe Island, acoustic and sighting data pulled together are providing strong evidence for year-round presence of this species in the area.

It is important to consider that the passive acoustic monitoring only detects animals that are vocalizing; therefore, it is possible that silent animals were present and not registered by the hydrophone. Future studies should also focus on the detection range of the hydrophone, given that the propagation of upcalls vocalizations depends on environmental conditions specific to each recording site (Laurinolli *et al.* 2003). Furthermore, the automatic detector will have to be improved by adding a higher variety of signals, to avoid the underestimation of acoustic presence.

Finally, these results on the near year-round acoustic presence of southern right whale off Chiloe Island, and particularly the identification of gunshots, highlights the importance of this area for such small southeast Pacific southern right whale population, and provides a better understanding of their habitat use off the coast of Chile. Future efforts will focus on study sites off Northern Chile and Peru.

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