Coupling passive acoustic and oceanographic monitoring to understand the drivers of blue whale distribution in Northern Chilean Patagonia

EMSO TIME SERIES CONFERENCE
OBSERVING OCEAN SOUND
20-22 OCTOBER 2021
CANARY ISLANDS SPAIN

Buchan Susannah J.[1,2,3], Pérez-Santos Iván1, [1,4], Narváez Diego[1,2], Castro Leonardo[1,2], Stafford Kathleen M.[5], Baumgartner Mark F.[3], Valle-Levinson Arnoldo[6], Gutiérrez Laura[1], Rojas Constanza[1], Neira Sergio[1,2]

[1]Centro de Investigación Oceanográfica COPAS Sur-Austral, Universidad de Concepción, Casilla 160-C, 4070043, Concepción, Región del Bio, Chile; [2]Departmento de Oceanografía, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Casilla 160-C, 4070043, Concepción, Región del Bio, Chile; [3]Woods Hole Oceanographic Institution, Biology Department, 266 Woods Hole Road, Woods Hole, Massachusetts, 02543, USA; [4]Centro i~mar, Universidad de Los Lagos, Camino a Chinquihue km 6, Puerto Montt, Región del Los Lagos, Chile; [5]Applied Physics Laboratory, University of Washington, Henderson Hall, 1013 NE 40th St., Seattle, Washington, 98105, USA; [6]University of Florida, Civil and Coastal Engineering Department, 365 Weil Hall, PO Box 116580, Gainesville, Florida, 32611-6580, USA.

Highlights:

- This study couples passive aocustic, active acoustic and oceanographic time series data (Fig. 3) to understand the drivers of blue whale acoustic presence on their feeding gorund over seasonal and submonthly timescales using two acoustic signals: blue whale song calls and D-calls.
- Blue whale presence (song and D-call) was strongly associated with zooplankton backscatter over the study period (Fig. 4 a-c) .
- Song calls followed a seasonal cycle (Fig. 3a), but D-calls appeared to respond to short term variations in backscatter and wind stress over submonthly scales (Fig. 3a and 5).
- Short-lived events of increased wind stress with periodicities of 2-8 days and 16-30 days were correlated with D-call presence (Fig. 4), possibly due to the effect of wind stress on prey - and therefore whale - aggregation.
- The spatial scales over which hydrophones (i.e., detection range) and oceanographic instruments monitor the ocean environment must be considered when coupling PAM and oceanographic data.

Research Question: What drives blue whale acoustic presence on the Northern Chilean Patagonia mega-estuarine feeding ground over seasonal and submonthly time scales?

Methods: An oceanographic mooring was deployed at 43° 51.96'S, 73° 31.28'W in the Corcovado Gulf (Fig. 1a) at a water depth of 162 m between January 2016 and February 2017. The mooring was equipped with a hydrophone for collecting PAM data and an ADCP for collecting zooplankton backscatter data. Seasonal sampling cruises were conducted every 3 months to collect stratified zooplankton net samples to validate the ADCP backscatter data. Meteorological data (wind speed and direction) were also collected continuously at the nearby port of Melinka.

Blue whale song and D-calls were detected using automatic detection methods and reviewed by an analyst. Backscatter was processed as time series at 50m, 100m and integrated over the entire water column. Zonal and meridional wind stress was obtained.

Hydrophone detection range was estimated 2.75 km and 15.3 km for song calls and 1.4 to 6 km for D-calls.

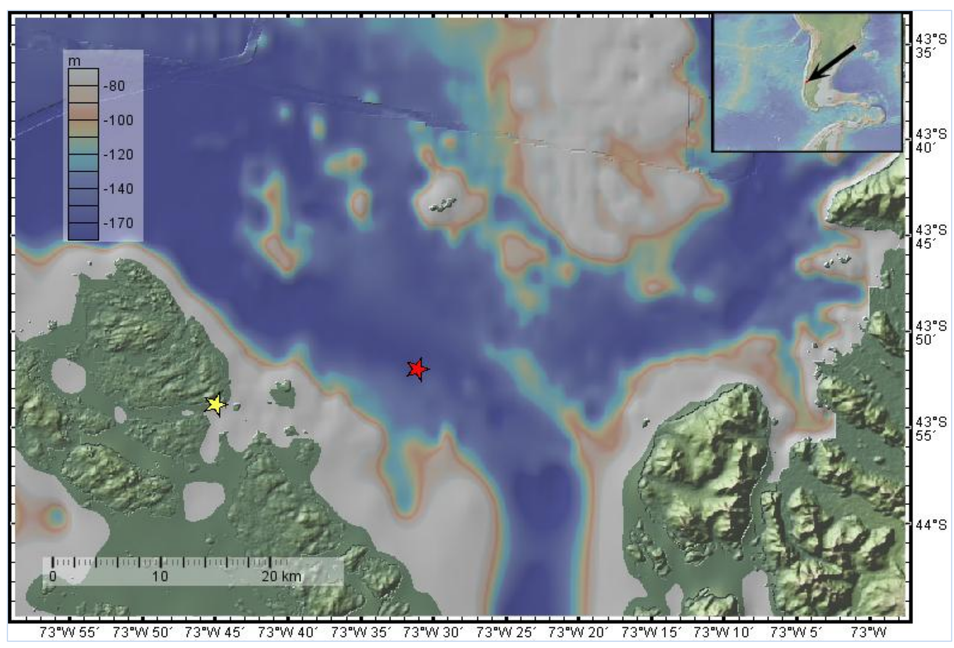

Figure 1: Map of study site in the Corcovado Gulf with mooring location (red star) and meterological station (yellow star).

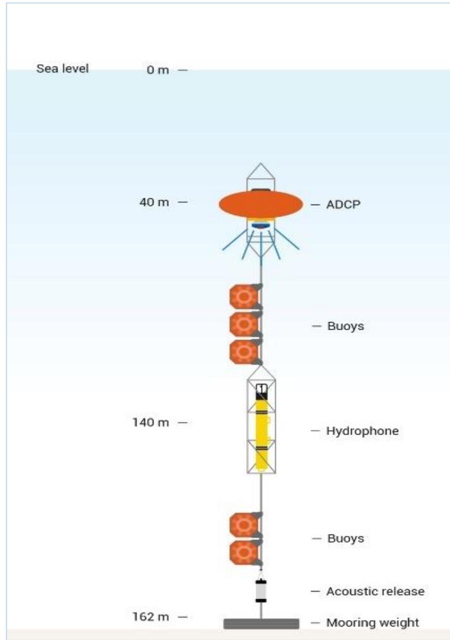

Figure 2: Mooring design, including hydrophone and ADCP.

Statistical analyses: To test the hypothesis that blue whale submonthly acoustic presence is related to zooplankton backscatter or wind stress over the 6-month summer feeding season, generalized linear models (GLMs) with a binomial link function were fitted in R (R Core Team, 2019) for daily blue whale acoustic presence as the response variable, and either integrated backscatter (Sa) over 45-160 m, Sv at 50 m, Sv at 100 m, or zonal or meridional wind stress as explanatory variables.

Wind stress was found to be non-significant over the summer feeding season (see Results), so in order to examine any effects at shorter time scales (<1 month), wavelet coherence was calculated, which is a measure of correlation (magnitude-squared coherence) between two wavelet time series at specific periods. Since no submonthly signal was detected in the wavelet time series for song calls, wavelet coherence was only applied to comparisons of D-calls to meridional and zonal wind stress.

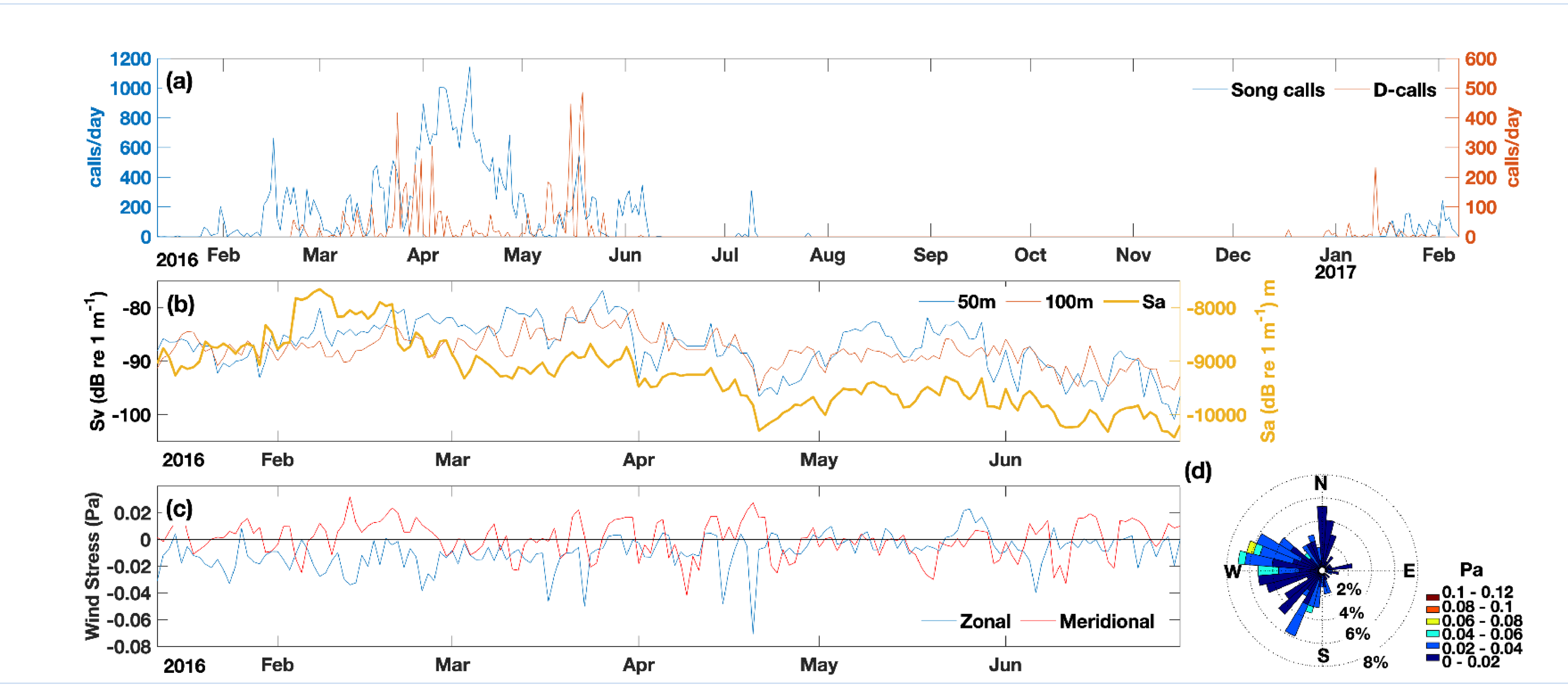

Figure 3: Time series data for (a) Southeast Pacific blue whale song calls and D-calls. Note: No song calls were present between August and December 2016; no D-calls were present June and November 2016; (b) Volume backscattering strength (Sv in dB, re m^{-1}) calculated from the ADCP at 50 m and 100m depth, and integrated backscatter over 45 m and 160 m (Sa in (dB re 1 m^{-1}) m), (c) zonal (u) and meridional (v) wind stress (Pa); (d) wind rose diagram representing the wind stress (Pa) and direction between January and November 2016; (e) tidal amplitude (m).

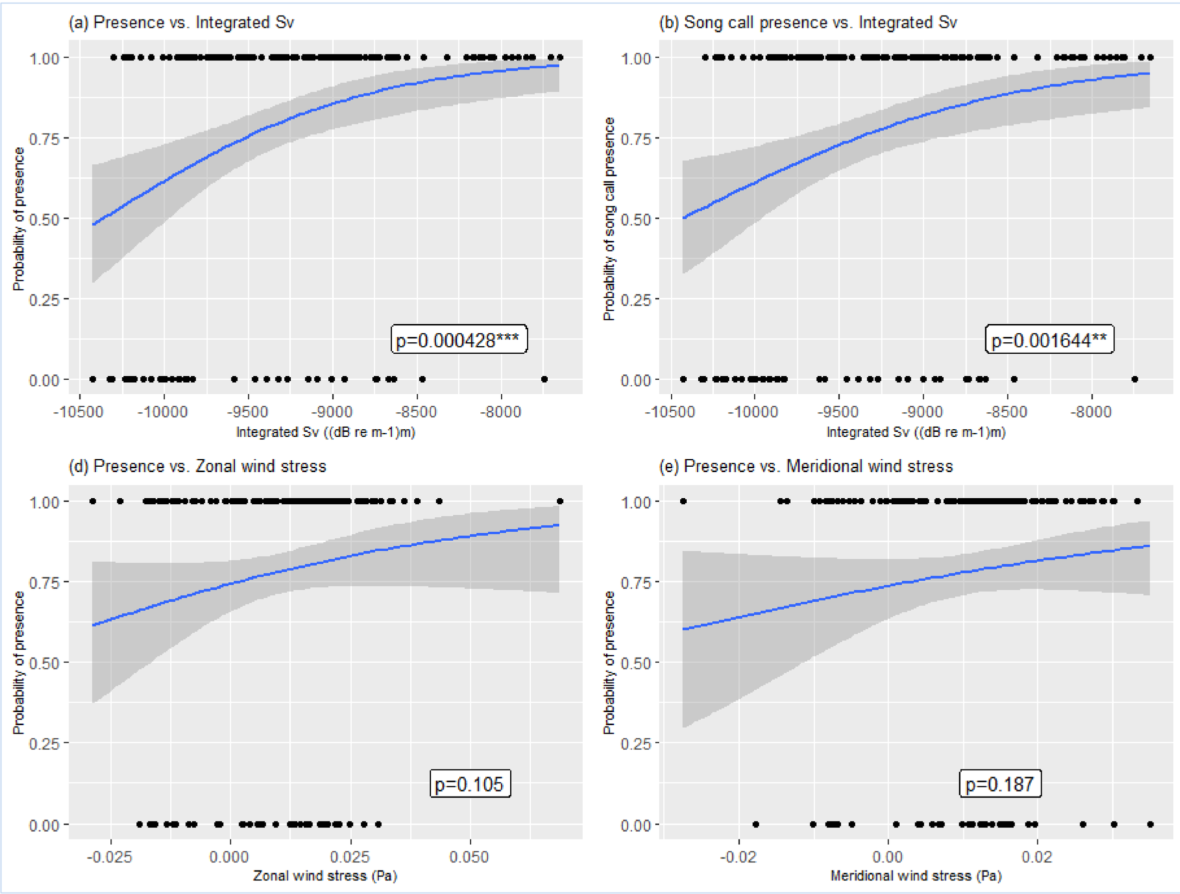

Figure 4: Response curves (blue line) and 95% confidence intervals (grey shaded area) for generalized linear models (GLMs) of: (a) daily blue whale acoustic presence (song call + D-call) and integrated backscatter (Sa) over 45-160 m, (b) song call presence and integrated backscatter (Sa) over 45-160 m, (c) D-call presence and integrated backscatter (Sa) over 45-160 m, (d) zonal and (e) meridional wind stress (Pa). Inset boxes report coefficient values ** 0.05 > p > 0.001, *** p < 0.001.

Results and Discussion:

Seasonal variation:

- A 3-month lag between the seasonal onsets of high zooplankton backscatter (October) and blue whale acoustic presence (January), and an almost immediate drop in blue whale acoustic presence with the seasonal decrease of backscatter (June) (Fig. 3). This may be explained by the use of memory by animals when timing their arrival on the feeding ground (Abrahms et al. 2019), but the timing of departure may be more related to detection of low prey availability.
- Over the summer feeding season, blue whale acoustic presence (songs and D-calls) was strongly associated with zooplankton backscatter (GLM coefficient p<<0.0001) (Fig. 4). This is in line with known blue whale predation on euphausiids (e.g., Buchan & Quiñones 2016).
- Song calls followed a seasonal cycle, D-calls did not (Fig. 3).

Submonthly variation:

- Significant periodicities in the wavelet analysis that fluctuated between 1-7 days and 12-32 days for D-calls, but no significant submonthly periodicities were detected for song calls (wavelet analysis not shown).
- Short-lived events of increased wind stress with periodicities of 2-8 days and 16-30 days were correlated with D-call periodicities (wavelet coherence, Fig. 5), suggesting wind stress may contribute to the aggregation of prey, and consequently whales.
- D-calls appeared to respond to short term variations in environmental conditions over submonthly scales. This in line with Szesciorka et al., (2020) off California, who found that environmental drivers have a much greater influence on the production of D-calls vs. song calls.

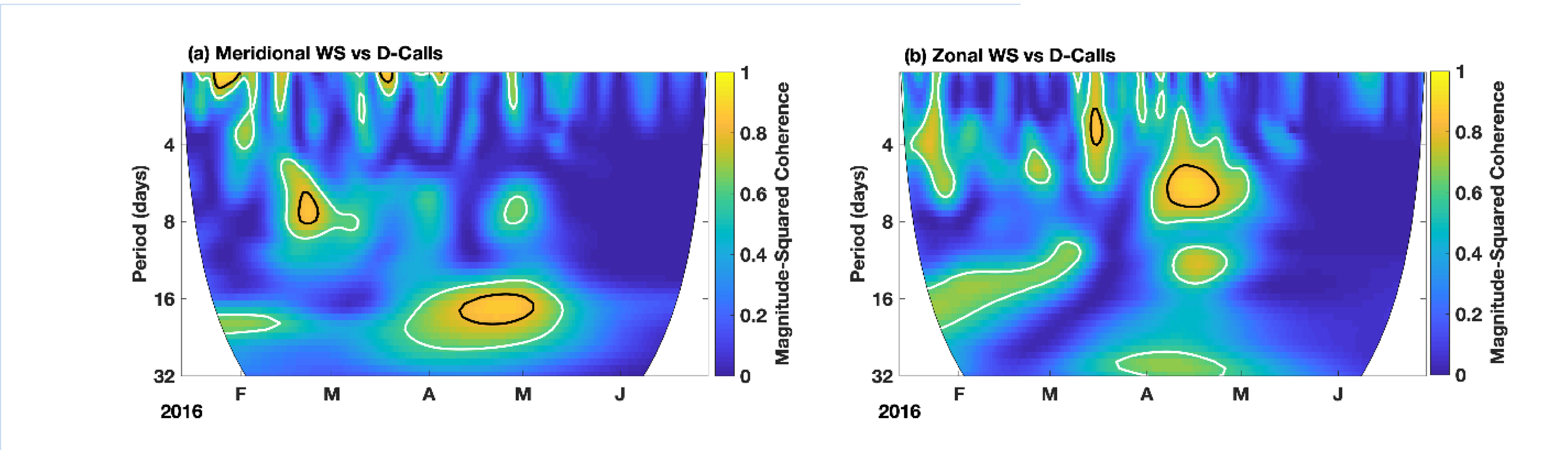

Figure 5: Wavelet coherence analysis of (a) D-calls and meridional wind stress (Pa); (b) D-calls and zonal wind stress (Pa). White contour lines indicate >0.6 magnitude-squared coherence and black contour lines indicate >0.8 magnitude-squared coherence.

Considerations for coupling passive acoustic and oceanographic data:

- The spatial scales over which hydrophones (i.e., detection range) and oceanographic instruments monitor the ocean environment must be considered when coupling PAM and oceanographic data.
- Hydrophone detection ranges must be estimated for each signal type; in this study detection range was estimated at between 2.75 km and 15.3 km for song calls and 1.4 to 6 km for D-calls.
- Knowledge needed on the spatial scales of prey patch variation: how do they compare to hydrophone detection ranges?

References:

Abrahms, B., Hazen, E.L., Aikens, E.O., Savoca, M.S., Goldbogen, J.A., Bograd, S.J., Jacox, M.G., Irvine, L.M., Palacios, D.M., Mate, B.R., 2019. Memory and resource tracking drive blue whale migrations. Proc. Natl. Acad. Sci. U. S. A. 116, 5582–5587. https://doi.org/10.1073/pnas.1819031116

Buchan, S.J., Quiñones, R., 2016. First insights into the oceanographic characteristics of a blue whale feeding ground in northern Patagonia, Chile. Mar. Ecol. Prog. Ser. 554, 183–199. https://doi.org/10.3354/meps11762

Szesciorka, A.R., Ballance, L.T., Širović, A., Rice, A., Ohman, M.D., Hildebrand, J.A., Franks, P.J.S., 2020. Timing is everything: Drivers of interannual variability in blue whale migration. Sci. Rep. 10, 1–9. https://doi.org/10.1038/s41598-020-64855-y

Funding:

- Agencia Nacional de Investigación y Desarrollo (ANID) grant PFB31 and ANID APOYO CCTE AFB170006, Chile
- Office of Naval Research grant N00014-17-1-2606, USA
- Fondo de Investigacion Pesquera FIPA 2015-07 grant, Chile
- Ecoclimatico project CIEP R17A10002, Chile