Marine Physical Laboratory of the Scripps Institution of Oceanography University of California, San Diego

Spatial variability of fin whale song in the Southern California Bight

Progress report

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Fin whale, photo by Ana Širović

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14. ABSTRACT

The fin whale (Balaenoptera physalus) is an endangered species of mystecete that is relatively common and likely resident in the Southern California Bight (SCB). Fin whale song, made of 20 Hz pulses with distinct interpulse intervals (IPIs) may be one possible tool to help delineate between populations. The common fin whale song type in the SCB is doublet song, which is made of pulses repeated at two alternating IPIs of different lengths. A variant of the doublet, a singlet song, also occurs and has a single IPI that corresponds to one of the distinct IPI of the doublet song. Based on the analysis of fin whale song patterns at one location within the Bight, we have been able to describe songs from resident and "transient" or pan-Pacific populations of fin whales. With this project, we are extending the analysis to additional sites in the SCB to get a more detailed picture of the spatial and temporal variability in resident and pan-Pacific populations of fin whales in this area of substantial naval importance.
Fin whale song patterns were analyzed from High-frequency Acoustic Recording Package (HARP) data collected at four sites in the Southern California Bight collected between 2005 and 2014. The sites were chosen to cover both inshore (sites P and Q) and offshore (sites C and H) areas as well as southerly and northerly extent of the Bight. A single year of data, from September 2009 to September 2010, was analyzed from all sites and additional years of data were analyzed from two sites (H and C). Two days per months were selected to analyze song patterns over time. During the selected day, the start time of each 20 Hz pulse in a sequence was picked from a spectrogram and saved to a spreadsheet. After all the 20 Hz pulse start times were picked in a day, IPIs were calculated for each picked sequence. Individual sequences with matching IPI patterns were pooled and sorted to separate short and long IPIs. The daily median and first and third quartiles for each IPI of each distinct sequence type were calculated. We present the IPIs for each site over the

time period analyzed to compare spatial and temporal patterns in song occurrence across the SCB.
Preliminary results show that the fin whale songs recorded between 2009 and 2010 across all four sites had the same doublet IPIs corresponding to "short doublet" song likely attributed to resident population. Overall the highest variability in the IPIs was measured in songs at the northernmost site, site C. Singlet variants of the doublet songs were also detected at all sites, most commonly during the fall. The IPI duration of singlet songs was equivalent to the shorter IPI in doublet song. The "long doublet" or "seasonally variable" song that has also been termed the pan-Pacific song, appeared at both sites where long-term analysis was performed, sites C and H. This song only appeared in its singlet version and was more common from 2005-2007, but it was also detected intermittently later (in 2008, 2010, and 2011). We are continuing to process song pattern data from additional years to evaluate whether the population of fin whales in the SCB consists mainly of resident animals or if animals with a larger, pan-Pacific range are also present.

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Table of Contents

Executive summary 1
Introduction 2
Methods 3
Preliminary results 4
Further work 7
References 8

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Executive summary

The fin whale (*Balaenoptera physalus*) is an endangered species of mystecete that is relatively common and likely resident in the Southern California Bight (SCB). Fin whale song, made of 20 Hz pulses with distinct interpulse intervals (IPIs) may be one possible tool to help delineate between populations. The common fin whale song type in the SCB is doublet song, which is made of pulses repeated at two alternating IPIs of different lengths. A variant of the doublet, a singlet song, also occurs and has a single IPI that corresponds to one of the distinct IPI of the doublet song. Based on the analysis of fin whale song patterns at one location within the Bight, we have been able to describe songs from resident and "transient" or pan-Pacific populations of fin whales. With this project, we are extending the analysis to additional sites in the SCB to get a more detailed picture of the spatial and temporal variability in resident and pan-Pacific populations of fin whales in this area of substantial naval importance.

Fin whale song patterns were analyzed from High-frequency Acoustic Recording Package (HARP) data collected at four sites in the Southern California Bight collected between 2005 and 2014. The sites were chosen to cover both inshore (sites P and Q) and offshore (sites C and H) areas as well as southerly and northerly extent of the Bight. A single year of data, from September 2009 to September 2010, was analyzed from all sites and additional years of data were analyzed from two sites (H and C). Two days per months were selected to analyze song patterns over time. During the selected day, the start time of each 20 Hz pulse in a sequence was picked from a spectrogram and saved to a spreadsheet. After all the 20 Hz pulse start times were picked in a day, IPIs were calculated for each picked sequence. Individual sequences with matching IPI patterns were pooled and sorted to separate short and long IPIs. The daily median and first and third quartiles for each IPI of each distinct sequence type were calculated. We present the IPIs for each site over the time period analyzed to compare spatial and temporal patterns in song occurrence across the SCB.

Preliminary results show that the fin whale songs recorded between 2009 and 2010 across all four sites had the same doublet IPIs corresponding to "short doublet" song likely attributed to resident population. Overall the highest variability in the IPIs was measured in songs at the northernmost site, site C. Singlet variants of the doublet songs were also detected at all sites, most commonly during the fall. The IPI duration of singlet songs was equivalent to the shorter IPI in doublet song. The "long doublet" or "seasonally variable" song that has also been termed the pan-Pacific song, appeared at both sites where long-term analysis was performed, sites C and H. This song only appeared in its singlet version and was more common from 2005-2007, but it was also detected intermittently later (in 2008, 2010, and 2011). We are continuing to process song pattern data from additional years to evaluate whether the population of fin whales in the SCB consists mainly of resident animals or if animals with a larger, pan-Pacific range are also present.

Introduction

The fin whale (*Balaenoptera physalus*) is an endangered species of mystecete that is relatively common in the Southern California Bight (SCB). A genetic study showed the North Pacific population, which the SCB animals are a part of, are a distinct subspecies (Archer et al. 2013). The migration patterns among this population do not always conform to the traditional baleen whale seasonal migration trajectories. For example, there is a resident population of fin whales in the Gulf of California (Berube et al. 2002), and possibly another one in Southern California (Širović et al. 2015). Fin whale song may be one possible tool to help delineate between populations (Hatch & Clark 2004).

Fin whale song consists of low frequency, 20 Hz pulses arranged in regular sequences (Watkins et al. 1987). These songs are thought to be produced by males and to have a reproductive function (Croll et al. 2002). There are regional differences in the interpulse intervals (IPI) and higher frequency pulse components of songs, suggesting that these differences may indicate population structure (Hatch & Clark 2004, Širović et al. 2009, Castellote et al. 2012). In Southern California, the songs do not contain the higher frequency pulse component, therefore the IPI has been used as a distinguishing feature to separate different songs (Oleson et al. 2014, Širović et al. 2017). The common song types in the SCB are doublets (Figure 1), which are made of pulses repeated at two alternating IPIs of different lengths. However, occasionally these songs can be produced with just a single IPI, then termed singlet songs. These singlets are a variant of the doublet as the IPI lengths are comparable to those in the doublet song; in some cases they are produced from just the shorter of the two IPI doublet intervals, and in other from the longer IPI doublet interval.

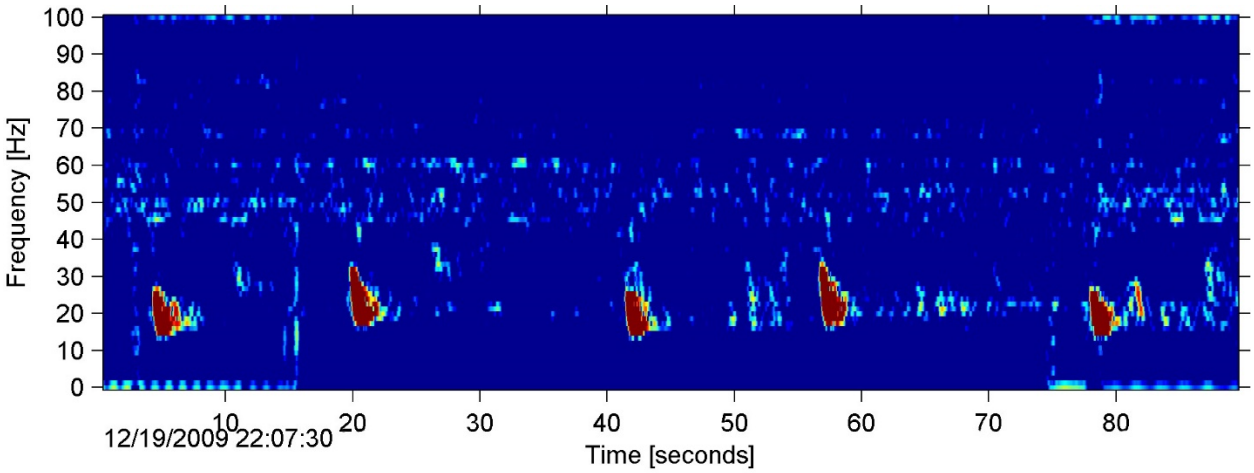

Figure 1. Example spectrogram of doublet song recorded in the Southern California Bight (1500-point FFT length and 95% overlap).

In Southern California fin whales produce 20 Hz calls year-round, with a decrease in calling during the summer (Širović et al. 2015). Based on the analysis of their song patterns at one location within the Bight, we have been able to describe songs from resident and "transient" or pan-Pacific populations of fin whales (Oleson et al. 2014, Širović et al. 2017). With this project, we are extending this analysis to additional sites in the SCB to get a more complete picture of the

spatial, as well as temporal, variability in hypothesized resident and pan-Pacific populations of fin whales in this area of substantial naval importance.

Methods

Fin whale song patterns were analyzed from High-frequency Acoustic Recording Package (HARP) data collected at four sites in the Southern California Bight. The sites were chosen to cover both inshore and offshore areas as well as southerly and northerly extent of the Bight (Figure 2). Data collection at two sites, H and C, occurred over multiple years starting as early as 2005, while the collection at sites P and Q was shorter and the analysis thus far was focused on data collected from 2009-2010 (Table 1). All data were recorded continuously (except the first few months at site C and recordings from October 2007 to March 2008 at site H) at a sample rate of 200 kHz. To enable faster analysis, all data were downsampled to have an effective sample rate of 2 kHz.

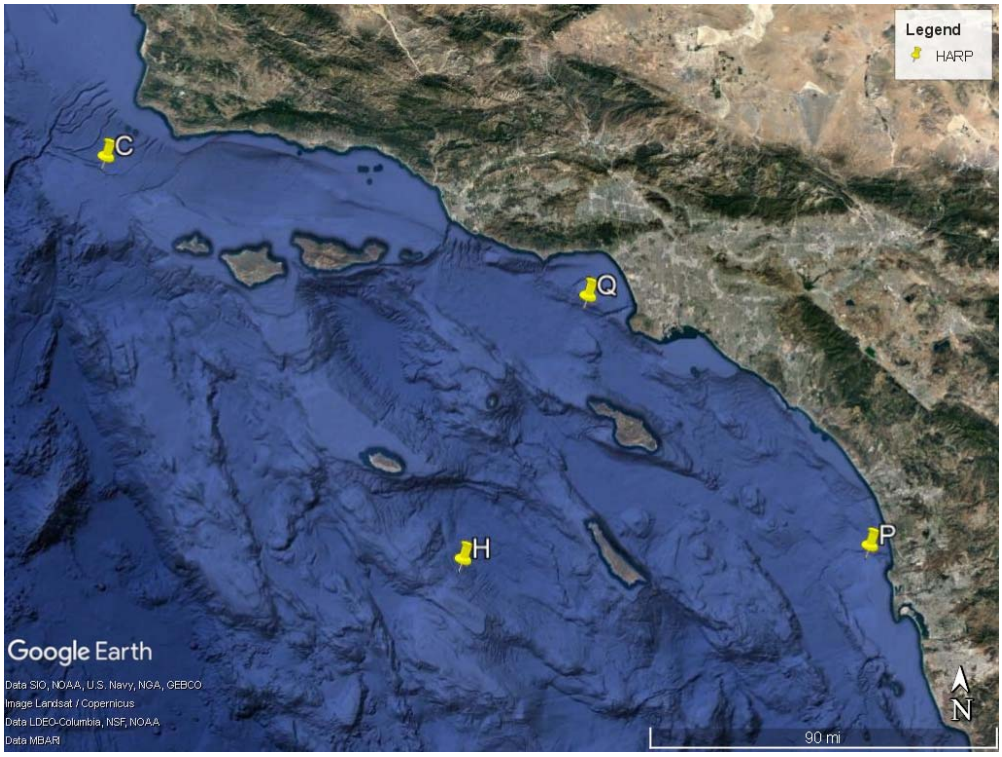

Figure 2. Deployment locations of HARPs used for this study

We used two days per month with fin whale songs for detailed analysis of song patterns over time (following methods described by Oleson et al. 2014 and Širović et al. 2017). During each month with data, we randomly selected one day before the 15th of the month and one after the 15th. Spectrograms were scrutinized for each selected day and the start time of each 20 Hz pulse in a sequence was picked and saved to a spreadsheet. Spectrogram display parameters were set to 60 or 120 s of data, and frequency range 0-150 Hz, with 1 Hz frequency and 0.1 s temporal

resolutions. Pulse start times were picked only when a clear IPI pattern was visible for a period of a minimum of 2 min. If two whale songs overlapped in time but were clearly distinguishable due to differences in intensity or spectral features, only one was picked at a time. If too many whales were calling and it was impossible to distinguish individual songs, no 20 Hz pulse start times were picked. If no fin whale song that could be picked was identified during the randomly selected day, we used a nearby day with identifiable song and performed the analysis on those songs as described above.

Table 1. HARP deployment locations used for the analysis of fin whale song patterns, including years of existing and analyzed recording data.

Site	Latitude (N)	Longitude (W)	Years with recordings	Years analyzed to date
C	34° 18.9′	120° 48.1′	2005 – current	2005 – 2014
H	32° 50.8′	119° 10.6′	2007 – current	2007 – 2012
P	32° 53.6′	117° 22.8′	2009 – 2010, 2013 – current	2009 – 2010
Q	33° 49.2′	118° 37.8′	2009 – 2010	2009 – 2010

After all the 20 Hz pulse start times were picked in a day, again following methods described in Oleson et al. (2014) and Širović et al. (2017), IPIs were calculated for each picked sequence. Sequences with similar IPI patterns during each day were identified during this post-processing. Individual sequences with matching IPI patterns were pooled and sorted to separate short and long IPIs. The daily median and first and third quartiles for each distinct IPI length were calculated. The IPIs and the arrangement of pulses occurring together with similar timing (i.e. singlet or doublet) were assessed to create song categories. We plotted the song IPIs for each site over the time period analyzed to compare any spatial and temporal patterns in song occurrence across the SCB.

Preliminary results

To date, we have analyzed one full year of song occurrence at all four sites, with additional years analyzed at the northernmost site C and southern site H. Analyses conducted thus far indicate that the fin whale songs recorded between 2009 and 2010 across all four sites had the same doublet IPIs (Figure 3). This doublet song was detected during most of the year in the 2009-2010 period, but was least common at site P. Typically, the longer IPIs of the doublet song were more variable than the shorter IPIs of the doublet song. Overall the highest variability in the IPIs was measured in songs at the northernmost site, site C. This was also the site where there was the most variability in the doublet song IPIs during the winter and early summer. Singlet variants of the doublet songs were detected at all sites, most commonly during the fall. The IPI duration of singlet songs was equivalent to the shorter IPI in doublet song. During summer, singlet songs were only detected at site C (Figure 3). All of these IPIs from doublet songs corresponded to the

"short doublet" song as described by Širović et al. (2017) and could indicate a resident population.

When expanded over the longer time period, an additional song, the "long doublet" or "seasonally variable" song that has been reported across the eastern Pacific (Oleson et al. 2014, Širović et al. 2017), appears at two sites, C and H (Figure 4). This song only appeared in its singlet version and was more common from 2005-2007, but it was also detected intermittently in latter years (in 2008, 2010, and 2011). In most cases when this long doublet song was detected at one site, it was also detected within a couple of months on the other site available for long-term analysis (Figure 4). The short doublet song, which appears to be specific to the SCB, exhibits the same gradually increasing IPI trend at both sites (Širović et al. 2017). In the early years when data were available for analysis, the short doublet song appeared to be more variable. High variability in later years seems to be limited to the singlet versions of the song (Figure 4).

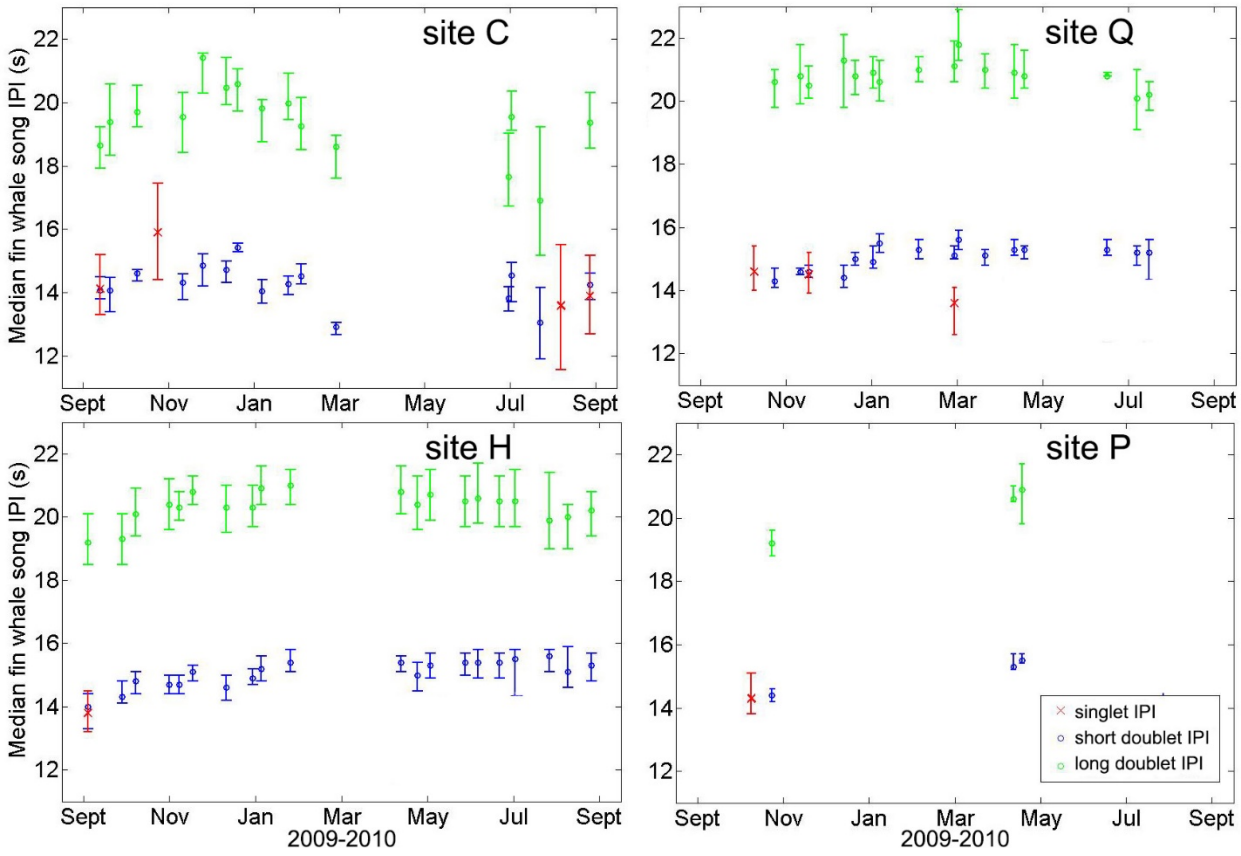

Figure 3. Inpterpulse intervals (IPIs) of fin whale short doublet songs recorded at four sites, C, Q, H, and P, in the Southern California Bight between September 2009 and September 2010. Doublet song median IPIs are represented with a circle and short IPI of doublet songs are marked with blue and long IPIs with green. Singlets are marked in red with median marked with x. Whiskers represent the first and third quartiles of those medians.

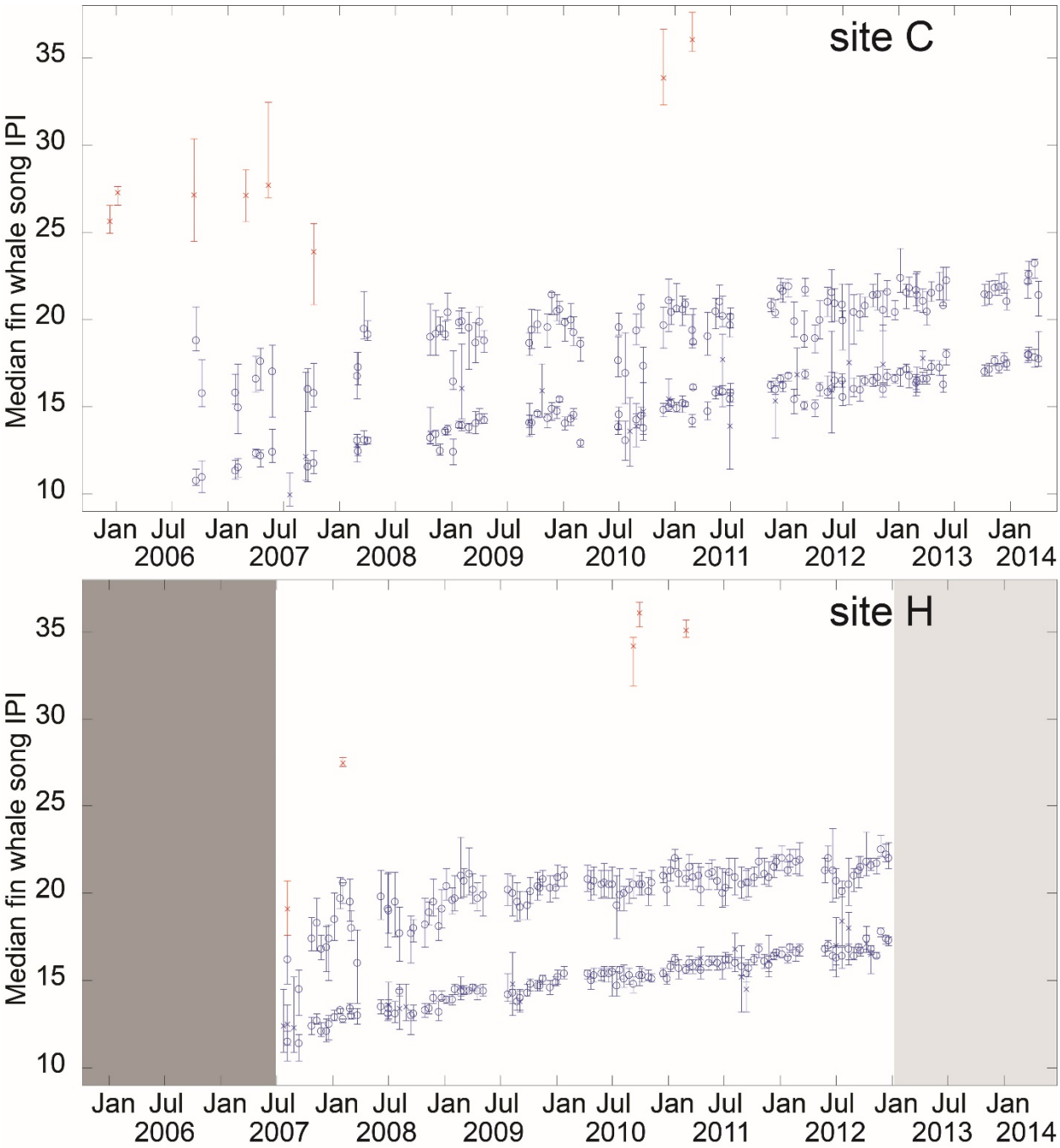

Figure 4. Inpterpulse intervals (IPIs) of fin whale doublet songs recorded between December 2005 and January 2014 at two sites, C and H, in the Southern California Bight. Long doublet song is represented with red and short doublet song is represented with blue. In both cases, circle denotes median IPIs for doublet songs while x denotes the median IPI of singlet song. Whiskers represent the first and third quartiles of those median. Dark grey shading represents time period with no data and light grey is time period that has not been analyzed yet.

Further work

The results presented here are preliminary as this work is ongoing. In the coming months, we will continue the analysis of fin whale song IPIs at sites H and C, as well as adding a year from the available data at site P. Additionally, we need to conduct a post-processing review of the data analyzed from site C to determine the sources of larger variability in longer IPIs and singlet songs at this site. In short, we will continue to evaluate the song patterns recorded in the SCB to determine whether the population of fin whales in the SCB consists mainly of resident animals or if animals with a larger, pan-Pacific range are also present.

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