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Fin whale song variability in the Southern California Bight, from 2008 through 2012

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Fin whale song variability in the Southern California Bight, from 2008 through 2012

A thesis submitted in partial satisfaction of the requirements for the degree in Master of Science

in

Biology

by

Jasmine Buccowich

Committee in charge:

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James Nieh, Co-Chair
Kaustuv Roy
Ana Širović

2014
The Thesis of Jasmine Buccowich is approved and it is acceptable in quality and form for publication on microfilm and electronically:

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Co-Chair

Chair

University of California, San Diego

2014
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ABSTRACT OF THE THESIS

Fin whale song variability in the Southern California Bight, from 2008 through 2012

by

Jasmine Buccowich

Master of Science in Biology

University of California, San Diego, 2014

Professor John Hildebrand, Chair
Professor James Nieh, Co-Chair

Male fin whales (*Balaenoptera physalus*) sing a low frequency song consisting of downswept calls with most energy around 20 Hz. There are some indications fin whale song patterns may be used as a population indicator as they vary amongst regions. Four and a half years of recordings from the San Nicolas Basin in Southern California were analyzed to investigate changes in song inter-pulse-intervals (IPI). The song patterns detected at this site were the Southern California singlet and doublet, and the Gulf of
California triplet pattern. The Southern California doublet IPIs increased by ~5 s during the study period; this was the most abundant song type with IPI of ~17 - 23 s in late 2012. The singlet was the second most common song type with an IPI in 2012 of ~18.7 s and it also increased by ~5 s over the course of the study. The doublets were present year-round with slight seasonal variability. The singlet presence was higher in the fall and winter. The Gulf of California triplet song pattern was recorded on only one day with IPIs 6 - 6 - 20 s. A comprehensive explanation for the increasing IPI is not evident although the relationship to ship noise may be important and should be further researched.
INTRODUCTION

Fin whales (*Balaenoptera physalus*) are widely distributed in all of the world’s oceans (Mizroch et al., 2009). They are known to migrate to higher latitudes in the summer and lower latitudes in the winter although some regions, such as Southern California, host resident populations (Forney and Barlow, 1998; Širović et al., 2013). Early 20th century whaling has left fin whale populations heavily depleted with the greatest number of individuals taken among all the commercially whaled species (Mizroch et al., 2009). As a result of extensive whaling, fin whales were listed as endangered under the Endangered Species Act in 1970 and under the IUCN Red List in 1996 (Reilly et al., 2013). With the current restrictions on whaling, fin whale numbers are believed to be recovering although it is unknown how quickly and whether this trend is occurring in all populations (Reilly et al., 2013). Although there are only two recognized subspecies of fin whales for the Northern and Southern hemispheres, recent genetic work suggests that the fin whales should be further divided into three subspecies: Northern Pacific, Southern Ocean, and North Atlantic subspecies (Archer et al., 2013). Within these clades, additional subpopulations of fin whales may be characterized by their song pattern and interval variations (Clark et al., 2002; Delarue et al., 2009; Edds, 1988; Hatch and Clark, 2004; Thompson et al., 1992; Watkins et al., 1987).

Fin whale songs can be consistent in their temporal and frequency pattern across a region (Castellote et al., 2012b; Delarue et al., 2009; Hatch and Clark, 2004). The song is created by production of stereotyped calls in a fixed pattern (Clark et al., 2002; Širović et al., 2013; Watkins et al., 1987). These repeated calls are short-frequency downsweeps
that have peak intensity centered around 20 Hz (Širović et al., 2004; Širović et al., 2013; Watkins et al., 1987). The 20 Hz calls are also found outside of song context and are suspected to be used for social communication and maintaining proximity (McDonald et al., 1995). This use of the 20 Hz call is referred to as call-counter call and can be distinguished from the fin whale song through its inconsistent intervals (McDonald et al., 1995). The interval between calls is known as the inter-pulse interval (IPI) (Watkins et al., 1987). Depending on the region, this pattern in fin whale song can be distinct and can consist of varying combinations of singlets, doublets, or triplets. The terms singlet, doublet, and triplet refer to the number of IPIs in a pattern rather than the number of calls in a pattern. For example, a doublet will have three calls with two different IPIs that alternate in a regular pattern. Singlets have one consistent IPI and triplets have two similar length IPIs and one different length IPI.

Regional variation has been identified in some fin whale song IPIs (Castellote et al., 2012b; Delarue et al., 2009; Hatch and Clark, 2004). Hatch and Clark (2004) sampled 400 fin whales from different locations and only used characteristics found in their songs to match the whale with the location with 82% accuracy (Hatch and Clark, 2004). It has been suggested that whale songs be used in assessment of stock structure for conservation management purposes where genetic samples cannot be usefully implemented (Ford and Fisher, 1982; McDonald et al., 2006a; Rendell and Whitehead, 2003). Not only are comprehensive genetic samples of a population more difficult to obtain, but the genetic data can reflect millions of years of evolutionary genetics (Clapham et al., 2008; McDonald et al., 2006a). Thus the genetics of the populations may not be evolving fast enough to represent the current trends in population structure that are on a decadal time
frame (Clapham et al., 2008; McDonald et al., 2006a). Acoustic monitoring is a relatively cheap and noninvasive method to gather informative data to assess separation in fin whale populations.

The function of the whale song remains undetermined although it is thought to be involved in courtship or mate selection (Croll et al., 2002). Fin whale song activity peaks during mating season between December and February (Watkins et al., 1987). The 20 Hz calls are less consistent and less abundant in the other months although fin whales are still sighted in the areas of acoustic monitoring (Forney and Barlow, 1998; Watkins et al., 1987). In addition, singing fin whales have been identified as male (Croll et al., 2002; Watkins et al., 1987). Blue (Balaenoptera musculus) and humpback whales (Megaptera novaeangliae) also share this exclusive male song production which occurs most commonly around breeding season (Croll et al., 2002; Oleson et al., 2007; Watkins et al., 1987). The discrete fin whale songs may serve to delineate different breeding populations.

Some whale songs are subject to seasonal change and annual variability while others stay constant. Humpback whale songs change in phrase and complexity over the years (Noad et al., 2000). This versatility is not typically seen in the more static fin and blue whale songs, although the tonal frequency of blue whale calls declines over time (McDonald et al., 2009). The seasonally variable IPIs in fin whale song have been found in the North Atlantic and the central and eastern North Pacific (Morano et al., 2012; Oleson et al., in review). Seasonally variable IPIs have shorter IPIs at the beginning of the breeding season and increase in length later in the season (Morano et al., 2012; Oleson et al., in review). In contrast to that, a gradual increase of the doublet intervals of fin whale calls was observed in the Southern California Bight between years 2009 and
2010 without a clear seasonal cycle. To explore the changing song pattern in more detail, four and a half years of acoustic recordings from a site north of Tanner Bank in the Southern California Bight were analyzed in this study.
METHODS

Passive acoustic data were gathered in the Southern California bight north of Tanner Bank, in the San Nicolas Basin (32° 56.54N, 119° 10.217W, depth 1000 m) from June 2008 through December 2012 (Figure 1). High-frequency Acoustic Recording Packages (HARPs) were deployed to allow year long acoustic data collection (Wiggins et al., 2007). These acoustic recordings were converted to long-term spectral averages (LTSAs) to allow visualization and analysis using a MATLAB-based program called Triton (Wiggins et al., 2007). The LTSAs had 5 s temporal and 1 Hz frequency resolution.

To determine long-term trends in IPI, one random day each from the first and second half of every month was chosen. For each year, the same selected days were analyzed. The data were initially scrutinized in hourly increments for presence of fin whale calls. When fin whale song was observed in an hour, it was further analyzed with a finer time resolution (2 to 4 min increments) and start times of each call were logged. The finer time resolution allowed for more precise logging. It also allowed for better identification of song patterns amongst ambient and masking noise. In the event of low quality fin songs on a given day, the two days before or after the intended date were analyzed until a day with a clear song pattern was found. Days with low quality song data were those that either had too faint or too few fin calls, an abundance of indistinguishable songs, or strong presence of ambient noise masking. Songs from those days were not included to ensure accuracy of IPI measurements. Periods with no data were: 2008- 1st half of October; 2009- 2nd half of May to 1st half of July; 2010- 1st half of February to 2nd half of March, and 2nd half of November; 2012- 2nd half of March to 1st half of May.
A fin song was defined as a sequence of calls having six or more consistent intervals in a clear pattern. If the calls did not satisfy this requirement, they were not analyzed. Each call start time was recorded from the same position on a call’s downsweep; the IPI was calculated as a difference in seconds from the start of one call to the start of the subsequent call (Figure 2) (Watkins et al., 1987). The start times were measured for the entirety of the calling bout. The end of the bout was indicated by a long gap between calls, or when the song pattern became unintelligible. Unintelligible song pattern included those that had overlapping calls, inconsistent IPIs, or ambient noise masking. The IPI was measured for every clear song present on a given day. No inferences of song pattern or song quantity were made during the logging of the calls. Thus the pattern of the songs and IPI length on a given day were unknown until the IPIs were later analyzed.

All song IPIs within the same song pattern (i.e. singlet, doublet, triplet), found on the same day, were averaged together to create the average daily IPI and a standard deviation. For doublets, the first and second intervals were averaged separately. Likewise, triplet patterns resulted in three separately averaged intervals. Occasionally the fin whale song sequence would begin and end with a very short interval; these anomalous intervals were not included in the averages. The fin whale song would also sporadically have a longer IPI. When the IPI duration was equal to the previous first and second IPI combined (in other words, the fin song skipped a call in the pattern) or it was longer than this value, the IPIs were not included in the averages. If there was an interval that was shorter than this skipped value but longer than the expected second interval, it was included in the average.
An overall rate of change (s/year) in IPI was calculated over the entire dataset from June 2008 to December 2012. Yearly rates of IPI increase were also calculated for period from August to July of each available season, to correlate with the timing of the singing season. There were four years analyzed with a full song season cycle; June- July 2008 and August- December 2012 were not included in yearly IPI rate of change as the incomplete years and would give a false rate of change. The percent change per year was calculated by using the shortest IPI in each season. These occurred in August or September with the exception of the 2\textsuperscript{nd} IPI in 2010 which was the shortest in October. The data from August 2012 was included in calculating the percent change per year as it represented the shortest IPI of the next seasonal year.
RESULTS

There were three fin whale song patterns in Southern California: doublets, singlets, and, on one day in October 2011, a triplet. Doublets were the most common song pattern detected in this dataset. There was a gradual increase of the first IPI from June 2008 to December 2012 (Figure 3). In doublets, the shortest IPI occurred in September 2008 with an average IPI of 12.0 ± 1.2 s. The longest interval was in November 2012 with an IPI of 17.7 ± 0.6 s. The rate of the increase in the first IPI was 0.81 s/ year. The second IPI for the doublet also shows an increase in duration; it started at 17.6 ± 1.6 s in September 2008 and was 23.2 ± 2.6 s in November 2012. Overall rate of the increase of the second interval was 0.60 s/ year. There was also a slight seasonality in the IPI. In mid-July the intervals would shorten followed by an increase of IPI in September, some years showed a larger IPI shortening than others (Figure 3). The yearly IPI rates of change are larger than the overall calculation of the four and a half years which demonstrates the non-linear pattern of the IPI increase (Table 1). It also appears that the rates of change are slowing with each successive year.

The singlets were less commonly observed than doublets (Figure 4); 19.6% of analyzed days had singlets while 99% had doublets. The singlet presence varied by year (Table 2). The singlets were more common from August to December; there were only two days outside this range that had singlet presence (February 2009 and April 2011). The February 2009 singlet was the only singlet presence for the entire year and singlets were absent until April 2011. The singlets followed the same trend in IPI as the first IPI in a doublet; singlet IPIs increased in duration and generally tracked the duration as the first IPI in the doublet for the respective date. The shortest singlet IPI was 13.4 ± 2.3 s in
July 2008; the longest was 18.7 ± 2.6 s in July 2012. The rate of increase in IPI for singlets was 0.64 s/year. There was more variation in singlet IPI than in the doublet and triplet pattern.

The triplet was detected only on one day in October 2011 (Figure 5). The song was a mixture of 41% triplet and 59% doublet. The doublets were not similar to the other doublet IPIs found in the other days of analysis; they had the same IPI as triplets, but with one interval omitted. The IPI averages were 6.2 ± 0.1 s and 20.1 ± 0.5 s for the doublet and 6.2 ± 0.1 s, 6.2 ± 0.1 s, and 20.2 ± 0.7 s for the triplet.

To summarize, three fin whale song patterns were observed in Southern California: doublets, singlets, and triplets. There was an overall increase in IPI duration for doublets and singlets by approximately 5 s (~40% increase for singlet and first IPI, 26% for second IPI) over four and a half years with slight seasonal variability. The presence of the singlets may be seasonal.
DISCUSSION

Song as population indicator

Song pattern in some fin whale populations has been identified as regionally distinct (Castellote et al., 2012b; Edds, 1988; Hatch and Clark, 2004; Thompson et al., 1992; Watkins et al., 1987). The Southern California resident fin whale population has been acoustically and visually observed year round (Forney and Barlow, 1998; Širović et al., 2013). Thus it is not surprising the doublet was present throughout the year with a peak in song activity in fall and winter (Širović et al., 2013). The doublet pattern of 12 - 17 s was the pattern recorded the most in Southern California in 2008 and gradually increased to the observed 17 - 22 s in 2012.

The singlets appear to have seasonal presence in the Southern California Bight. The seasonality can be tentatively explained by migrating fin whales. Fin whales marked in Southern California in the winter have been recaptured in the Gulf of Alaska and Central California (Mizroch et al., 2009). These whales could be traveling through the area en route to breeding/feeding grounds, or they may be using Southern California for those purposes. The singlets are sometimes imbedded in a doublet sequences; the song type will switch from doublet to singlet in the same bout of calls. The singlet also shares a similar IPI length to the doublet first interval and follows the same increasing trend. Thus it is likely this singlet pattern is produced by the same animals producing doublets. The purpose of only doublet songs, only singlet songs, and doublet-singlet combinations are not yet understood. There could be a seasonal cue that causes adult males to produce singlets, or it may be that the singlets are a result of younger, smaller males. It seems unlikely that the singlets are representative of another subpopulation of whales.
The seasonally variable pattern previously observed in this area (Oleson et al., in review) was not found in this study, but was the common recorded call type in 2000-2003. The IPIs were ~27 - 32 s at the end of the singing season (Oleson et al., in review) which is much larger than what was seen in Southern California in 2008 through 2012. The seasonally variable pattern is still present across the central, western, and eastern North Pacific (Oleson et al., in review; Weirathmueller et al., 2013). There is a data gap from 2003 to 2008 and thus it is unknown when this seasonally variable call disappeared from Southern California. This song type could be an indicator of a migrating population which may have changed its migration pattern.

The origin of the new Southern California doublet IPI is unknown. Cultural transmission may be a viable explanation. Given that the seasonally variable call is still evident across much of the North Pacific (Weirathmueller et al., 2013, Širović pers. comm.) it is possible that song patterns are being transferred from one region to another; the new IPI could have come from a fin whale population from the Southern hemisphere.

Over this time period, the Gulf of California song type remained relatively consistent, with the IPI of 5 – 17 s from 1987 (triplet not recorded) (Thompson et al., 1992) which matches the more recent 6 - 20 s. It appears there was no cultural change in the Gulf of California population, which could be the results of low exchange which may be insufficient for song transfer. Although there was only one Gulf of California whale recorded at this site, the humpback song change was transferred by only two individuals singing a new song (Noad et al., 2000), and it is possible Gulf of California song type was present during additional, unanalyzed days. Conversely, it is difficult to compare across species with very different song types and fin whales may have greater difficulty
in transferring song. In addition, no other evidence of cultural transmission in other regions has been found in fin whale songs. To support or disprove this hypothesis, other IPIs along the eastern Pacific coast should be monitored over time to track changes and movement of song pattern.

The presence of the Gulf of California IPI pattern alludes to interaction between populations and/or shared use of the area. The 6 - 20 s doublet and 6 - 6 - 20 s triplet are common in the Gulf of California (Širović pers. comm.). This pattern, presumably produced by one individual, was recorded on one day in October 2011. The presence of the Gulf of California fin whale could be a consequence of warming sea surface temperatures that obscures the boundary of the Gulf of California whales. Bryde’s whales (Balaenoptera brydei) appear to have a northward range expansion starting in 2003, possibly driven by prey availability (Kerosky et al., 2012). It may be that environmental shifts are causing the fin whales to feed in different areas which catalyzes subpopulation interaction.

North Pacific fin whales and Gulf of California fin whales have been identified as separate populations on the genetic level with high isolation and low mitochondrial and nuclear gene flow (Berube et al., 2002). Similarly, the North Atlantic and Mediterranean Sea subpopulations share low gene flow and appear to have acoustic differences despite shared use of breeding grounds (Castellote et al., 2012b; Palsboll et al., 2004). Hatch and Clark (2004) found that sympatric populations with greater genetic similarities had more distinction in song types, while those that were genetically and geographically distant had more acoustic similarity (Hatch and Clark, 2004). The sympatric populations could be under strong pressure to diverge and the acoustic differentiation is the initial separation
while the genetic data is taking longer to show the reproductive separation (Hatch and Clark, 2004).

Currently it appears that song is an effective method for fin whale population identification for some regions. However the disappearance of one song type and the emergence of a new song type challenge the acceptance of fin whale song for reliable population distinction. Until more expansive acoustic studies can provide information about the origin of the new song type, fin whale song may not be useful to distinguish populations in all areas. Divergence among populations is apparent in the acoustic and genetic data. The low amount of gene flow between the Gulf of California populations and other North Pacific fin whales could be related to environmental events resulting in a separation of these populations temporally and/or spatially.

Song and reproduction

Acoustic displays for mate attraction are an honest indication of fitness which allow the intended mate to receive information about his/her selection (Bradbury and Vehrencamp, 2011). Fin whale songs are suspected to be involved in female mate selection or male to male competition. Evidence gathered in support of this theory includes the following: males have been found to be the only ones singing, the song is seasonally abundant during breeding season, males stop singing at the approach of another male, and some areas show variability in IPI by increasing in duration as the season progresses (Croll et al., 2002; Hatch and Clark, 2004; Morano et al., 2012; Watkins et al., 1987). Although the seasonal variability is thought to indicate
reproduction, it does not imply that populations with non-seasonal variable IPIs are non-reproductive.

The seasonality in the IPI durations indicates likely courtship functionality. Birds are also known to have this seasonal shift in call rate where song is linked with courtship intentions and reproductive states (Kunc et al., 2005; Leitner et al., 2001). As the season progresses, fewer females are available to mate; the song IPI could reflect this decreased reward for energy output and could cause a decreased call rate. Morano et al. (2012) described June through August to be the transition period between the short and the long IPI (Morano et al., 2012). This seasonal trend is weak in the Southern California data compared to the IPI in the central and eastern North Pacific and North Atlantic populations (Morano et al., 2012; Oleson et al., in review). The seasonally variable doublet recorded in Southern California from 2000 to 2003 showed IPI increase of 2.0 s and 1.8 s per month (Oleson et al., in review) while the current doublet’s largest rate of change was only +0.3 s per month (3.4 s/year). Despite the small increase compared to other seasonally variable song types, the song does appear to be resetting with each new season. Reproductive success is a possible explanation for this seasonal IPI variation, although it remains unknown how this mechanism works and why one region would be more strongly affected than another. More acoustic and behavioral studies are needed to further understand the seasonal IPI changes.

Whether the fin whale song is learned or innate is still unclear. Fin whales hear their natal song while maturing but they are also exposed to varying fin whale songs of different patterns throughout their lifetime (Hatch and Clark, 2004). Most animals that exhibit species specific temporal song characteristics have it genetically encoded
(Bradbury and Vehrencamp, 2011). In contrast, some cetaceans have shown the ability to learn and adapt their song within their lifetime such as the humpback whale (Noad et al., 2000). It is yet to be determined to what extent the song directs mating and the degree to which it can be modified.

**Reasons for increasing IPI**

Within the Southern California population there was an overall increase in the IPI. The Gulf of California whale also increased its IPI by approximately 1-2 s relative to previous recordings of 5 -18 s and 5 -5 -18 s recorded in 2005 (Širović pers. comm.). Two possible explanations for the increasing IPI are discussed. First will be the influence of increasing noise in the ocean directly on IPI. Second will be the influence of a spectral frequency decline of the song and its potential effect on IPI.

**Increased noise?** The increase in fin whale song IPI could be due to efforts to reduce propagation loss and noise overlap. This phenomenon is referred to as acoustic adaptation hypothesis (Bradbury and Vehrencamp, 2011). McDonald et al. (2006) saw a 12 dB rise in 30- 50 Hz ambient noise at a site west of San Nicolas Island from 1967 to 2004 (McDonald et al., 2006b). It would be useful to observe the IPI relationship with the corresponding noise measurements during these analyzed years to determine if the IPI increases during periods of high ambient noise. The growth of the fin whale population post whaling could also cause the amount of singers to increase which could also obscure individual songs. The decreased call rate can allow for more clarity in the signal when there is a crowding of fin whales.
The Gulf of California fin whales were not targeted for whaling and are also exposed to lower ship noise levels (Mizroch et al., 2009). The rate of change in the Gulf of California fin whale song recorded in 1987 of 5 – 17 s (Thompson et al., 1992) to 2004 of 5 – 18 s is 0.05 s/year (Širović pers. comm.). From 2004 to when it was next recorded in 2011, the rate of change was 0.13 s/year for the first IPI and 0.25 s/year for the second IPI. Due to lack of whaling, Gulf of California population has probably maintained a stable population size and would not see a rapid growth in singers that the Southern California population might. In addition to stable song production, a low amount of ship traffic in the Gulf of California may also contribute to the lower rate of change. Comparisons between populations with fast rate of change and slow rate of change would be beneficial to determine possible factors that influence IPI.

**Result of frequency decline?** There is indication that the peak frequency of the Southern California fin whales has decreased from 1966 at ~21 Hz to ~17 Hz in 2004 (McDonald et al., 2006b). As the fin whales shift their frequencies lower, it is possible that the increased energy required to produce low frequency call must be compensated by longer rest times reflected in the increased IPI. The driver that is causing the decrease of tonal frequency in blue whales (McDonald et al., 2009) may also be causing the frequency decline in fin whale song and their increased IPI. Fin whales and blue whales are closely related and share similar life histories as well as regional distribution. Due to their similarities it is likely that they are exposed to the same threats, environmental challenges, biological restrictions, etc.

It is difficult to determine what is causing this frequency decline. With the end of whaling and the expected increase of fin whale population, it may be less difficult for
males and females to find mates. Thus selective pressure on the male could have shifted to favor lower spectral frequency production to represent a larger body size rather than a signal with the furthest propagation. This was the preferred explanation to the blue whale tonal decrease by McDonald et al. (McDonald et al., 2009). One alternative interpretation is that ship noise has driven the fin whale song frequency down over the years. Similar to the acoustic adaptation hypothesis, the whales could be reducing their frequency to avoid calling within the ship noise frequency band. McDonald et al. (2009) assert that the benefits of reducing the spectral frequency would not outweigh the costs of lowered sound propagation; if ship noise was the driver a non-linear increase in frequency would be expected (McDonald et al., 2009). While a decreased frequency may not be the expected response, evidence suggests that ship noise may play a significant role in the observed fin whale trends.

High levels of ship noise have been found to have an immediate impact on fin whales and right whales. Fin whales in the Mediterranean have been found to decrease their peak frequency of the calls and increase their IPI in periods of high ambient noise (Castellote et al., 2012a). Comparison of song frequencies has also shown that the Gulf of California fin whales have higher frequency calls than other populations (Hatch and Clark, 2004) which may be attributed to a quieter environment. On the other hand, separate long-term studies have shown that the North Atlantic right whale, exposed to a lifetime of higher ship traffic, had higher spectral frequencies of calls than the Southern Atlantic right whale (Parks et al., 2007). To determine if these frequency differences amongst populations are caused by ship noise or genetics, more research is needed.
To assess the relationship of spectral frequency and IPI more thoroughly, a comprehensive analysis of the frequency shift of fin whales from multiple populations should be conducted. Physiological restrictions will limit the rate of change of the fin whale IPI as it becomes exponentially more difficult to continually produce lower frequency calls. This is tentatively seen in the decreased rate of change in IPI with each year in the Southern California population. A longer time-frame study of the IPI would need to be conducted to get a better understanding of this trend. It would be interesting to compare different rates of change simultaneously with ambient noise levels in the different corresponding oceans to assess worldwide changes in IPI.
CONCLUSIONS

The use of passive acoustics to study fin whales is an effective method that can provide valuable information to further the understanding of this species. Our data show an increase in the IPI of song from Southern California and Gulf of California fin whales, which may be driven by similar factors as those causing the decrease in blue whale tonal frequency. Data that would help further identify causes of the observed changes in fin whale IPI pattern include but are not limited to population growth estimates, migration trends, comprehensive IPI assessment of major fin whale populations, ambient noise and ship noise trends, and simultaneous genetic and acoustic sampling from the same whale. We also showed sympatric occurrence of the Gulf of California and Southern California whales but the context of their interactions remains unknown. It would be beneficial to study the Gulf of California population in more detail with respect to population size, distribution, migration, and varying IPIs. The Gulf of California population did not undergo whaling and is exposed to little ship traffic (Mizroch et al., 2009). Therefore knowing more about this population would allow comparative inferences for studying other fin whale populations. As acoustic monitoring becomes more popular there will be many opportunities to gather this information. With these data, the conservation of fin whales and other marine mammals may be able to be more effectively implemented.
FIGURES AND TABLES

Figure 1. Location of High-frequency Acoustic Recording Package is marked by the star (32° 56.54, 119° 33.77, depth 1000 m). Color denotes depth as shown on scale.
**Figure 2.** Spectrogram of doublet recorded on October 23, 2011. (2000-point FFT with 95% overlap, band pass filtered between 10 and 40 Hz; sample rate 2 kHz) Arrows indicate the position of the call at which the beginning and end of intervals are logged. Numbers indicate the inter-pulse interval (IPI) in seconds.
Figure 3. Daily average and standard error of the first (blue) and second (red) interval in the doublet song. Best fit regression line slope for the first interval was 0.81 s/year; the second interval slope was 0.60 s/year. Bar plot shows the total number of IPIs measured, including both the first and second intervals.
**Figure 4.** Daily average and standard error of the interval in the singlet song type. Best fit regression line has slope of 0.64 sec/year.

**Figure 5.** The Gulf of California triplet song recorded on October 22, 2011, shows switches from a triplet pattern to a doublet pattern and back to a triplet.
Table 1. The rate of yearly IPI change. Data from June-July 2008 and August-December 2012 were not included in the yearly assessment for the rate of change. The %change/year was calculated by using the shortest intervals of each year. The 2012 data was used for this as it represented the next seasonal year where the shortest interval would be.

<table>
<thead>
<tr>
<th>Year (August-July)</th>
<th>1st IPI (s/year)</th>
<th>1st IPI (%change/year)</th>
<th>2nd IPI (s/year)</th>
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<td>7</td>
<td>0.4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. The percentage of days with singlet presence by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>% Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>46</td>
</tr>
<tr>
<td>2009</td>
<td>5</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>21</td>
</tr>
<tr>
<td>2012</td>
<td>35</td>
</tr>
</tbody>
</table>
REFERENCES


Castellote, M., C. W. Clark, and M. O. Lammers, 2012a, Acoustic and behavioural changes by fin whales (Balaenoptera physalus) in response to shipping and airgun noise: Biological Conservation, v. 147, p. 115-122.


