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INTRODUCTION

Understanding stock structure is a key component to effective wildlife management (Wiens 1989, Shea *et al*. 1998). When the spatial distribution of a species during the breeding season is split into a number of independently breeding subpopulations, each referred to as a population stock (Wiens 1989), unique conservation measures must be applied in order to minimize extirpations and genetic loss. In order to accurately predict the population dynamics and response to environmental and anthropogenic changes, resource managers must understand the location and size of these stocks.

In the North Pacific, fin whales (*Balaenoptera physalus*) are classified as a single population by the International Whaling Commission (IWC), however data has been presented to suggest that further subdivision is appropriate (Mizroch 1984, Clapham *et al.* 2008, Carretta *et al.* 2009). Solely for the purposes of setting catch limits, the IWC separates the East China Sea from the rest of the North Pacific. The National Oceanic and Atmospheric Administration (NOAA) recognizes 3 stocks within United States waters including Alaskan, Hawaiian, and Washington/Oregon/California stocks (Carretta *et al.* 2009). Thompson *et al.* (1992) hypothesized that fin whales in the Sea of Cortez are a separate regional stock based on acoustic data, which was later verified with additional acoustic and genetic analyses (Bérubé et al 2002, Hatch 2004). However, additional work is needed to determine such fine differences throughout the rest of the eastern Pacific. Traditional approaches to marine mammal stock assessments have used morphological differences, photo-identification, tagging, and genetics in an effort to predict the demographic trends of the populations (Dizon *et al.* 1992). However, each of the above techniques is labor intensive and requires adequate sampling of individuals across a wide geographic range and in varying conditions (Brown *et al.* 1996, Mellinger & Clark 2000). Further, morphological and genetic differentiation of stocks results from thousands of years of evolution, whereas overhunting and management operate on far shorter time scales (Mellinger & Barlow 2003, Clapham *et al.* 2008, Delarue *et al.* 2009). Stock assessment and management is most likely to be successful when combinations of these tools are applied (Mellinger & Barlow 2003).

Acoustics provides another tool for use in understanding the stock structure of cetaceans (Mellinger & Barlow 2003). Whale song varies both within and between species, and there is often a characteristic song type associated with each species (Watkins *et al.* 1987, McDonald *et al.* 2006). Stereotypic song often consists of a series of calls and may be characterized by the call duration, frequency characteristics, and intercall interval. Stereotypic fin whale song is a series of low frequency 20 Hz pulses, doublet pulses, or triplet pulses (Watkins *et al.* 1987). Each pulse lasts approximately 1 second and sweeps downward within a subset of the range from 44Hz to 15Hz (Watkins *et al.* 1987, Thompson *et al.* 1992, Croll *et al.* 2002). Fin whale song has been recorded with estimated source intensities up to 199 decibels relative to 1 µPa of sound pressure (Širović *et al.* 2007). Geographic variation in these characteristics, especially in interpulse interval, has allowed researchers to differentiate fin whale stocks in the North Atlantic (Delarue *et al.* 2009) and globally (Hatch 2004).

The low frequency and high intensity of fin whale song allows for long transmission distances. This characteristic makes it suitable for long distance communication and allows for passive acoustic monitoring of broad areas of the ocean (Stafford *et al.* 1998, Širović *et al. 2007*). However, it also makes linking individuals or species to particular vocalizations more difficult (Edds 1982). The accuracy with which locations of acoustically sampled whales can be estimated varies widely across recording methods. High intensity calls recorded via temporary anonymous acoustic recorders or towed arrays can be assumed to be from singers within approximately 10 kilometers of the known location(s) of the hydrophone(s), while singers recorded via stationary mid-water or bottom-mounted acoustic recorders can be detected hundreds of kilometers away from hydrophones (Stafford *et al.* 1998*)*. Because the sonobuoys used in this study were deployed opportunistically at sites where whales were sighted, high intensity calls may be attributed to the sighted individuals or nearby groups of animals. However, it is also possible that the sonobuoys may detect calls from individuals hundreds of kilometers away.

Long term stability has been seen in some characteristics of cetacean song, including characteristics which demonstrate geographic variance. McDonald *et al.* (2006) described 9 geographic variants of blue whale song, at least 5 of which have remained constant for over 30 years. Fin whales have also been identified to a specific region based upon their song, and Hatch (2004) found that interpulse interval was the strongest differentiator among regions. Specifically, Hatch (2004) found differences among regions existed in both the durations of individual interpulse intervals and the combinations of intervals observed among singers, with the degree of regional differentiation varying among regional comparisons. Delarue *et al.* (2009) found significant variation in interpulse interval between callers in the Gulf of Saint Lawrence and callers in the Gulf of Maine. In addition to the timing of calls and features of the calls themselves, singers were found to differ regionally in the call-type composition of their song, with the proportion of singers using backbeats and the presence of additional higher frequency calls varying among regions. Seasonal and inter-annual variation in both intercall interval and incorporation of additional call types has been found in some regions (Hatch 2004, Oleson *et al.* 2009 & in prep). For example, Hatch (2004) found that fin whales singing in the late summer and early fall incorporated more backbeats into their songs than those singing during the winter and spring months. Among singers from the northeastern North Atlantic sampled between 1993 and 2002, patterns of intercall interval showed differences among years, with a dominant pattern lasting several years followed by another dominant pattern again lasting several years.

Acoustic differentiation does not necessarily correspond with genetic differentiation (Hatch 2004). This may be due to differences in the time scales associated with developing each of these indicators. Genetic differences offer a glimpse of past stock structure and may take long periods of time to evolve (Carvalho & Hauser 1994). In contrast, the biological uses of song are not well understood, and it has been hypothesized that vocalizations serve as a reproductive isolating mechanism (West-Eberhard 1983, McDonald *et al.* 2006). If whale song is an isolation mechanism, it may offer a shorter term forward-looking perspective on stock structure that would aid in determining management practices. Studies have found differences in one or both of acoustics and genetics (Thompson *et al.* 1992, Bérubé *et al.* 2002, Mellinger and Barlow 2003) between population stocks. Hatch (2004) provided preliminary evidence that fin whale song features were negatively correlated with metrics of isolation among males, that is, changes in their neutrally-evolving DNA. This provided possible support for the hypothesis that fin whale males, due to their role in mate selection, may be more likely to diverge in regions in which singers are sympatric, either physically or acoustically. Used in conjunction with other techniques, acoustic analysis of whale song may allow for finer-scale population stocks to be defined.

Here we present a preliminary summary of fin whale acoustics and stock structure in the North Pacific. We quantify geographic and temporal variation in the interpulse interval of fin whale song on recordings from NOAA cruises and compare this information with published and unpublished data. This variation provides information about the population structure for North Pacific fin whales that may be used by wildlife managers. We also include an introduction to the use of acoustics in cetacean population assessment in order to promote interdisciplinary collaboration.

METHODS

Navy surplus sonobuoys (type 53 and 57) deployed opportunistically during cetacean surveys from 2000 to 2010 were examined to assess the presence of fin whale song and how it might relate to fin whale stock structure along the west coast of the United States and Mexico and in Hawaiian waters (Table 1). One additional recording off the coast of Peru (from the STAR 2003 cruise) was also examined. Sonobuoy signals were received on ICOM R-100 receivers and recorded to Sony DAT (digital audio tape) at a 48000 Hz sample rate in the field.

Each recording was digitized and decimated to 240 Hz, and all calls contained therein were extracted and analyzed. DAT recordings were transferred to 16bit ".wav" files at a sampling rate of 48000 Hz using a Sony TCD-D8 DAT player (Sony Corporation, Tokyo, Japan), a Creative Labs SB0130 Extigy sound card (Creative Technology Ltd, Jurong East, Singapore), and Ishmael 1.0 software (Mellinger 2001). MATLAB® version 2007b (Mathworks, Natick, MA) was then used to progressively down-sample the files to a 240 Hz sampling rate by decimation factors of 5, 5, 4, and 2. The downsampled files were visually scanned for all marine mammal calls below 70 Hz in Raven Pro version 1.3 (The Cornell Lab of Ornithology, Ithaca, NY) using a 256-sample FFT with a Hann view window and 75% overlap. The spectrogram was viewed from 0 to 70 Hz on a 20-inch LCD monitor with 175 seconds visible at any given time. Acoustic pulses with frequencies between 15 Hz and 40 Hz and durations of approximately 1 second were attributed to fin whales. Each call was marked, and the beginning time, ending time, lowest frequency, center time, highest frequency, center frequency, peak frequency, delta frequency, and delta time were measured and extracted using Raven. The center frequency was calculated at the weighted average of time and intensity of sound within the call. Annotations were also made to denote the likely species that produced the call and relative quality of the call. These annotations were made upon visual observation of the spectrogram to identify high signal-to-noise ratios where a single caller could be easily identified. During this study, no effort was made to identify the calling animal by visual or genetic studies, with one exception (sonobuoy deployed off Peru during STAR 2003). One sonobuoy recording (S#284 HICEAS 2002) had been previously analyzed; however, our analysis was made independent of this previous analysis.

Our analysis includes all series of pulses at least five minutes in length that were attributed to fin whales. Each call was attributed to an individual of the species under the premise that interpulse interval within a given pulse series remains nearly constant (Watkins *et al.* 1987). In keeping with prior usage, we term these regular series of pulses as "song" (Croll *et al.* 2002, Hatch 2004, Delarue *et al.* 2009). Interpulse interval was calculated from two points: the center of sequential calls and the start of sequential calls. In the case of doublet and triplet calls, interpulse interval was calculated between each sequential pulse in the pulse train irrespective of its placement within the doublet or triplet (Figure 1). Doublets and triplets were identified as clusters of pulses with constant interpulse intervals between pulses within a cluster and between clusters. Wilcoxon rank sum tests were applied to test for differences in mean and standard deviation of these two measures within a given recording. The interpulse interval based on center frequency for each of singlet and doublet callers on each recording was plotted by month. These results were then compared with the existing literature, as well as some recent as yet unpublished reports, on fin whale vocalizations in the North Pacific.

RESULTS

We examined 200 sonobuoy recordings from the West Coast of the United States and Mexico (Figure 2) and from waters surrounding the Hawaiian Islands (Figure 3) between 2000 and 2010. Thirteen of these recordings contained fin whale song of at least 5 minutes in duration (Table 2). Although our sample size was insufficient to allow for model fitting, visual inspection revealed an increase in interpulse interval over the season in the eastern Pacific (Figure 4) but not in Hawaiian waters (Figure 5). We did not see significant differences between center interpulse interval and start interpulse interval for either means (W=45, p=0.724) or standard deviations (W=42, p=0.931).

The fin whale recording off the coast of Peru contained 523 fin whale calls, all of which contained low-frequency 20 Hz pulses with associated 84 Hz pulses. This is the only recording that contained a higher-frequency pulse associated with the typical 20 Hz fin whale calls. Genetic analysis of a biopsy obtained from an animal within this sighting confirmed its identity as a southern hemisphere fin whale (E. Archer, unpublished data).

DISCUSSION

To use acoustics effectively as a tool for stock assessment, certain assumptions must be made about both the vocalizations themselves and the recordings. First, the vocalizations must be unequivocally attributed to this species, to the exclusion of all other species. Second, the vocalizations must contain at least one characteristic that is stereotyped by geographic region. Ideally, the same characteristic would show the same stereotypic differences over years if not decades, although intra-annual differentiation may still help resolve structural questions. Finally, there must be data over a sufficient geographic and temporal scale to provide the resolution necessary for acoustics to contribute to the stock assessment of that species.

To apply acoustics to identification of species, the calls must be sufficiently different from those of other species so that they can be accurately attributed. One of our recordings from HICEAS 2002 contained calls that, based on examination of acoustics alone, could be attributed to fin whales but were previously found to be produced by sei whales, *Balaenoptera borealis* (Rankin and Barlow 2007). Globally, most calls attributed to fin whales were pulses ranging from 18-25 Hz (Watkins *et al. 1987,* Gedamke 2009*)*; however, pulses with frequencies as high as 135 Hz have also been attributed to fin whales in some regions (Thompson *et al.* 1992, Mcdonald & Fox 1999, Hatch 2004).The sei whale calls detected on 20 November 2002, during the HICEAS survey, were pulses that ranged from 21-39 Hz (Rankin and Barlow 2007) and were similar to '20- to 35- Hz" calls previously attributed to fin whales (Thompson *et al.* 1992, McDonald & Fox 1999). This recordings also contained sounds outside this frequency range, including a stereotyped lower frequency pulse which exhibited an interpulse interval similar to that observed in our (see buoys from HICEAS 2002 in Table 2) and others' fin whale recordings (Oleson *et. al* 2009 & in prep). These are the only published recordings of sei whales in the N. Pacific, and further clarification of calls associated with sei whales may be necessary before any calls with frequencies greater than 25 Hz can be attributed to fin whales without visual or genetic confirmation of species identity. This must be resolved before calls of this type can provide information for stock structure.

At least one characteristic of the vocalization must be stereotyped to a species in a given region but also must exhibit variation within the species across regions presumed to host different populations. The calls must be stable over time both within and between seasons. Our results parallel other results that have shown a seasonal increase in interpulse interval from July-October (Oleson *et al.* 2009 & in prep). Additional work may be required to accurately describe this trend, and analysis of fin whale interpulse interval must take this seasonality into consideration. Interpulse interval has been effective in stock resolution elsewhere (Hatch 2004, Delarue 2009), and our results detected geographic variation of interpulse interval in the North Pacific. This suggests that given a larger sample size, interpulse interval may be effective for resolving stocks in the North Pacific. Higher-frequency components, not detected in fin whale calls in the North Pacific, have been found to have regional differences in the Southern Ocean (Gedamke 2009) and the North Atlantic (Hatch 2004). Indeed, we detected short 84 Hz pulses in the single recording from the Southern Hemisphere (Peru). However, based on results by Hatch (2004) that confirmed the absence of this component in the North Pacific, our methods examined recordings to a high of 70 Hz. Therefore, we cannot confirm the presence or absence of this higher frequency component in the North Pacific. Based on the work by Hatch (2004) within this region, interpulse interval appears to be the most reliable metric of differentiation.

The distance over which a sound can be detected varies based on the characteristics of the sound, the oceanographic and geographic conditions through which it propagates, and the sensitivity of the receiver to sounds at that frequency. In general, low frequency sounds such as fin whale calls travel great distances and are less affected by reflection, refraction, and absorption than higher-frequency calls (Richardson *et al.* 1995). Shallow water increases transmission loss through absorption by the seafloor and surface. Due to variation in temperature, salinity, and pressure, deep water often contains a deep sound channel (also called the Sound Frequency and Ranging, or SOFAR channel) between 600m and 1200m that greatly reduces transmission loss for low frequency sounds (Richardson *et al.* 1995). Within this channel, fin whale sounds are capable of carrying thousands of kilometers, however use of this channel for communication would require both the caller and listener to be within the channel.

Although fin whales may be able to dive to these depths, the majority of their dives are to less than 100m, so it is unlikely that the SOFAR channel is used for communication (Panigada *et al.* 1999*)*. In practice, it is reasonable to assume that whale communication may take place at ranges of tens to hundreds of kilometers level (Širović *et al.* 2007*)*. Thus, it is unlikely that fin whale calls travel far enough to homogenize populations across ocean basins.

The quantity and quality of recordings must also be of sufficient resolution to address both the geographical and temporal variation in calls. Ideally, the distribution of recordings will cover the full range of the species throughout a year. This approach will allow researchers to determine if the recordings are from a single population of highly migratory animals or from smaller isolated stocks. A collaborative effort among multiple researchers and institutions using multiple tools is one way to obtain the necessary volume of recordings to help define stock boundaries. However, this strategy requires that data analysis be conducted in a standardized manner that allows for comparison of multiple results. For example, previous studies have measured the interpulse interval using either the start or the center of each call. To date, no studies have examined differences in these two measures and whether differences might affect the resulting interpulse interval. In our study, we compared both measures of interpulse interval and did not find a significant difference between interpulse interval as measured from the center versus beginning of each call. This suggests that previous results using either measure may be compared. However, for future studies we recommend that researchers measure interpulse interval between the centers of successive calls. This measure is the weighted average location and intensity of sound within the call and is therefore less subject to variability based upon the spectrogram parameters chosen by the researcher as well as differences in the signal to noise ratio.

A number of tools are available to obtain acoustic data including sonobuoys (Richardson *et al.* 1995, McDonald 2004), acoustic tags (Johnson & Tyack 2003), and autonomous recording packages (ARPs, Wiggins 2003) (See Appendix I for descriptions). Each tool offers a unique blend of benefits for researchers. Sonobuoys are limited to only a few hours of recording, but they may be deployed at a number of sites where animals are sighted and can thus offer wide geographic distribution at the expense of temporal scale. Likewise, localization of sonobuoys using either their DIFAR features or multiple sonobuoys may allow for direct linking of a call to an individual animal (McDonald 2004). Acoustic tags are attached directly to an animal and may provide recording of calls or may be associated with sonobuoy recordings of that individual. Depending on the data that are recorded by the tag, behavior may be correlated to calling activity. Visual data and genetic samples may also be obtained to verify the identity of callers and may provide a level of ground-truthing for genetic-acoustic comparisons. In contrast, ARPs offer long term recordings at a relatively low cost but are limited to a single site and caller identity cannot be determined. Clusters of ARPs, hydrophones or seismographs for recording geophysical or naval data offer the long term recording benefits of ARPs with the additional potential to localize animals. This allows for individuals or groups of callers to be tracked and may reveal migration patterns or spatial distribution of callers. Each method offers its own limitations and benefits and is most likely to be effective when used in connection with others.

A multidisciplinary approach using acoustics, genetics, morphology, and behavioral studies is most likely to offer an accurate assessment of fin whale stock structure. Each method offers a unique balance of labor requirements, cost, and certainty. Combining methods will not only increase confidence and resolution of any conclusions that are made but will also increase confidence in the ability of each method to provide an accurate assessment of stock structure. Further, discussion and collaboration among researchers and wildlife managers both within and outside the field of acoustics is likely to produce the most accurate and successful results during the re-examination of stock assessments.

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TABLES

Table 1: Summary information from NOAA surveys in which sonobuoy recordings were analyzed. Table includes: cruise name, cruise number, year, location, and report reference. For more detailed information, see the referenced cruise report.

Cruise Name	Cruise Number	Year	Location	Report
Stenella Abundance Research Project (STAR)	1615, 1616	2000	Eastern Tropical Pacific	Kinzey *et al.* 2001
Oregon, California, and Washington Line-Transect Expedition (ORCAWALE)	1617	2001	US West Coast	Appler *et al.* 2001
Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS)	1621	2002	Hawaiian Islands	Barlow *et al.* 2004
STAR	1623, 1624	2003	Eastern Tropical Pacific	Jackson *et al.* 2004
Collaborative Survey of Cetacean Abundance and Pelagic Ecosystem (CSCAPE)	1628	2005	US West Coast	Forney 2007
STAR	1630	2006	Eastern Tropical Pacific	Jackson *et al.* 2008
ORCAWALE	1635	2008	US West Coast	Barlow *et al. 2010*
HICEAS	1641, 1642	2010	Hawaiian Islands	

Table 2: Summary information for sonobuoys where fin whale song was detected. The buoy on 9 Oct 2010 contained triplet calls with interpulse intervals of 1.48 ± 0.35 (n=9), 1.46 ± 0.37 (n=8), and 24.47 ± 4.11 (n=8) seconds. The two buoys from HICEAS 2002 are known to contain sei whale calls.

Cruise Name	Date	Latitude	Longitude	Sighting number	Singlet (s)		Doublet Interval 1 (s)		Doublet Interval 2 (s)		Frequency Range (Hz)	
					Mean ± sd	Count	Mean ± sd	Count	Mean ± sd	Count	High	Low
ORCAWALE 01	9/30/01	34.598	-122.951	261	12.38 ± 4.04	23	2.47 ± 0.94	31	17.26 ± 6.05	22	23.5	6.4
ORCAWALE 01	10/9/01	32.365	-118.942	291	15.28 ± 5.02	60	na	0	na	0	24.5	8.5
ORCAWALE 01	10/14/01	37.251	-126.740	299	26.8 ± 1.7	2	10.35 ± 19.79	78	16.35 ± 10.83	85	28.8	17.3
ORCAWALE 01	10/25/01	45.233	-126.933	339	17.01 ± 4.53	19	1.87 ± 0.17	6	17.93 ± 2.31	4	24.0	10.4
HICEAS 02	11/20/02	21.422	-156.010	284	15.85 ± 6.71	73	6.39 ± 5.73	97	14.42 ± 6.69	86	29.6	5.3
HICEAS 02	11/20/02	21.397	-156.002	284	15.36 ± 5.02	41	na	na	na	0	47.8	7.2
CSCAPE 05	10/23/05	45.674	-124.426	1442	15.44 ± 12.39	125	na	na	na	0	29.9	21.3
CSCAPE 05	11/22/05	35.574	-122.919	1560	23.68 ± 1.18	31	10.87 ± 0.93	67	17.41 ± 14.15	67	27.2	20.0
HICEAS 10	9/29/10	17.7182	-157.274	na	16.19 ± 1.76	32	na	0	na	0	20.2	13.3
HICEAS 10	10/7/10	24.633	-168.700	na	18.06 ± 3.17	40	na	0	na	0	24.3	12.8
HICEAS 10	10/9/10	25.2576	-170.7053	na	(see caption)	0	na	0	na	0	33.4	21.6
HICEAS 10	10/15/10	24.1328	-167.803	na	22.56 ± 3.15	17	na	0	na	0	26.1	14.9
HICEAS 10	10/16/10	25.0025	-167.1227	na	20.38 ± 6.85	42	na	0	na	0	34.7	6.9
HICEAS 10	10/17/10	24.0801	-166.084	na	21.31 ± 6.82	27	1.6 ± 0.32	12	13.65 ± 7.79	9	33.1	11.2

FIGURES

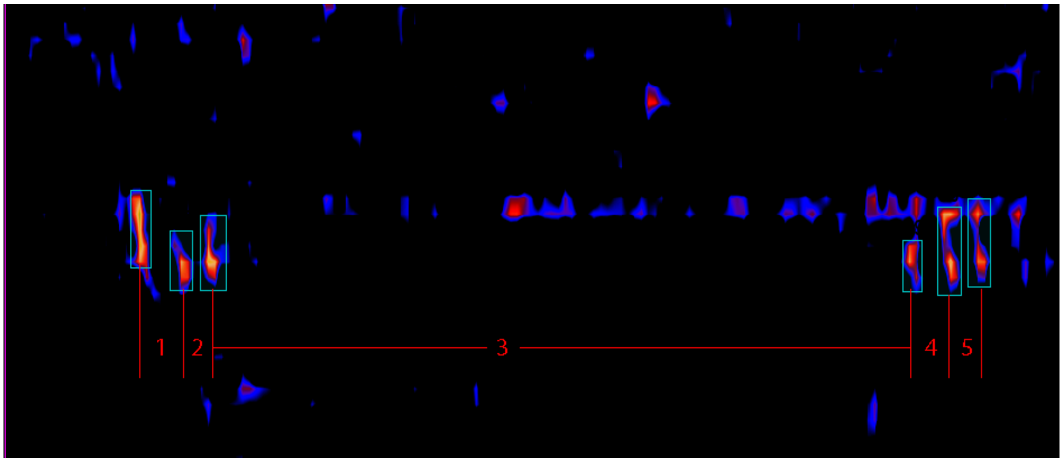

Figure 1: Example of a triplet call. Five interpulse intervals would be extracted from this call as labeled above.

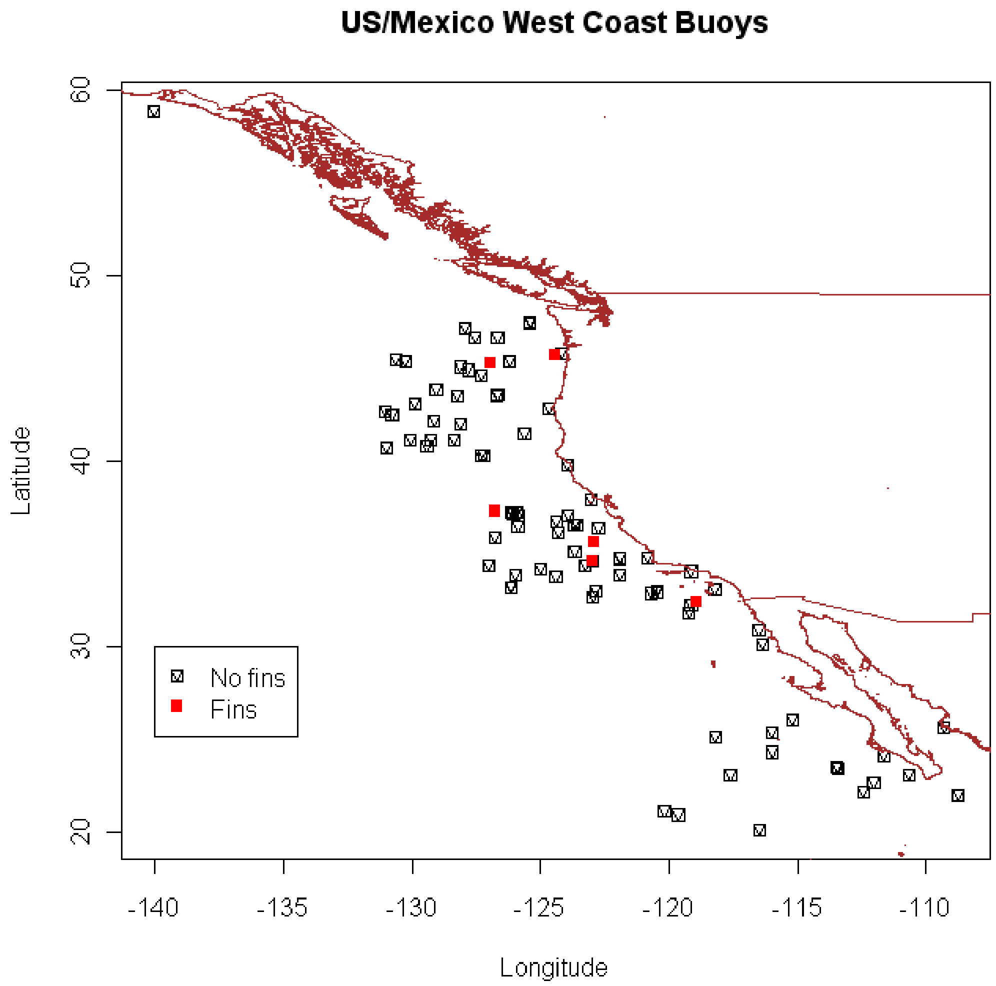

Figure 2: Locations of sonobuoys with recordings that we examined for assumed fin whale sounds off the west coast of the U.S. and Mexico. Buoys with sounds that were classified as fin whale song are depicted in red.

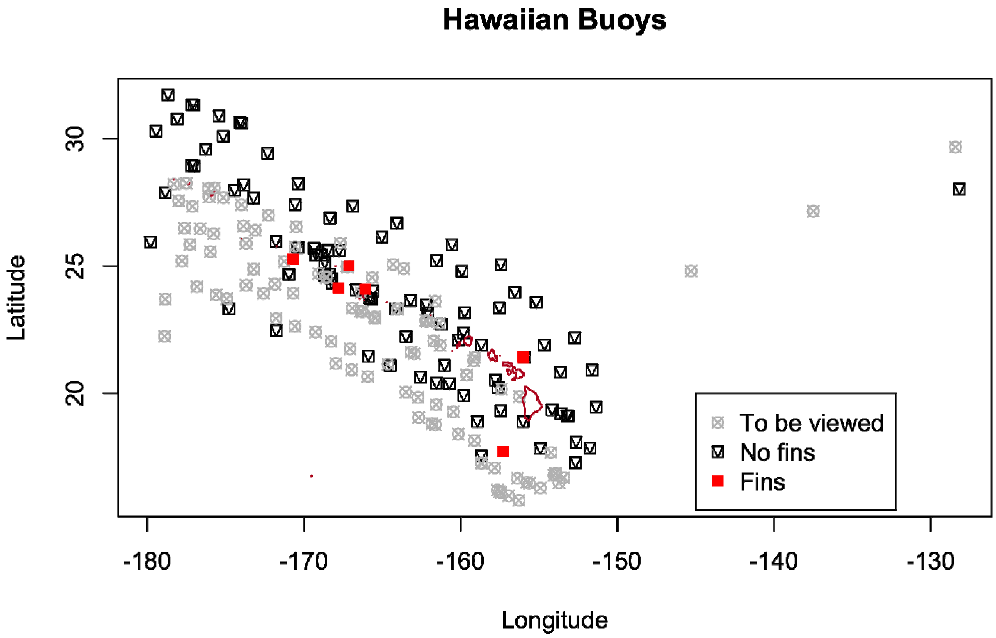

Figure 3: Locations of buoys with recordings that were scanned for assumed fin whale sounds in Hawaiian waters. Buoys with sounds classified as fin whale song are depicted in red.

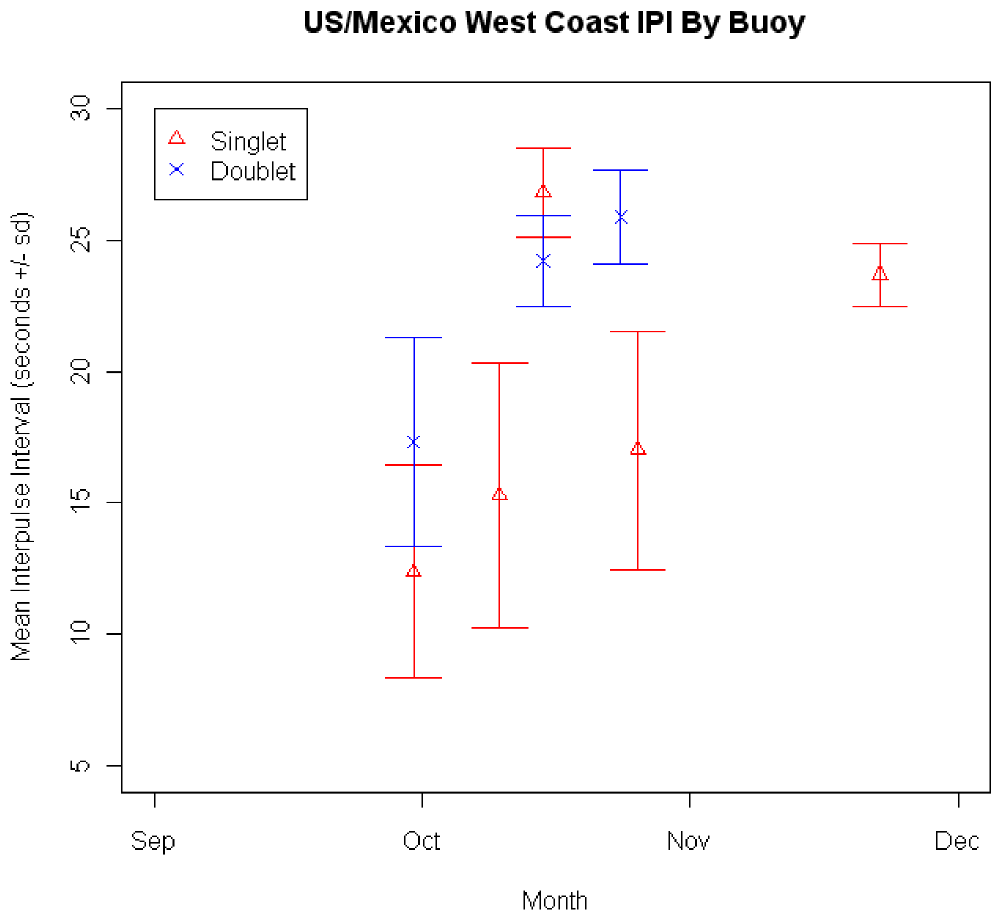

Figure 4: Mean and standard deviation of interpulse interval for singlet and doublet calls recorded on each buoy off the west coast of the United States and Mexico.

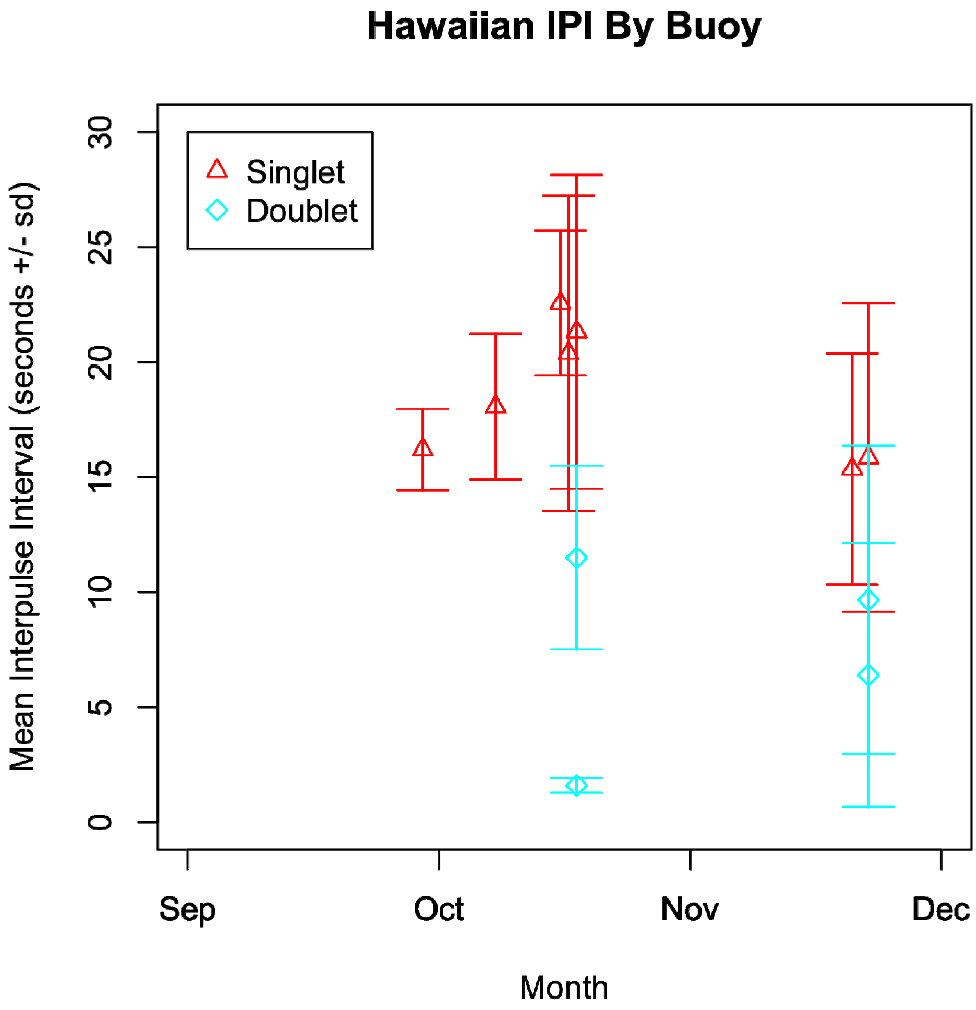

Figure 5: Mean and standard deviation of interpulse interval for singlet and doublet calls recorded on each buoy in Hawaiian waters.

APPENDIX I: GLOSSARY OF ACOUSTICS TERMS

Acoustic tag: A small package consisting of sensors that is attached directly to the animal. The sensors may include a hydrophone, recording system, depth sensor, velocimeter, or other sensors. Tags may also record behaviors, locations, and other variables. Tags may transmit data remotely or data may be retrieved with the tag itself (Johnson & Tyack 2003).

Aliasing: A process which causes spurious frequencies to appear in a spectrogram due to insufficient sampling rate. To avoid aliasing, a low pass filter must be applied to remove any sounds above the Nyquist frequency (Richardson *et al.* 1995).

Autonomous recording platform (ARP, Autonomous recording unit, ARU): A battery-operated, anchored device with a tethered hydrophone for long term recording. They are generally low frequency (less than 1 kHz) and may recording continuously or duty cycle for periods greater than 1 year (Wiggins 2003).

Backbeat: A slightly lower frequency (15-18 Hz), less common, and less intense pulse produced by fin whales (Clark *et al.* 2002, Hatch 2004).

Band-pass filter: A filter that allows only sound within a chosen range of frequencies to pass through (Richardson *et al.* 1995).

Deep sound channel (SOFAR channel): An area between 600m and 1200m depth that traps sound and thus eliminates propagation loss from surface and bottom reflections. The depth of the sound channel varies geographically. It allows for the transmission of sound across long distances (Richardson *et al.* 1995).

Duty cycle: The percentage of time an animal is producing sound and available for acoustic detection. Also, the percentage of time that an acoustic recorder is turned on (Mellinger & Clark 2003).

Gaps: Quiet periods between bouts of song that are longer in duration than rests. (Watkins *et al.* 1987).

Fast Fourier Transform (FFT): A method to more quickly calculate the discrete Fourier transform. In acoustics, it is used to extract the frequencies from a waveform representation of sound and generate a spectrogram. Time and frequency resolution are inversely related and are determined by the chosen sample size. Appendix B of the Canary 1.2 User's Manual (Carif *et al.* 1995) offers a good introduction to choosing these parameters (Cochran *et al.* 1967).

Frequency: The number of repeats per unit time. It is often expressed in hertz (Hz), waves per second (Holbrow *et al.* 2010).

High-pass filter: A filter that allows only sound above a certain frequency to pass through (Richardson *et al.* 1995).

Intensity: A measurement of the pressure level of sound. It is often expressed in the logarithmic decibel scale (dB) and proportional to the square of amplitude (Kuttruff 2007).

Intercall interval: The length of time between the same point on two successive vocalizations. For stereotyped fin whale calls, this may also be referred to as the interpulse interval (Watkins *et al.* 1987).

Low-pass filter (anti-aliasing filter): A filter that allows only sound below a certain frequency to pass through. A low-pass filter can be used to prevent aliasing; an anti-aliasing filter would be set to the Nyquist frequency (Richardson *et al.* 1995).

Nyquist frequency: The highest frequency that can be accurately represented in a digitized signal. It is equal to ½ of the sampling rate. (Carif *et al.* 1995)

Propagation (transmission): The characteristics of a wave as it travels. Underwater propagation may be impacted by the depth and other characteristics of the water, including: temperature, salinity, stratification of the water column, seafloor composition, etc. (Richardson *et al.* 1995).

Pulse: A short duration sound with little or no frequency modulation. For fin whales, individual fin whale sounds that may be components of longer pulse series (Watkins *et al.* 1987).

Pulse series (pulse trains, signal bouts, song): Repetitive fin whale pulses with stereotyped interpulse intervals (Watkins *et al.* 1987).

Rests: Quiet periods within bouts of song that are shorter in duration than gaps. In general, rests are of duration 1 to 20 minutes (Watkins *et al.* 1987).

Sampling rate: The number of measures of sound amplitude taken per unit time in a digitized file. For a discussion of digital vs. analog sound recordings, see Appendix A of the Canary 1.2 User's Manual (Carif *et al.* 1995). The sampling rate should be at least twice the frequency sounds of interest (for example, examination of a 100Hz sound requires at least a 200Hz sample rate, which should be combined with an anti-aliasing filter at the Nyquist frequency, 100 Hz) (Richardson *et al.* 1995).

Seismometer: A device designed to measure seismic activity. They may also be useful for recording biological noises below approximately 50Hz (Gaspá Rebull *et al.* 2006).

Sonobuoy: An expendable free-floating device that monitors and transmits acoustic information via a radio signal. The tethered hydrophone may be set to depths of up to 300m.These are designed for monitoring submarines and are particularly useful for low frequency sounds below 2000 Hz (McDonald 2004, Richardson *et al.* 1995).

Spectrogram: A depiction of sound with frequency as a function of time (Richardson *et al.* 1995).

Towed array: A set of one or more hydrophones that are towed behind a ship by and transmit acoustic information via a cable (Richardson *et al.* 1995).

Waveform: A depiction of sound with amplitude or strength as a function of time (Richardson *et al.* 1995).

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