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Changes in the use of a winter breeding area revealed by male humpback whale chorusing

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Approximately half of the north Pacific humpback whale (*Megaptera novaeangliae*) population migrates from high latitude feeding grounds to Hawaii each winter and spring to breed. Beginning in 2015, unusually low numbers of whales began to be reported in Hawaii and this trend continued through 2018. To examine this reported trend, data from bottom-moored acoustic recorders were analyzed for the period between 2014 and 2018 at three monitoring sites off Maui. Male humpback whale song chorusing was used as a proxy for relative whale presence and activity within and between years. Results show that averaged monthly root-mean-square sound pressure levels trended down more than 6 dB re 1 uPa over the monitoring period, suggesting that the number of singing males or the amount of time they spent singing decreased substantially over the four-year period. Further, the timing of the chorusing peak within the seasons shifted, suggesting that whales left the breeding area earlier than in past years. It remains unclear whether these observations reflect a decrease in population size or a behavioral response to an environmental stressor. However, the trend is consistent with a concurrent decline reported by other researchers in Hawaii linked with climatic anomalies in the eastern north Pacific.

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1. INTRODUCTION

Like most mysticete species, humpback whales (*Megaptera novaeangliae*) migrate from their high latitude summer feeding areas to breeding grounds at lower latitudes in the winter months. In the North Pacific, the primary breeding grounds for humpback whales are the Hawaiian Islands, where approximately half of the population migrates to breed. The Hawaii distinct population segment (DPS) of the North Pacific humpback whale population has been on a steady recovery trend for the past several decades after depletion from whaling. The last formal count of the DPS in 2008 estimated that approximately 10,000 whales use the Hawaiian Islands each year and that the population was growing at an annual rate of about 6% (Calambokidis et al. 2008). Based on this assessment and a review of humpback populations worldwide, in 2016 the National Oceanic and Atmospheric Administration (NOAA) issued a ruling delisting the Hawaiʻi DPS of humpback whales from its endangered status.

Coincident with the timing of the delisting ruling, reports began emerging of unusually low numbers of whales in Hawaii during in the 2015/16 breeding season. Since this time, the Hawaii DPS has exhibited substantial fluctuations in the number of whales observed annually on both the breeding grounds in Hawaii and the feeding grounds in Alaska (NOAA, 2019; Cartwright et al 2019). Here, results are presented from five years of acoustic monitoring between 2014 and 2018 off Maui, Hawaii examining the fluctuations in whale numbers that took place during this time. Humpback whales are ideally suited for acoustic monitoring because during the winter and spring months singing males become the dominant source of acoustic energy in the marine soundscape of Hawaii (Au et al, 2000). As more whales arrive and begin to sing, the chorus of their song raises ambient acoustic levels, which can be used to monitor the timing of the whales' arrival, their peak abundance and their departure from the area, and also to draw comparisons between breeding seasons.

2. METHODS

Beginning in 2014, passive acoustic monitoring was initiated in the west Maui region in Hawaii at three locations (Kahekili, mile marker 17 - MM17, and Olowalu) using bottom-moored Ecological Acoustic Recorders (EARs) (Fig. 1) as part of a project aimed at characterizing the soundscape of Maui's shallow water habitats. The EAR is a microprocessor-based autonomous recorder that samples the ambient sound field on a programmable duty cycle (Lammers et al. 2008). The EARs were programmed to sample at a rate of 25 kilohertz (kHz) for 30 seconds every 300 seconds (5 minutes), providing ~12.5 kHz of Nyquist bandwidth recording at a 10 percent duty cycle. This bandwidth and duty cycle is well suited to capture the singing of humpback whales (Au et al, 2000 & 2006). Two EARs were deployed at depths of 11.2 m (Kahekili and MM17) and one at 10.1 m (Olowalu). The EARs were recovered, refurbished, and re-deployed approximately every 6 months, or as logistics and weather conditions allowed.

The data recorded by EARs were processed using a custom Matlab program to calculate the root-mean-square sound pressure levels (RMS SPL) of the 0-1.5 kHz frequency band in each 30-second recording file as follows:

$$\text{RMS SPL} = 20\log\sqrt{\frac{1}{T}\int_0^T p^2(t)\mathrm{d}t}$$

Where T is the duration of each file (30s) and $p(t)$ is the pressure p re 1 μPa at time t. This approach uses the acoustic energy from the cumulative amount of singing as a relative metric of whale abundance (Au et al, 2000) under the assumptions that the amount of chorusing is proportional to the number of whales and the proportion of singing whales is population size-independent. Data were smoothed with a running average of n=10 for visualization using with the *TTR* package in R (R Core Team 2016).

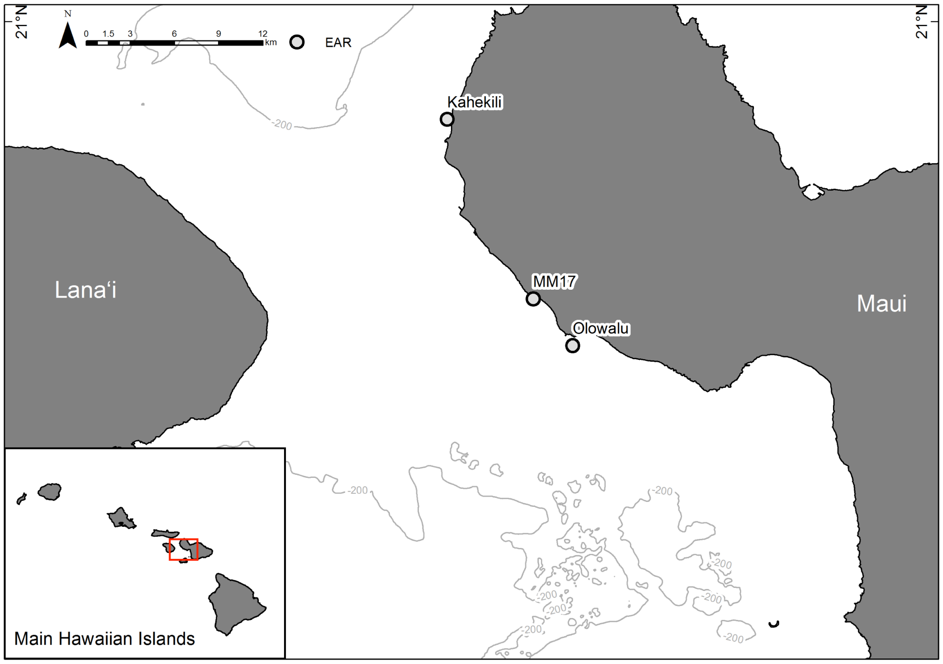

Figure 1. Map of the Maui study area showing the location of the three EAR monitoring locations at Kahekili, mile marker 17 (MM17) and Olowalu

3. RESULTS

Data were obtained during four consecutive whale breeding seasons (2014-2018) from two recording locations (Kahekili and Olowalu), but only for two breeding seasons (2014-2016) at the third site (MM17) due to malfunctions with the EAR in 2017 and 2018. At all three locations, chorusing levels began to increase in November, peaked between January and March, and decreased through April, closely matching the timing of humpback whale presence in Hawaii.

Chorusing levels exhibited a decling trend at all sites over the monitored years, with the highest levels recorded during the 2014/15 breeding season and the lowest levels during the 2017/18 season (Fig. 2). At Kahekili the maximal difference in levels between the 2014/15 and 2017/18 seasons ranged from 1.97 dB in November to 7.78 dB in March. Moreover, the peak of chorusing activity shifted from March to February over the four years. At MM17 inter-annual differences between the two monitored years ranged from 3.87 dB in January to 6.07 dB in April. In addition, a secondary peak in chorusing activity present during March of 2015 was absent in 2016. Finally, at Olowalu decreases in chorusing levels over the four years ranged between 2 dB during the month of November to 9.45 dB in March. Similar to Kahekili, the peak of chorusing activity gradually shifted earlier over the four years.

In addition to substantial decreases in chorusing levels during the peak of the breeding season, a decrease in the duration of the season was observed at all three locations during the four year period. Although little variation was observed at the start of the season, with chorusing levels consistently rising during December, there was notable variability in the timing of the season's end. Over the four years of monitoring at Kahekili and Olowalu, the main decline in chorusing gradually shifted from the month of April to the month of March.

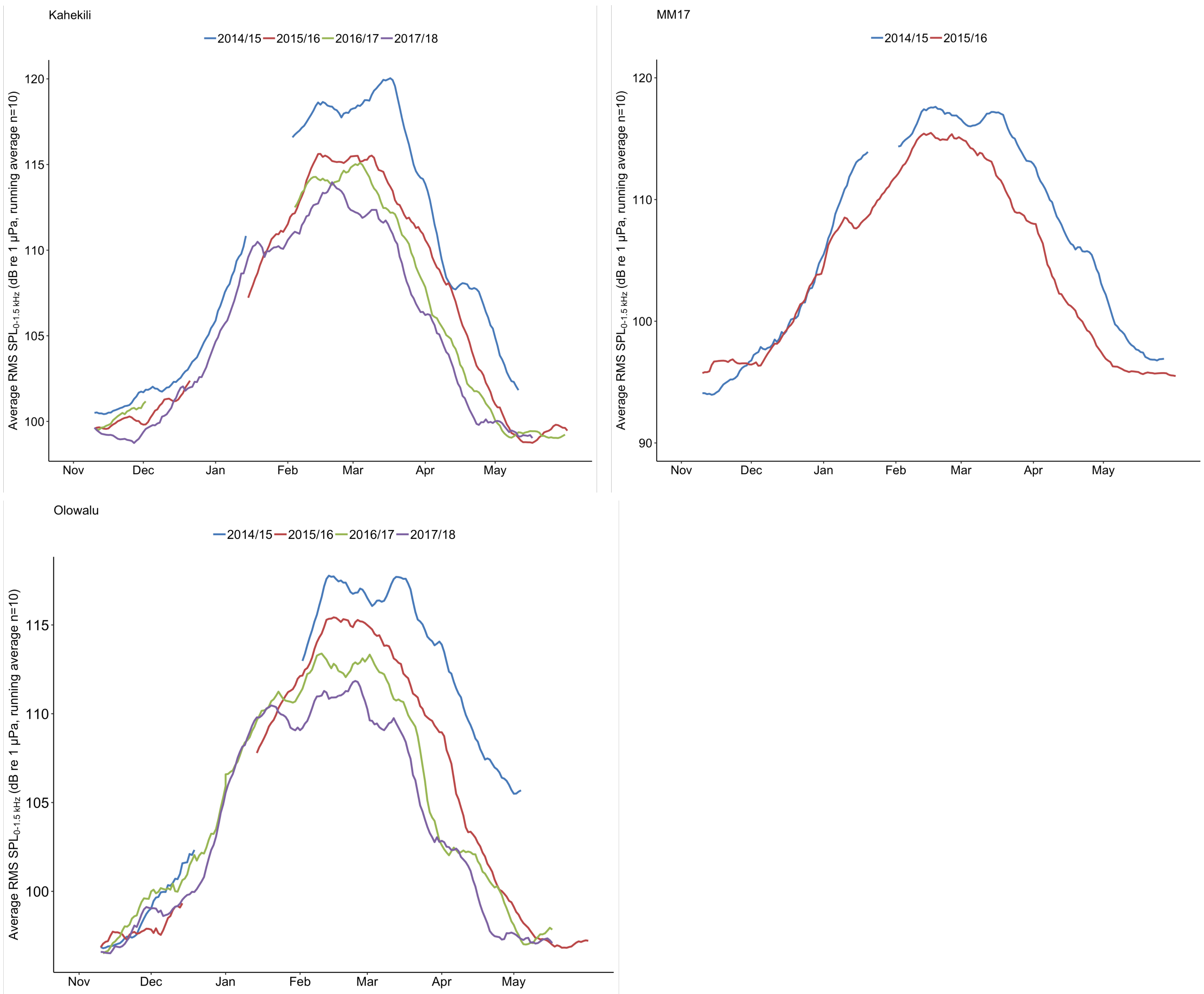

Figure 2. Daily root-mean-squared sound pressure levels (RMS SPL) in dB re 1 µPa in the 0-1.5 kHz frequency band, smoothed with a running average of n=10, between November, 1, and May, 30, for the three EAR recording sites off Maui, Hawai'i.

4. DISCUSSION AND CONCLUSION

Humpback whale chorusing levels off Maui exhibited a declining trend during the monitored period that was consistent with observations of reduced whale numbers reported by commercial operators, citizen science efforts and by other researchers during the same period (NOAA, 2019; Cartwright et al, 2019). The reduction in chorusing levels suggests the decrease in singing activity was substantial, considering that a 6 dB reduction represents a halving of the acoustic energy received and that a decrease of nearly 8 dB was observed over four years during the month of March at Olowalu. The acoustic data alone are not sufficient to draw firm conclusions about the actual reduction in whale numbers during the four-year period because changes in whale behavior could also have contributed to lower chorusing levels (e.g. fewer males choosing to sing or sing for less time). However, concurrent vessel and shore-based surveys conducted off Maui and Hawaii island during the 2015-18 period indicate that a reduction of

~50% or greater in whale abundance occurred during this time (NOAA, 2019), suggesting that the chorusing levels measured in decibels tracked whale abundance relatively well. Additional efforts to coordinate acoustic measurements with concurrent visual survey data will be required to more accurately define the relationship between male chorusing and total whale abundance.

The cause of the reduction in whale presence in Hawaii between 2015 and 2018 remains a topic of discussion. There is a general consensus that a combination of climatological factors played an important role (NOAA, 2019). Between 2014 and 2017 an oceanic heat wave, a strong El Niño and a warming period in the Pacific Decadal Oscillation cycle all contributed to unusually warm water in the northeast Pacific (Gentemann et al 2017). This led to changes in ocean circulation patterns, which affected nutrient availability and consequently primary productivity. These changes resulted in collapses at multiple trophic levels across the ecosystem, which likely affected humpback whales' feeding abilities. There is still uncertainty, however, about how this translated to the reduced presence of whales observed in Hawaii. It is unclear whether the lower whale numbers observed reflected a decrease in the population (i.e. a die-off), a shift in the distribution of whales (e.g. going to other breeding habitats), a change in migration patterns (skipped or shorter migration), or some combination of these.

The results presented provide additional empirical evidence that the Hawaii humpback whale DPS experienced unexpected changes in the population following its delisting in 2016. Continued monitoring will help reveal the extent and nature of these observed changes. Acoustic monitoring of whale singing activity is a promising, cost-effective method of tracking long-term patterns in the dynamics of the population. When expanded to additional parts of the archipelago, this method will likely provide additional insights regarding both the spatial and temporal distribution of whales as they adapt to a changing ocean.

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