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Humpback whale calls detected in tropical ocean basin between known Mexico and Hawaii breeding assemblies

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Abstract: Humpback whales migrate in winter from northern feeding grounds to geographically separate breeding assemblies in near-shore waters of Mexico and Hawaii. Currently assessed as distinct populations warranting separate management, their shared song composition and interchange of photo-identified whales question this paradigm. To investigate a potential connection an autonomous Wave Glider performed a 6965.5 km, 100-day (round trip) acoustic survey from Hawaii toward Mexico circa 20° N, from January 15 to April 25, 2018. The 2272 h of recordings included humpback whale calls to approximately midway from Hawaii to Mexico. Explanations include an undocumented migration route, offshore assembly, or mid-season travel between assemblies.

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[WJL]
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1. Introduction

Humpback whale behavior and distribution have been relatively well studied in near-shore locations but far less explored in deep ocean basins. North Pacific humpback whales summer in feeding grounds on continental shelves around the Pacific Rim from California to Japan, and, in winter, migrate southwards across deep seas to several traditional tropical breeding grounds—two of these are the Mexican mainland coast and offshore islands (Revillagigedo Islands), and the Hawaiian Islands (Rice, 1978; Calambokidis *et al.*, 2008).

The current U.S. National Marine Fisheries Service policy is that these winter breeding populations are functionally separate and represent distinct population segments (Bettridge *et al.*, 2015; Federal Register, 2016). This assessment is complicated by clear evidence of interaction between the populations. The complex, changing song is markedly similar in Hawaii and Mexico year to year—only possible through interaction (e.g., Payne and Guinee, 1983; Cerchio *et al.*, 2001), and photo-identification matches of individual whales show interchange between these assemblies (e.g., Darling and Jurasz, 1983; Calambokitis *et al.*, 2001; Forestell and Urban, 2007). The question arises as to whether the apparent winter isolation of the Hawaii and Mexico humpback whale populations is biologically significant, or simply a reflection of human perspective and accessibility.

Humpback whale males broadcast distinctive songs during the winter season as they migrate across oceans and assemble in subtropical breeding grounds (Payne and McVay, 1971). These calls, ubiquitous in any congregation of whales, are loud, ranging from 151 to 173 dB re. 1 μPa at 1 m with frequency range from 20 Hz to 24 kHz (Au *et al.*, 2006), providing a ready means of acoustic detection.

While remote acoustic monitoring systems moored near shore or on seamounts have become commonplace, their reach into deep ocean basins has been more limited (largely naval and seismic listening stations). This is changing with the development and proving of remotely controlled autonomous vehicles that actively survey deep-sea regions (Baumgartner *et al.*, 2013; Klinck *et al.*, 2015). The vehicle used in this study was a wave-powered Wave Glider (WG) (Liquid Robotics, a Boeing Company,

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Sunnyvale, CA) fitted with a hydrophone and sent out to sea between Hawaii and Mexico to record whale calls.

The purpose of this study was to determine if humpback whales were present in offshore tropical waters in the winter breeding season in addition to their traditional near-shore assemblies.

2. Methods

2.1 Platform, instrument package, and control

The WG consisted of a surfboard-sized surface platform (the float) tethered by an umbilical cable to a submerged glider (the sub) 8 m (26 ft) below the surface (Liquid Robotics, Inc., 2018; Goodoni *et al.*, 2018). The float included three solar panels, instrument package, surface and underwater cameras, and communications systems. A latest generation SV3 WG (command and control unit named Europa), was used in this study.

The hydrophone was an Ocean Sonics Ltd. (Truro Heights, NS, Canada) icListen SB2-Ethernet digital hydrophone (sampling rate range from 1 to 512 kHz; frequency response 10 Hz to 100 kHz ±3 dB; sensitivity of −171 dBV re: 1 μPa). It was mounted below the sub fuselage at minus 8.5 m (28 ft) (see Goodoni *et al.*, 2018). Recording (sampling rate of 32 kHz, 24 bit depth) was continuous in 1 min WAV files stored in two separate 4 TB solid state drives. Other data collection included surface and sub photographic images,[1] sea surface temperature, salinity, weather, speed, and location.

2.2 Analysis

Both raw and filtered audio files were analyzed. Files were filtered (in the lab) using a low-pass Chebyshev type I Infinite Impulse Response filter of order 8 and then followed up with a band stop filter to reduce glider rudder noise (produced at 325 Hz, with additional harmonics at 650, 975, and 1300 Hz). (See Bingham *et al.*, 2012 for more information on WG self-noise.) Recordings were examined via spectrographs and aurally with Raven Pro 1.5 software. The initial review of the data was performed manually by four Jupiter Foundation personnel (B.G., M.K.G., M.G.T., and A.J.T.) with a combined 24 years of experience with humpback whale song collection. Call detectors were not used as the quality (distance) of calls varied dramatically and this, combined with self-noise of the glider, made them ineffective (also see Baumgartner *et al.*, 2013; Klinck *et al.*, 2015). Likely humpback whale calls, with date, time. and location, were sent to J.D.D. (with 40 yr experience with humpback songs) to confirm identification, and compare with current Hawaii songs.

2.3 Survey

The route of Europa from departure January 16 to recovery April 25, a total of 100 days and 6965.5 km round trip, is illustrated in Fig. 1. The "circa 20° N latitude" survey ranged from 18.7° N to 23° N. The March 13 turnaround occurred over the Baja California Seamount Province at 53 days, 3266 km from South Point Hawaii, and 1274 km from Baja California, Mexico coast. The WG then retraced its outgoing route back to Hawaii. A total of 2272 h of sound recordings were collected. The speed of the survey, dependent upon wave size and current direction, ranged from approximately 2–4 km/h (1–2 knots) with average speed 2.7 km/h (1.5 knots) across the whole mission.

3. Results

Several thousand (estimate 4000+) cetacean calls were recorded over the 100-day survey. These, categorized as humpback whales, minke whales and unidentified cetaceans are summarized in the supplementary material.[2] The most common call was the distinctive minke whale "boing" identified on every day over the entire 6000+ km round trip from and to South Point, Hawaii.

Humpback whale calls were identified on 30 days from January 20 to February 23 as Europa headed east beyond South Point, Hawaii as illustrated in Fig. 1, with an example and details in the supplemental material.[2] That is, humpback calls were heard on all but 5 days between departure from Hawaii and February 23, 2184 km (1179 nm) east of Hawaii. On many days there were multiple detections (up to 377) over periods of hours (up to 23 of 24 h of a day) and over as many as 16 days running (January 20–February 4). A conservative count came to 2048 humpback whale call detections over the 30 days (see the supplementary material[2]). Since one whale can make many calls, the number of calls does not indicate the number of whales encountered.

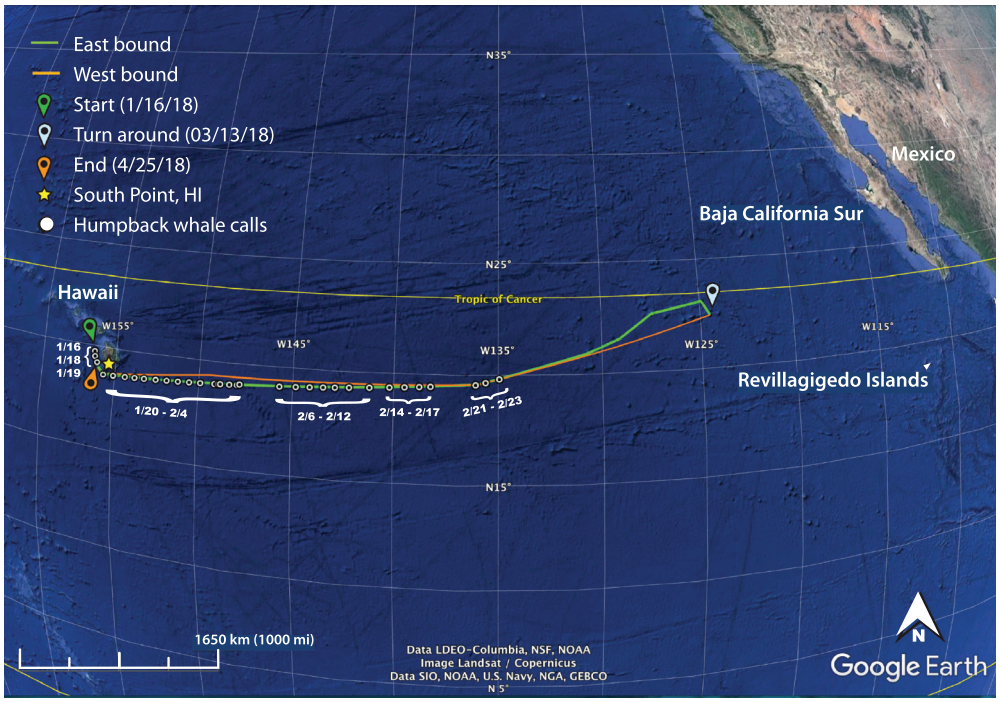

Fig. 1. The route of Europa between departure from Hawaii January 16 and return April 25, 2018. The outbound route is marked in green and the inbound in orange. Locations of humpback whales recorded are shown by white dots with corresponding dates. Unidentified cetacean calls further to east of the February 23 position [as indicated in the supplementary material (footnote 2)] likely included humpback whales too distant to identify with confidence.

The WG did not closely intersect a humpback whale singer, and a clear full song was not obtained. Therefore, all of the offshore (i.e., east of Hawaii into mid-ocean, Fig. 1) humpback whale calls were faint relative to any familiar close-up recording of song. The quality of recordings was offset with quantity: literally thousands of song fragments over multiple days, including a variety of individual units, harmonics of units, and repetitive single unit or multiple unit phrases.

We are confident these are humpback whale calls because, in general, the variety, complexity, frequency range, and repetition over hours and days was entirely consistent with humpback song and song session, and there are no other known cetacean calls in this latitude with which to confuse these collective identifiers. More specifically, calls recorded offshore were similar to units and patterns in current humpback songs from the Hawaii assembly. Examples are given in Fig. 2, with spectrograph comparison, notes, and measurements in the supplementary material.[2]

The purpose of the Fig. 2 comparisons is *not to prove* that each pair, Offshore and in Hawaii, is of the same specific pattern or call. In fact, they may well be the same, but there is clearly insufficient information in the faint calls for quantitative analyses and to be definitive. Its purpose is to show examples of the variety of calls and patterns recorded via Europa Offshore—and their similarity to generic humpback whale call characteristics, as well as to current Hawaii songs.

Humpback calls were not identified with confidence after February 23 through to the westernmost point of the survey on March 13 (Fig. 1). There were unidentified cetacean calls recorded after the February 23 date (see the supplementary material[2]) that could well have been humpback whales due to frequency range and contour, however, they lacked the clarity and/or repetitiveness necessary to declare them as such. The drop-off in identifiable humpback song coincided with a minor change in course northwards, at most 3.5° latitude or 389 km (210 nm) with no obvious change in sea surface temperature (average 24 °C before and after course shift). The return trip westbound re-surveyed the same locations where, 8 weeks earlier, humpback whales had been heard. Humpback whale calls were not identified on the later passage.

4. Discussion

To our knowledge, humpback whales have not been previously reported in these mid-ocean tropical latitudes between Mexico and Hawaii winter assemblies. Humpback whales were heard from Hawaii eastward at about 19° N, to near the halfway point to

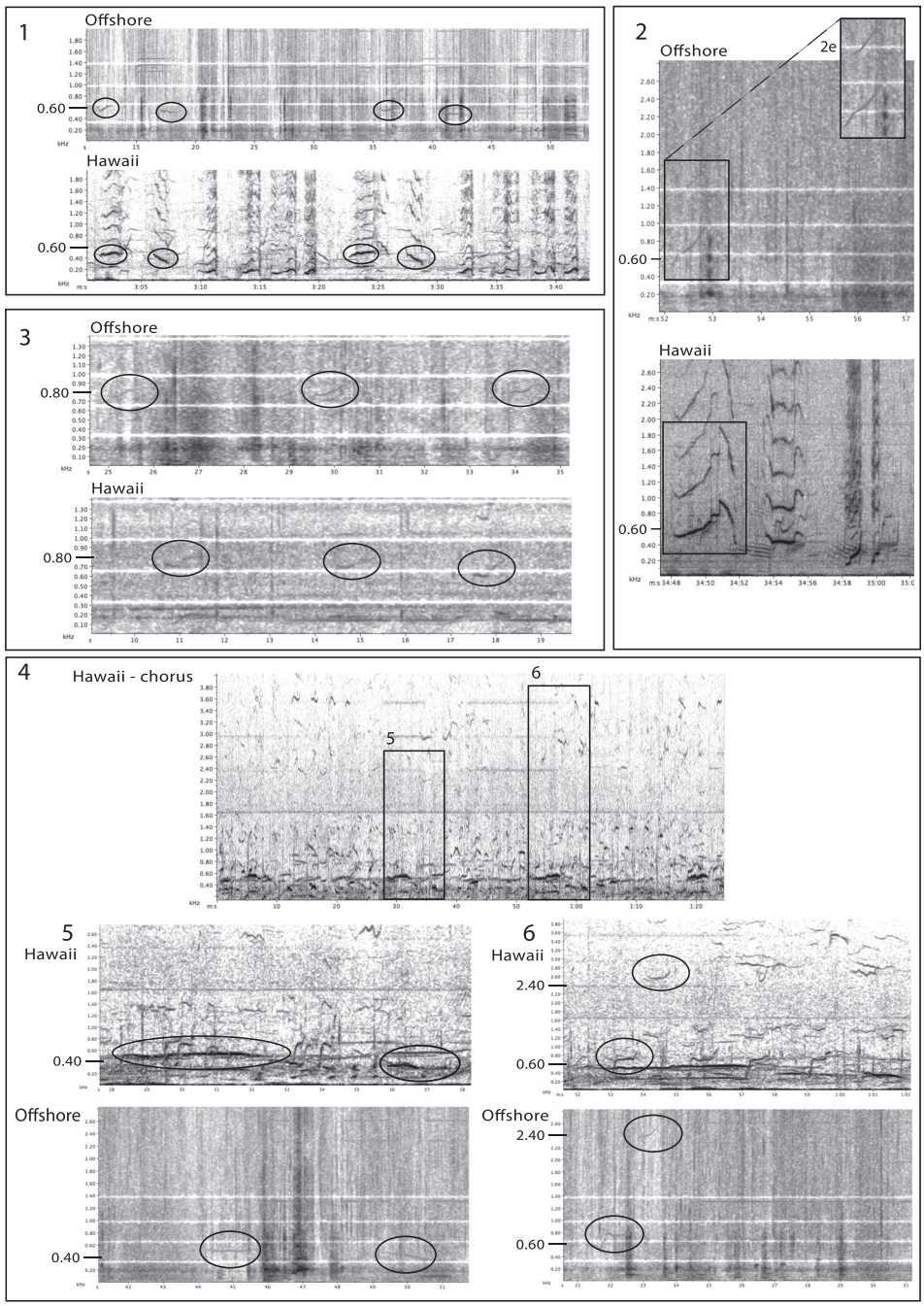

Fig. 2. Examples of humpback whale calls recorded from the Offshore Europa survey (as in Fig. 1) and Hawaii in 2018. Examples 1 and 2 are a comparison between close singers in Maui and distant songs Offshore (2e indicates photo-enhanced contour); example 3 is a comparison between recordings from Europa WG when in Hawaii among humpback whales and from Europa Offshore; example 4 first shows a distant chorus of humpback whales from Maui with the characteristic wide variety of calls, then followed by two zoomed-in comparisons (examples 5 and 6) with Europa Offshore recordings. The white bands are the result of filtered self-noise of the WG. (Spectrographs, all Hann window, 50% overlap, FFT/DFT: e.g., 1 Offshore 1024, HI 16 385; e.g., 2 Offshore 1042, HI 8192; e.g., 3 Offshore 2048, HI 1024; e.g., 4096; e.g., 5 Offshore 1024, HI 8192; e.g., 6 Offshore 1024, HI 4096).

Mexico (2184 km of approximately 4300 km to Revillagigedo Islands or 4700 km to the Baja Peninsula). Some calls heard over another 18 days eastbound may have been humpbacks, but could not be declared so with confidence, hence whether their distribution continued further east is an open question.

The position of Europa represented the approximate location of the calling whales. An exact measure of the distance the whale was from Europa is difficult to determine due to varying sound source levels, depths emitted, immediate oceanography, and competing background noise levels (ambient and self-noise). An estimate based on source levels of humpback whales, 151–173 dB re. 1 μPa at 1 m (Au *et al.*, 2006), and presuming the calls were made at a typical shallow singer depth (<30 m),

indicated detectable distance could range from 5.5–126 km (3–68 nm), the latter high distance only applicable if acoustic propagation conditions supported a first or second convergence zone.

There are two explanations for not hearing a full song during the 30 days of humpback whale call detections. The first is that full song cycles were produced by the whales but only fragments heard due to a combination of distance and noise. This was the initial assumption considering typical song cycles are common during migrations and winter assemblies. The second is that the whales were not actually producing the full cyclical song; just uttering components of it—the fragments recorded. If this is the case it could be a hint of a different function of the calls in this offshore circumstance.

Possible explanations for this presence of humpback whales in tropical mid-ocean during breeding season include the following.

The survey came across aberrant or atypical behavior, that is a small number of whales doing something out of the ordinary and hence not of population-scale significance. The time frame and geographic range of encounters (30 days of call recordings over 2184 km) seems to lessen this possibility—however it cannot be ruled out.

The survey route may have intersected an undocumented migration corridor from northern feeding grounds to Hawaii. If so, it would indicate whales first traveled directly southwards until they reached the ~20° N, Hawaii–Mexico latitudes, then made a turn to the west on a course to Hawaii. This would run counter to the current picture of North Pacific migration routes determined by satellite tags that suggests most are, more or less, straight-line (shortest distance) courses from feeding ground departure to winter destination (Mate *et al.*, 2007). On the other hand, intriguing in the context of this paper, are two clusters of humpback song detections made in March–April 1997, in the mid northeast Pacific 900–1000 km off the coast of California (30° N, 130° W and 36° N, 134° W) (Norris *et al.*, 1999). These are 1110–1776 km further north, but later in season, and near directly "above" the eastern-most detections (134° W) in this survey.

These detections could represent an offshore winter assembly of humpback whales separate from, but largely analogous to, those that occur in nearshore Mexico or Hawaii waters. To date, all humpback winter assemblies globally are characterized by (1) shallow banks (<200 m) relative to surrounding deep seas, and (2) a sea water temperature range of 21.1 °C–28.3 °C (Rasmussen *et al.*, 2007). Europa's survey route met the temperature characteristics (21 °C–27 °C, Mean 24 °C), so the question which arises in this explanation is on the necessity of shallow water to humpback whale breeding activities. While shallowness is presumed to play a role in nurturing/survival of young humpback whale calves, it may not be necessary for adult mating related activities. A winter migration may occur without any nearshore appearance of the whales.

Another possible explanation is that humpback whales travel between the known Mexican and Hawaiian assemblies within the same winter. Mixing of males in the same season would be the simplest (although not the only) explanation for shared song composition between these populations. In addition, while there are multiple records of individuals photo-identified in both Mexico and Hawaii in different years (e.g., Darling and Jurasz 1983; Calambokidis *et al.*, 2001), there also exists a single report of a whale identified in both locations within the same winter, which, if accurate,[3] would add weight to this potential explanation. The whale was reported photo-identified on February 5, 1986 in the Revillagigedo Archipelago, Mexico and 51 days later on March 28 and 29, 1986 off Kauai, Hawaii (Forestall and Urban, 2007).

This survey indicates that humpback whales were present in offshore tropical waters during the winter breeding season at the same latitudes as the traditional nearshore assemblies. Observations as they stand complicate assessments of humpback whale abundance and behavior in the northeast Pacific. Two of the possible explanations, an offshore assembly or within-winter travel between two traditional assemblies, would have significant implications to current management tenets.

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[1]Time-lapse series of images from the two Europa cameras, surface and underwater, are accessible on the website blog: http://jupiterfoundation.org/current (as of June 2019).

[2]See supplementary materials at https://doi.org/10.1121/1.5111970 for (1) summary of calls detected categorized as humpback whale, minke whale or unidentified cetacean, and spectrograph example of humpback and minke whale calls, (2) details on locations and duration of humpback whale detections, and (3) detail: comparison of offshore Europa humpback calls with current Hawaii song.

[3]This is clearly a match between Mexico and Hawaii, and a whale was seen in Mexico in 1986; however, an effort to verify the year of the March identification in Hawaii by the National Marine Mammal Laboratory in Seattle, who initially found the match, was not successful. Note that this match was published 21 years after it occurred, and with extensive ID matching since no further evidence of within season interchange has been discovered.

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