Comparison of High-frequency Echolocation Clicks (likely *Kogia*) in Two Simultaneously Collected Passive Acoustic Data Sets Sampled at 200 kHz and 320 kHz

Karlina P. Merkens
Erin M. Oleson

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Fisheries Science Center

NOAA Technical Memorandum NMFS-PIFSC-74
https://doi.org/10.25923/jjss-er34

September 2018

Comparison of High-frequency Echolocation Clicks (likely *Kogia*) in Two Simultaneously Collected Passive Acoustic Data Sets Sampled at 200 kHz and 320 kHz

Karlina P. Merkens
Erin M. Oleson

Pacific Islands Fisheries Science Center
National Marine Fisheries Service
1845 Wasp Boulevard
Honolulu, HI 96818

NOAA Technical Memorandum NMFS-PIFSC-74

September 2018

U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Oceanic and Atmospheric Administration
RDML Tim Gallaudet, Ph.D., USN Ret., Acting NOAA Administrator

National Marine Fisheries Service
Chris Oliver, Assistant Administrator for Fisheries

Recommended citation:

Merkens KP, Oleson EM. 2018. Comparison of high-frequency echolocation clicks (likely Kogia) in two simultaneously collected passive acoustic data sets sampled at 200 kHz and 320 kHz. NOAA Tech Memo. NMFS-PIFSC-74, 21 p. doi:10.25923/jjss-er34.

Copies of this report are available from:

Science Operations Division
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

Or online at:

https://www.pifsc.noaa.gov/library/

Contents

Abstract

Several species of odontocetes, including those in the genus *Kogia*, produce high-frequency (> 100 kHz) echolocation clicks. To compare the detection performance of High-frequency Acoustic Recording Packages (HARPs) for these signals, two instruments were deployed simultaneously on the same mooring off the Kona coast of the Island of Hawai'i. One instrument sampled at 200 kHz, while the other sampled at 320 kHz. The instrument sampling at 320 kHz recorded the full frequency content of high-frequency clicks and formed the basis for a comparison of relative click detection rates in the data sampled at 200 kHz, where clicks were aliased and truncated at the Nyquist frequency of 100 kHz. We compared a variety of detection metrics, including the number of high-frequency clicks, the number of encounters including high-frequency clicks, and the number of days with high-frequency click detections within each data set. This comparison revealed that the 200 kHz sampled data set contained 69% of the high-frequency click encounters relative to the 320 kHz sampled data set, representing 89% of days with high-frequency click detections. The vast majority of long-term passive acoustic data sets collected as part of the Pacific Islands Passive Acoustic Network are sampled at 200 kHz and this comparison suggests that measures of high-frequency click occurrence at the scale of days or longer are likely unbiased. Researchers should be cautious using 200 kHz sampled data to infer fine-scale (e.g. hourly) occurrence, as such measures are more likely to be biased by other factors that may influence high-frequency click detection on a similar scale.

Introduction

The Pacific Islands Fisheries Science Center has been conducting long-term passive acoustic monitoring of cetaceans at 13 sites around the central and western North Pacific Ocean since 2005 as part of the Pacific Islands Passive Acoustic Network (PIPAN). Calibrated High-frequency Acoustic Recording Packages (HARPs; Wiggins & Hildebrand 2007) have been used at all PIPAN sites since the Network's inception allowing for direct comparison of data sets within and across the Network. PIPAN includes a location off the Kona coast of Hawai'i Island since 2007. This region has been identified as a Biologically Important Area for several species, including an island-associated population of dwarf sperm whales (*Kogia sima*; Baird et al. 2013; Baird et al. 2015). The majority of recordings within PIPAN have been collected at a 200 kHz acoustic sampling rate. Although recording at a 200 kHz sampling rate captures the signals of most cetacean species, this bandwidth is insufficient to describe the full extent of all sounds produced by all species, and is not expected to effectively record the sounds of the highest frequency sound producers, such as those of the genus *Kogia* (Madsen et al. 2005; Merkens et al. 2018).

Narrow band high-frequency (NBHF) clicks have been recorded in the presence of pygmy (*K. breviceps*; Madsen et al. 2005) and dwarf sperm whales (Merkens et al. 2018) at several locations worldwide. These previous studies found that clicks from the two species have a peak frequency above 110 kHz and very little energy extending below 100 kHz. Additionally, the authors found that individual clicks have a fairly long duration (100–300 μs) with many cycles per click (~ 10–20), and they showed that the interclick-interval is generally around 200 ms, but is widely spread from 50–500 ms (Madsen et al. 2005; Merkens et al. 2018). No notable frequency sweep has previously been reported. NBHF clicks have been detected within the PIPAN data sets from Kona when the site was occupied by a HARP sampling at 320 kHz. Such deployments are rare, as they are accompanied by shorter monitoring periods due to battery and disk limitations. A 200 kHz sampling rate is not high enough to record NBHF clicks; however, we have observed clicks with energy entirely above 90 kHz that appear cut-off at the system Nyquist of 100 kHz, suggesting the frequency content of these clicks extends to higher frequencies. Additionally, similar clicks with energy starting as low as 90 kHz have not been observed in the 320 kHz data set, suggesting some aliasing effect of higher frequency energy. Although they are not a perfect match to the sounds produced by *Kogia*, no other cetacean species known to occur within Hawaiian waters produces echolocation clicks at such high-frequency. We hypothesize that the high-frequency, incomplete clicks observed within the 200 kHz data set are from *Kogia*, with detection below the Nyquist resulting from aliasing and other frequency warping within the 200 kHz HARP systems. Although detection of *Kogia* using such distorted clicks may preclude use of these data to understand certain aspects of the clicks themselves, the occurrence of *Kogia* clicks in the lower frequency data set would enable examination of *Kogia* occurrence much more broadly, both temporally and geographically within the PIPAN data set.

To examine the relationship between NBHF clicks detected in the 320 kHz data, and the highest-frequency clicks detected in the 200 kHz data, we deployed a single mooring containing both systems at our usual Kona monitoring site and compare the timing and characteristics of click detection across the simultaneously sampled data sets. This report seeks to address two questions using those data:

1. Are the high-frequency clicks seen within the 200 kHz data consistent with NBHF clicks?
2. If so, how does the detection rate of NBHF clicks in 200 kHz sampling rate data compare with recordings made at a higher sampling rate?

Methods

We deployed two HARPs on the same mooring off the Kona coast of Hawai'i Island, with hydrophones at a depth of 665 m (Figure 1). Both instruments included two-stage hydrophones (see Wiggins & Hildebrand 2007). In one HARP (v 2.84), configured for a 200-kHz acoustic sample rate ("200 data"), the high-frequency hydrophone was an ITC-1042[1] , a spherical, omni-directional transducer with a near flat frequency response from 10 kHz to 100 kHz (– 202 ± 2dB dB rms re V/µPa). The other HARP (v 2.6), configured for 320-kHz sampling ("320 data"), used a spherical HS-150[2] sensor as the high-frequency hydrophone, with frequency response peak at 70 kHz of –202 ± 4 dB rms re V/µPa. Both hydrophones were calibrated at the U.S. Navy's Transducer Evaluation Center (TRANSDEC) in San Diego, CA. In both instruments the signal from the hydrophone was passed to a preamplifier providing approximately 50 dB of gain, and through an 11-pole low-pass/anti-alias filter, before being digitized with 16 bits of resolution.

To assess the relative detection rate of high-frequency clicks detection within the 200 and 320 data sets, two detection methods were employed. First, a trained analyst (KPM) used MATLAB (2013, Mathworks, Natick, MA) and the custom software *Triton* (version triton-logger-2014-05-19) to manually examine 0.5-h sections of long-term spectral averages (LTSAs, Wiggins and Hildebrand 2007) overlapping by 0.25 h to ensure thorough checking of the entire data set. The analyst identified the start and end of click "encounters" in both data sets. Each encounter was defined as a set of two or more clicks that could be easily identified as high-frequency clicks, separated from other high-frequency clicks by no more than 3 min. The detections were compared to determine how many encounters, hours with clicks, and days with clicks were missed by only looking at the 200 data vs. the 320 data, and by only looking at human detections vs. the automated detections.

[1] www.itc-transducers.com
[2] www.humbertek.co.uk

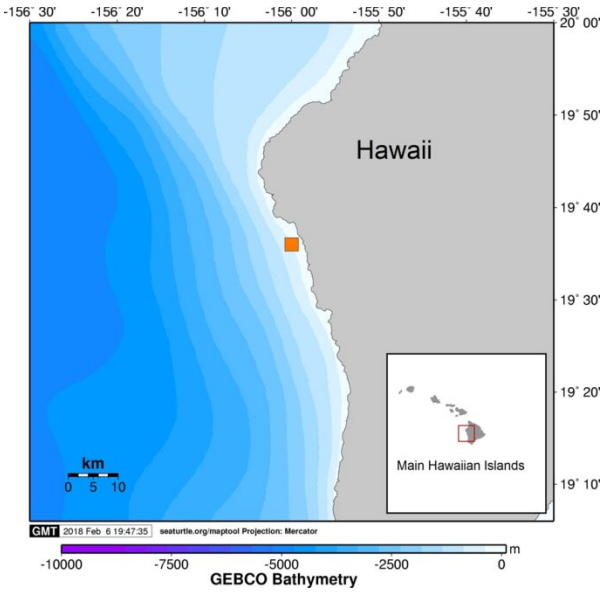

Figure 1. Map of location of HARP deployment (orange square) off the Kona coast of the big island of Hawai'i. Water depth is shown in blue scale.

Automated click-detection methods are often preferred for examining large data sets, as they save time and effort and provide more consistent results compared to manual data examination. As such, the second detection approach used a two-stage, custom MATLAB-based automated click detector based on Soldevilla et al. (2008), Roch et al. (2011) and Baumann-Pickering et al. (2013).[3] The detector identified individual clicks that met predetermined criteria (including thresholds for click energy, peak frequency, and click duration) based on the characteristics of clicks from recordings of *Kogia* from other locations. The settings were then manually optimized for the 320 data by iteratively adjusting thresholds for those criteria to ensure that as many as possible of the encounters found by the human analyst were also identified by the automated detector. Even with loosely constrained thresholds for the click energy, frequency, and duration criteria there were relatively few false positives, thus, the thresholds could be set generously to minimize the chance of missed detections. In the 200 data the characteristics of high-frequency clicks were more difficult to isolate from the sounds produced by more common beaked whales or delphinids, as well as vessels, and echosounders, so it was much more difficult to automatically exclude false positives from the detector output. Therefore we optimized the detector for two scenarios, and ran each version separately: first, to detect as many of the manual encounters as possible, which required time-intensive hand-culling of many false positive detections, and second, to ensure detection of NBHF signals on a daily scale, thereby limiting the number of false positives, but also missing a portion of the individual encounters.

To compare the characteristics of the high-frequency clicks observed in the 200 and 320 data sets, the automated detector was used to extract the parameters of the clicks that were present during the manually identified encounters. After all false positives were removed from the initial detector output, the detector was run only between encounter start and end times to extract individual clicks from each of those encounters. The settings of the detector could be adjusted to

[3] Archived code is available at http://doi.org/10.5281/zenodo.164881.

be highly sensitive because only high-frequency clicks should be present during these specified encounter times. This highly-sensitive detector was run over both data sets to allow general comparison between the characteristics of clicks in both data sets.

Many HARP data sets within PIPAN are duty-cycled to provide longer periods of recording between instrument servicing. To examine the impact of such duty cycling on high-frequency click detections, we simulated a variety of duty cycles within the continuous data set. Most HARP data sets record for a minimum of 5 min before turning off for a specified period. We imposed duty cycles including 5 min of recording followed by off periods of 1, 2, 3, 5, 7, 10, 15, 20, 25, 30, and 35 min, which are duty-cycles currently represented in individual deployments within the broad PIPAN data set. We then iterated through all possible start times and measured the mean number of 5-min sampling cycles that contained high-frequency click encounters that would have been completely missed.

Data Collection

The mooring containing both 200 and 320 systems was deployed on 3 July 2016, and recovered on 13 September 2016. The data from both instruments had no notable gaps in recording, damaged data or otherwise unusable data. The 200 data spanned 71 days, from 4 July 2016, to 13 September 2016; while the 320 data spanned 45 days, from 4 July 2016, to 18 August 2016. This analysis includes the data from the time period when both instruments were recording, 4 July 2016, to 18 August 2016.

Detection Rates

Manual analysis of the 320 data resulted in 54 true encounters of NBHF clicks (Tables 1 A & B). These encounters lasted from 2 s to 28 min, with median duration of 4 min. The automated detector identified 73 true encounters, of which 20 were missed by the human analyst (human recall = 0.74). The human analyst found an additional detection, resulting in 1.3% of detections missed by the automated detector. When NBHF encounters were aggregated into hourly bins, there were 47 h with clicks identified by the automated detector, of which 8 h were missed by the human analyst (human recall = 0.83). Similar aggregation by day, resulted in 19 days with NBHF click encounters, of which two were missed by the human (human recall = 0.89). The detections missed by the human analyst were primarily groups of very low amplitude clicks that were not readily apparent in the LTSA. The automated detector was both efficient, producing relatively few false positives (30 false-positive encounters), and effective, identifying more encounters, and therefore hours and days with clicks, than the human analyst. The amount of time required of the human analyst was roughly the same for both methods (~ 4 h), with the detector taking 1–2 h for optimization and 1–2 h for output verification, and the detailed human analysis requiring ~ 4 h total.

Table 1. Performance by detection method (A), and comparison of detection performance (B). Note: the 320 automated detector missed 1 encounter that was found by the human analyst (~ 1%) (no unique hours or days missed).

(A) Detection Method

Data set	320 (human)	320 (auto)	200 (human)	200 (auto - optimized for encounters)	200 (auto - optimized for days)
Total encounters	54	73	36	46	27
Unique hours	39	47	31	35	24
Unique days	17	19	14	16	13

(B) Comparison among Methods (recall by *)

Data set	200 (human)* vs 320 (human)	320 (human)* vs 320 (auto)	200 (human)* vs 200 (auto - optimized for encounters)	200 (auto - optimized for days)* vs 200 (human)
Total encounters	0.67	0.74	0.78	0.75
Unique hours	0.79	0.83	0.89	0.77
Unique days	0.82	0.89	0.88	0.93

Manual analysis of the 200 data resulted in 36 encounters. The detector optimized to identify the maximum number of manual encounters found many total encounter detections (958) of which most (911) were false positives. This detector performed better than the human analyst overall, but required a large amount of time by the human analyst to verify the detector output. It identified 47 encounters, and although it missed two of the encounters found by the human analyst, it identified nine encounters that the human missed (human recall 0.78). On an hourly scale, this detector identified 35 h with clicks, 4 of which were missed by the human (human recall 0.89), and on a daily scale it found clicks on 16 days, 3 of which were missed by the human analyst, but it missed 1 day in which the human found clicks (human recall 0.88). In contrast to the more detailed detector described above, the detector optimized for identifying the maximum number of unique days while minimizing the number of false positives in the 200 data performed worse than the human analyst. This detector identified 110 total detections with 84 false positives, which required significantly less time by the human for verification. Compared to the human this detector missed 9 encounters (detector recall 0.75), 7 unique hours (detector

recall 0.77) and 1 unique day (detector recall 0.93). Because there were so few days with detections overall (14), missing just 1 day reduced the recall notably; however, adjusting the detector thresholds to include that additional day greatly increased the number of false positives, significantly increasing the time required to verify the detector output, and reducing the usefulness of this detector version.

Comparison of the timing of the manual and automated detections between the 200 and 320 data sets confirmed that the Nyquist-truncated, high-frequency clicks in the 200 data are the same as the NBHF clicks found in the 320 data. An example encounter found in both data sets is shown in Figure 2. Further examination of manual and automated detector performance between the two data sets indicates that while NBHF clicks can be identified within the 200 data, the lower-frequency sampling rate does preclude recording and detection of all encounters within the detection distance of the recorder. Comparison of the manual detections between data sets revealed that 18 encounters found in the 320 data were not identified in the 200 data (recall 0.67, Table 1). An example of a missed encounter is shown in Figure 3. Five of these missed encounters were masked (four by high amplitude delphinid clicks and one by high amplitude echosounder/anthropogenic noise). The majority of the missed encounters were generally low amplitude, with little-to-no energy below 100 kHz in the 320 data. All encounters manually identified in the 200 data were also identified within the 320 data. Comparison of the automated detection rate between the 200 and 320 data sets followed a similar pattern, with more detections in the 320 data. The 200 data contained 26 fewer encounters (recall 0.65), and when those encounters were aggregated, represented 2 fewer days, and 11 fewer hours. The miss rate between the manual and automated detection methods are very similar (Table 1).

The alignment of high-frequency click encounters between the 200 and 320 data sets and the relatively high detection rate within the 200 data set suggests that a HARP sampling at 200 kHz may be sufficient for monitoring the occurrence of high-frequency clicks at sites where such clicks are fairly regular and abundant. However, the miss rate does suggest that caution is warranted, and significant bias may occur if the frequency response characteristics of the HARP reduce detection at the highest frequencies, or if detections are rare. Neither a human analyst nor an automated detector resulted in complete assessment of all high-frequency click periods; however, the automated detector performance was superior, locating periods of high-frequency clicking among masking noise. The relationship between the number of detections in 320 kHz and 200 kHz data set may not be as consistent at other sites.

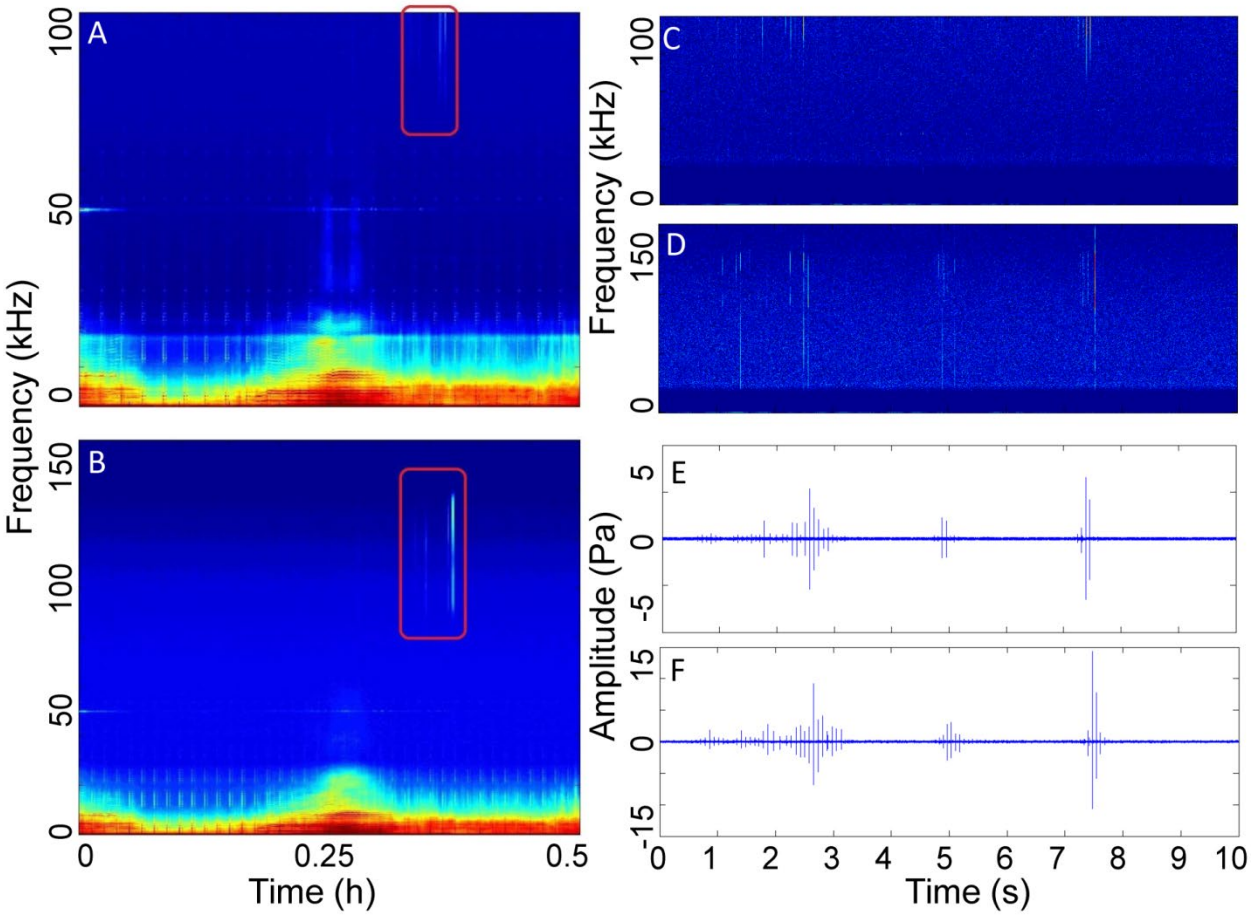

Figure 2. Example high-frequency encounter detected in both data sets. The 200 data is displayed in an LTSA (A), spectrogram (C) and time series (E), and 320 data is also displayed in an LTSA (B), spectrogram (D) and time series (F). In the LTSAs (A, B) and spectrograms (C, D) color denotes intensity. A red box surrounds the encounter in both LTSAs (A, B). Spectrograms (C, D) and time series (E, F) show the same 10 s example.

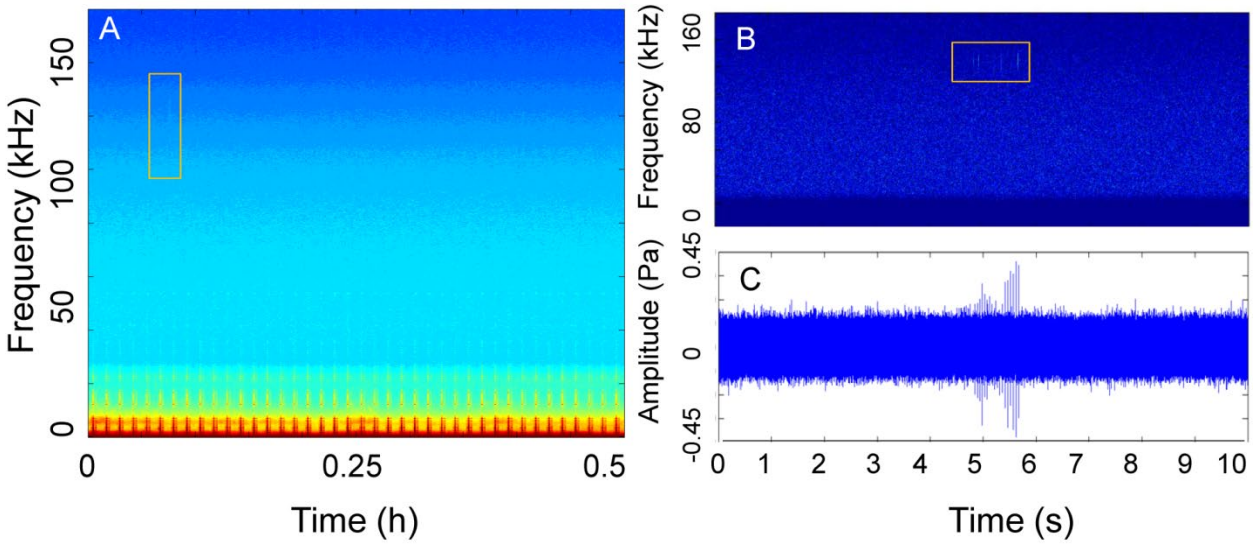

Figure 3. Example high-frequency encounter that was only detected in the data sampled at 320 kHz, including LTSA (A), spectrogram (B) and time series (C). Low amplitude clicks present inside yellow boxes in LTSA (A) and spectrogram (B) and between 4.5 and 6 seconds in each time series (C).

Click Characteristics

Individual click characteristics were measured from the output of the detector, which was run only during the previously identified encounters (Table 2). Click duration and inter-click interval were measured for clicks detected within both data sets. Peak frequency and – 3 and – 10 dB bandwidths were measured for high-frequency clicks in the 320 data sets. Such measures were not possible in the 200 data because the spectra were truncated at higher frequencies (before the level of – 3 or – 10 dB). The peak frequency was measured for the 200 data for informational purposes only, and should not be directly compared to the full bandwidth 320 data because the signal was clearly truncated at the Nyquist frequency. These values measured from each data set were generally similar between data sets, but with very broad distributions. The mean click duration and inter-click intervals are within the ranges of previously documented non-HARP recordings of *K. sima* and *K. breviceps* (Table 2, Madsen et al. 2005; Merkens et al. 2018).

We used the output from the detector to explore whether click amplitude was a predictor for detection within the 200 kHz data set. The minimum, mean, median and maximum click amplitudes for encounters present in both the 200 and 320 data set were similar to those for encounters that were only present in the 320 data. Thus, although it seems logical that very low amplitude clicks are less likely to be present in the 200 data, the summary statistics on click amplitude for each encounter cannot be used as a simple way of identifying which will be detected in the 320 data.

Table 2. Comparison of click characteristics based on automated detector output, presented as mean (± standard deviation). *K. breviceps* recording of captive animal from Western North Atlantic Ocean (Madsen et al. 2005). *K. sima* recording of free-ranging

animals from Guam, Western North Pacific Ocean (Merkens et al. 2018). NA = not available because data were not full bandwidth (200).

Data set	200	320	K. breviceps (Madsen et al. 2005)	K. sima (Merkens et al. 2018)
95% click duration (µs)	221 (± 62)	138 (± 31)	119 (± 19)	186 (± 62)
Inter-click interval (ms)	111 (± 82)	99 (± 80)	40-70 (± NA)	110 (± 73)
Peak frequency (kHz)	NA	119 (± 9)	130 (± 1)	127 (± 2)
–3 dB bandwidth (kHz)	NA	23 (± 7)	8 (± 2)	10 (± 3)
–10 dB bandwidth (kHz)	NA	44 (± 14)	15 (± 3)	17 (± 7)

Impact of Duty-Cycling

Duty cycles with off-periods of 5 min or longer resulted in missing on average at least 50% of encounters in both data sets (Figure 4). Duty cycles with the longest off-period (35 min) meant missing a mean of 80% of encounters in both data sets, resulting in significant under-representation of mean high-frequency click occurrence on mean daily (35% missed for 320 data and 50% for 200 data) and mean hourly (50% missed for 320 data and 60% for 200 data) scales. This information can be used to apply a correction factor to detection rates at this recording site, or other sites with similar encounter rates.

Lower-frequency Clicks

Two encounters in the 200 data included typical high-frequency clicks interspersed with other clicks that had energy centered at 80–90 kHz but that did not extend up to 100 kHz (Figure 5). The corresponding 320 data showed typical high-frequency clicks but no clicks with energy entirely below 100 kHz. However, a "buzz-like" burst pulse (a series of rapid clicks, with a much shorter ICI than the majority of other clicks) in the 320 data, corresponded exactly in time with a burst pulse of 80–90 kHz clicks in the 200 data (Figures 5 C–F). It appears that the energy from these burst pulse clicks was somehow shifted to lower frequencies or aliased as part of recording and/or signal processing. These lower frequency clicks have been observed during encounters with other very high-frequency clicks in other 200 kHz sampling rate HARP recordings (e.g. Hodge 2011). Based on comparison of the clicks in the current data sets, it appears that when these clicks (with energy centered at frequencies above 70 kHz, but not extending to 100 kHz) are observed in the 200 data as part of a larger, more typical, encounter with only high-frequency clicks (i.e. no clicks from other species), those clicks can reasonably be assumed to be part of the larger high-frequency click encounter.

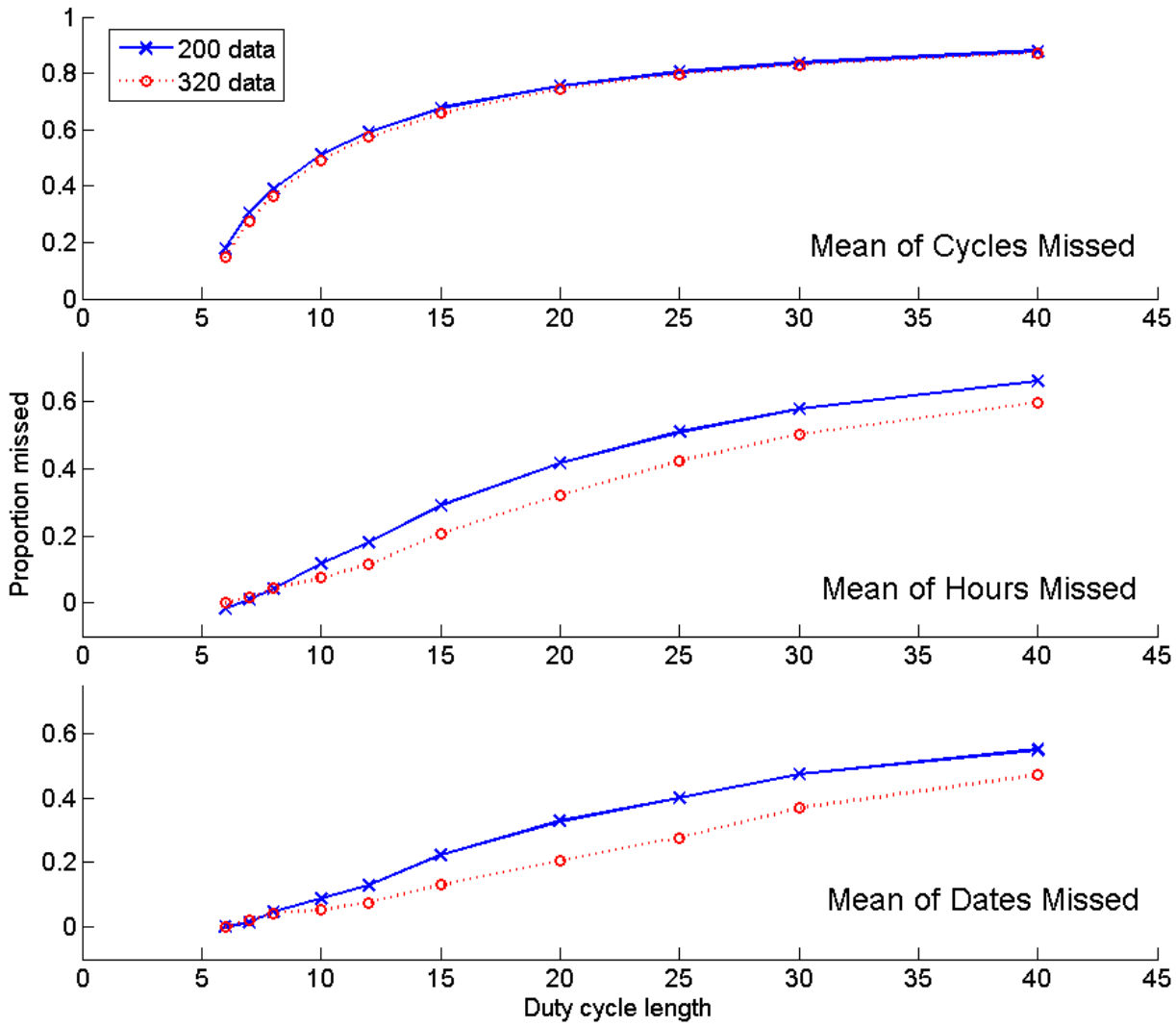

Figure 4. Effect of duty cycle on encounter rate from data sampled at 200 (blue solid line with x marker) and 320 (red dotted line with circle markers) kHz. Lines show mean proportion of cycles, unique hours and unique days that are missed as cycle length increases from 6 to 40 min between the start of 5-min recording periods.

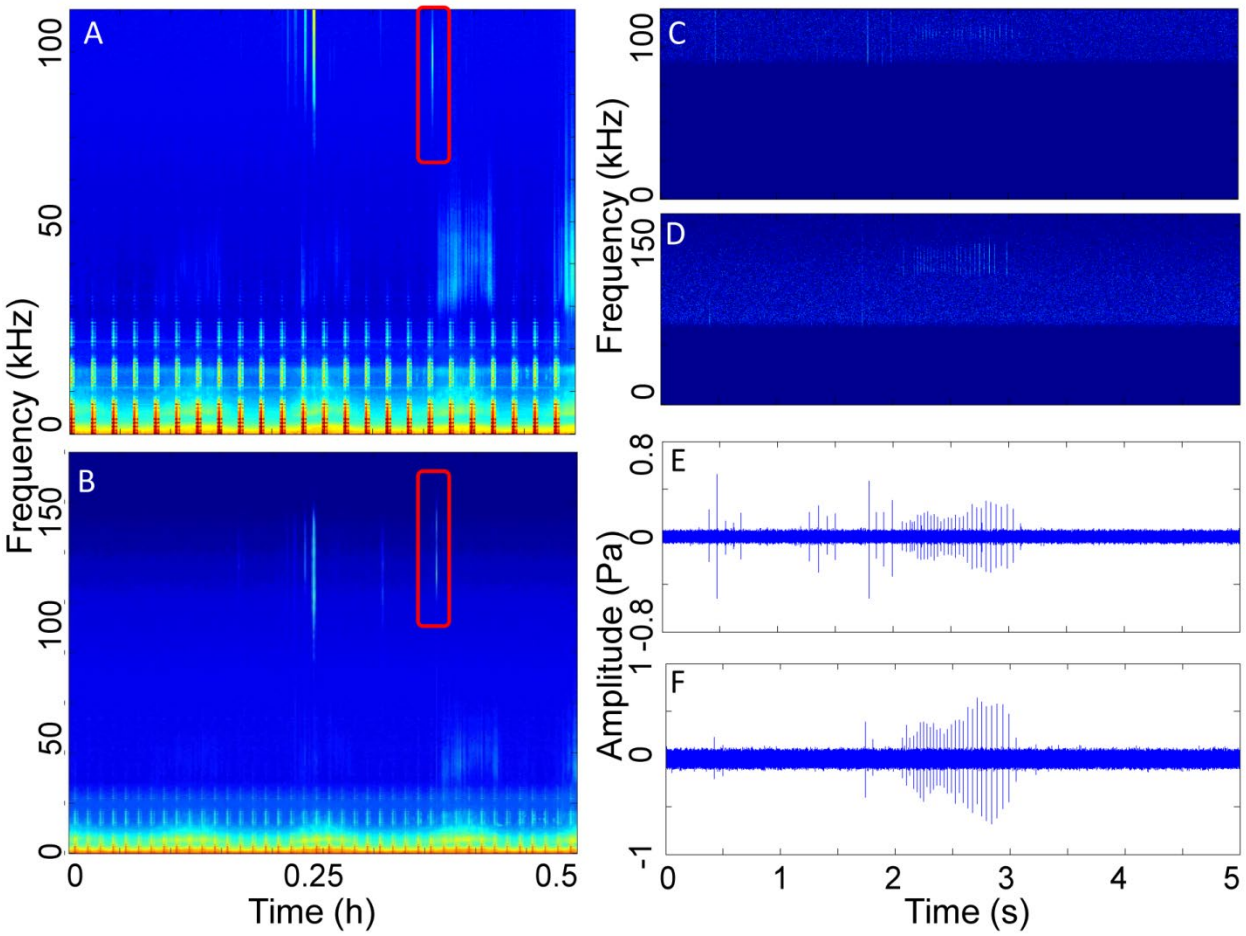

Figure 5. Example encounter from the 200 data that includes clicks with energy that does not extend to 100 kHz, and the same encounter in the 320 data. The 200 data are displayed in an LTSA (A), spectrogram (C) and time series (E), and 320 data also in an LTSA (B), spectrogram (D) and time series (F). Red box surrounds clicks in LTSA of 200 data (A) that do not extend to 100 kHz, and the same time period in the LTSA of the 320 data (B) where there is no energy below 100 kHz. The spectrograms (C, D) and time series (E, F) are all showing the same 5 s example, including the same "buzz-like" burst pulse sequence, between 2 and 3.5 s, that does not extend to 100 kHz in the 200 data. In the LTSAs (A, B) and spectrograms (C, D) color denotes intensity.

Discussion

Are the high-frequency clicks seen in the 200 kHz data "NBHF" clicks?

Periods of very high-frequency clicks encountered within the 320 data correspond in time with those detected in the 200 data, indicating a HARP sampling at 200 kHz can detect very high frequency clicks generally thought to be above the Nyquist frequency for this sampling rate. Measures of click frequency suggest these very high frequency clicks are being aliased into the 200 data set.

Clicks from *Kogia* and other species that generate similar signals have been termed narrow band, high-frequency (NBHF) clicks, based on their spectral characteristics. In general, these clicks

tend to have a peak frequency of 120–140 kHz, –3 dB bandwidth ~ 10 kHz and –10 dB bandwidth ~ 16 kHz (for *K. sima* and *K. breviceps*) (Madsen et al. 2005; Merkens et al. 2018). The clicks that were analyzed here, and similar clicks from other 320 kHz HARP recordings in Hawaii and in the Gulf of Mexico (J. Hildebrand et al. in review), are high-frequency (peak frequency ~ 120 kHz), however, they have a much broader bandwidth (mean –3 dB bandwidth ~23 dB, mean –10 dB bandwidth ~43 dB) than the clicks of *Kogia* recorded on other instruments at other locations. Although there is no standard definition of narrow band for the classification of NBHF clicks, the bandwidths presented here are twice as large as those for previously published NBHF clicks from *Kogia* (Madsen et al. 2005; Merkens et al. 2018), and are similar to other species of odontocetes that are not typically considered narrow band (e.g. beaked whales, Baumann-Pickering et al. 2013). There have been recordings of NBHF signals concurrent with visual sightings of *Kogia* using other types of acoustic recorders in the Pacific region (Merkens et al. 2018; Figure 6). We have not detected high-frequency clicks with a comparably narrow bandwidth in our PIPAN HARP data, despite frequent visual sightings of *Kogia* close to the HARP site (e.g. Baird et al. 2013; Baird et al. 2015).

The dissimilarity between high-frequency click characteristics recorded on HARPs and other sources may have multiple possible explanations. One possibility is that the high-frequency signals recorded on the HARP are generated by some species other than *Kogia*. While there are other species globally that generate NBHF clicks, none are known to live in the Hawai'i region. Alternatively, it is possible that these signals originate from *Kogia* or another NBHF-clicking species but represent a click type that has not previously been identified, such as a signal generated during a deep water behavioral state, or as a result of a different sound generation process that is only used while at depth. It is also possible that the NBHF signals generated by *Kogia* or other species are being distorted by the HARP hardware or data recording process, or by the signal processing regime. A preliminary examination of echosounder signals in the current data do reveal narrow band pings at high frequencies, which suggests that the HARP is capable of recording artificial narrow band signals. However, it is not clear whether or how biological signals may be recorded differently. Analysis of the spectral content of high-frequency (>100 kHz) clicks in HARP recordings needs further exploration and biological interpretation of these signals should proceed cautiously.

How does the detection rate of NBHF clicks compare between the 200 kHz and 320 kHz samples data sets?

There are clear differences in the detection rate of high-frequency clicks in simultaneously collected HARP data that are sampled at 200 kHz and 320 kHz. Some of these differences may be due to characteristics of the clicks themselves, which causes the signals to be undetectable by the 200 kHz instruments, and some differences may be due to signal digitization and processing (e.g. aliasing of higher-frequency signals down to lower frequencies, as in the burst-pulse clicks found at lower frequencies in the 200 data). The effect of these differences will vary based on the goals of the analysis. For a simple presence/absence assessment using 200-kHz sampling rate data that are recorded continuously or duty cycled with off-periods no longer than 5 min, bias or under-estimation of the aggregated daily or hourly occurrence would be minimal. When analyzing the total number of encounters and/or using data that are duty cycled at longer intervals, it would be prudent to address the impact of missed encounters before drawing conclusions or comparing to other data sets.

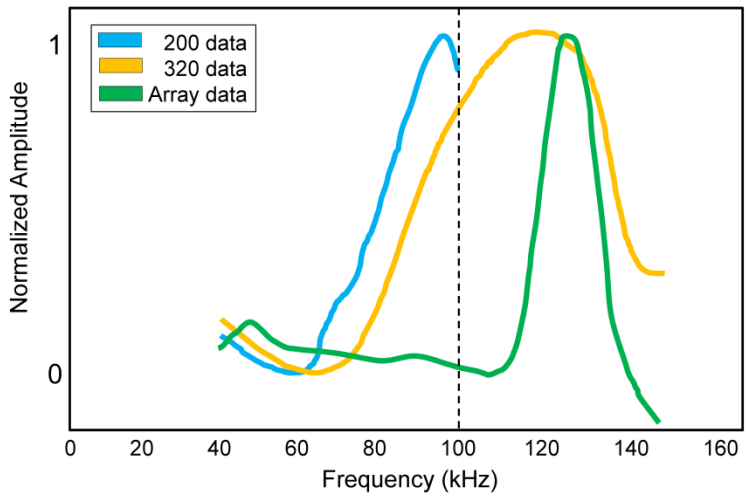

Figure 6. Mean spectra from encounters with high-frequency clicks from current HARP recordings (200 and 320 data, blue and yellow) and NBHF K. sima clicks recording from a surface array near Guam (Mariana Islands, Western Pacific, Merkens et al. 2018) (green). Dotted line denotes maximum frequency for 200 data.

Literature Cited

Baird RW, Webster DL, Aschettino JM, Schorr GS, McSweeney DJ. 2013. Odontocete cetaceans around the Main Hawaiian Islands: Habitat use and relative abundance from small-boat sighting surveys. Aquat Mamm. 39:253–269. doi:10.1578/AM.39.3.2013.253.

Baird RW, Cholewiak D, Webster DL, Schorr GS, Mahaffy SD, Curtice C, Harrison J, Van Parijs SM. 2015. Biologically Important Areas for Cetaceans Within U.S. Waters – Hawai‘i Region. Aquat Mamm. 41:54–64. doi:10.1578/AM.41.1.2015.54.

Baumann-Pickering S, McDonald MA, Simonis AE, et al. 2013. Species-specific beaked whale echolocation signals. J Acoust Soc Am. 134:2293–2301.

Hodge L. 2011. Monitoring Marine Mammals in Onslow Bay, North Carolina, Using Passive Acoustics [dissertation]. [Durham (NC)]:Duke University.

Madsen PT, Carder DA, Bedholm K, Ridgway SH. 2005. Porpoise clicks from a sperm whale nose—convergent evolution of 130 kHz pulses in toothed whale sonars? Bioacoustics. 15:195–206

Merkens K, Mann D, Janik VM, Claridge D, Hill M, Oleson E. 2018. Clicks of Dwarf sperm whales (*Kogia sima*). Mar Mamm Sci. Accepted.

Roch MA, Klinck H, Baumann-Pickering S, Mellinger DK, Qui S, Soldevilla MS, Hildebrand JA. 2011. Classification of echolocation clicks from odontocetes in the Southern California Bight. J Acoust Soc Am. 129:467–475.

Soldevilla MS, Henderson EE, Campbell GS, Wiggins SM, Hildebrand JA, Roch MA. 2008. Classification of Risso’s and Pacific white-sided dolphins using spectral properties of echolocation clicks. J Acoust Soc Am. 124:609–624.

Wiggins SM, Hildebrand JA. 2007. High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring. International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables and Related Technologies, 2007. p. 551–557.