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TECHNICAL REPORT XXXX
MARCH 2024

Assessing Exposure and Responses of Satellite-tagged Blainville's Beaked Whales on the Pacific Missile Range Facility, Hawai'i

E. Elizabeth Henderson
Cameron R. Martin
NIWC Pacific

Michaela A. Kratofil
Robin W. Baird
Annette E. Harnish
Cascadia Research Collective

Steve W. Martin
National Marine Mammal Foundation

Brandon L. Southall
SEA Inc.

Naval Information Warfare Center (NIWC) Pacific
San Diego, CA 92152-5001

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E. Elizabeth Henderson
Cameron R. Martin
NIWC Pacific

Michaela A. Kratofil
Robin W. Baird
Annette E. Harnish
Cascadia Research Collective

Steve W. Martin
National Marine Mammal Foundation
Brandon L. Southall
SEA Inc.

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San Diego, CA 92152-5001

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14. ABSTRACT

Tagging of cetaceans on or near active U.S. Navy training ranges provides for opportunistic behavioral response studies as the animals are exposed to real-world Navy training and testing activity, as compared to short duration-controlled exposure studies. Four Blainville's beaked whales were satellite-tagged on the Pacific Missile Range Facility (PMRF) off the island of Kaua'i in the Hawaiian Islands in 2014, 2021, and 2022. The animal tagged in 2014 left the area immediately, but their tag data still provides useful baseline information of behavior and habitat use in the area. Two Blainville's beaked whales were tagged from the same group in 2021. They remained together and were highly synchronized in their dive and movement behavior until the onset of mid-frequency active sonar (MFAS), at which time the whales appeared to separate. The dive behavior of the two animals tagged in 2021 were compared to acoustically detected group vocal periods (GVPs) on the range; 23 deep foraging dives were matched to GVPs, including three during MFAS exposures from three sources: hull-mounted MFAS, active sonobuoys, and helicopter-dipping MFAS.

The dive behavior of these two whales was statistically analyzed for changes during MFAS exposure, as well as during day and night diel periods between phases of the Submarine Command Course (SCC). Only the variable of intermediate dive depth during an inter-deep dive interval (IDDI) that occurred during an exposure period was outside the 95th percentile of baseline behavior. The beaked whales tagged in 2017 and 2022 did not have dive depth data available for analysis, but dive metrics derived from the other two whales were applied to estimate possible surface periods and times of intermediate and deep dives. In addition, the horizontal movement behavior of all four animals was examined before, during, and after MFAS exposure periods to determine if there were changes. Bearing, step length, travel speed, and turning angle were significantly different from baseline for at least one whales during and after periods of exposure, but the whales remained on the edge or near PMRF, where they were still exposed to MFAS. These data demonstrate that while there may have been some changes to dive behavior and horizontal movement in response to MFAS, these beaked whales did not display a strong avoidance response and remained in the area west of the range for the duration of the SCC. Both animals with tag deployments that lasted beyond the SCCs also returned to the range.

Little is known about the population of Blainville's beaked whales that occupy the waters off Kaua'i, but there are known to be resident beaked whale populations off the island of Hawai'i. If these animals are resident, they are likely regularly exposed to Navy training activity and the use of MFAS, and may have developed some tolerance to the sounds. It is likely that foraging needs drive their behavior regardless of anthropogenic activity or degree of habituation, and they continue to forage on the slope habitat off the range during exposures because that is where their prey is located. Additional tagging and photo-identification studies are critical to understand Blainville's beaked whale habitat use and residency in this area, and to be able to assess the potential impact of repeated exposures to MFAS. Prey mapping of the water column on and off the range would also provide insight into potential motivation of beaked whale behavior.

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Steve W. Martin
National Marine Mammal Foundation

Brandon L. Southall
Southall Environmental Associates, Inc.

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NIWC Pacific
San Diego, CA 92152-5001

NIWC Pacific
San Diego, California 92152-5001

P.M. McKenna, CAPT, USN
Commanding Officer

M.J. McMillan
Executive Director

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EXECUTIVE SUMMARY

Tagging of cetaceans on or near active U.S. Navy training ranges provides for opportunistic behavioral response studies as the animals are exposed to real-world Navy training and testing activity, as compared to short duration-controlled exposure studies. Four Blainville's beaked whales were satellite-tagged on the Pacific Missile Range Facility (PMRF) off the island of Kauaʻi in the Hawaiian Islands in 2014, 2021, and 2022. The animal tagged in 2014 left the area immediately, but their tag data still provides useful baseline information of behavior and habitat use in the area. Two Blainville's beaked whales were tagged from the same group in 2021. They remained together and were highly synchronized in their dive and movement behavior until the onset of mid-frequency active sonar (MFAS), at which time the whales appeared to separate. The dive behavior of the two animals tagged in 2021 were compared to acoustically detected group vocal periods (GVPs) on the range; 23 deep foraging dives were matched to GVPs, including three during MFAS exposures from three sources: hull-mounted MFAS, active sonobuoys, and helicopter-dipping MFAS.

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Little is known about the population of Blainville's beaked whales that occupy the waters off Kauaʻi, but there are known to be resident beaked whale populations off the island of Hawaiʻi. If these animals are resident, they are likely regularly exposed to Navy training activity and the use of MFAS, and may have developed some tolerance to the sounds. It is likely that foraging needs drive their behavior regardless of anthropogenic activity or degree of habituation, and they continue to forage on the slope habitat off the range during exposures because that is where their prey is located. Additional tagging and photo-identification studies are critical to understand Blainville's beaked whale habitat use and residency in this area, and to be able to assess the potential impact of repeated exposures to MFAS. Prey mapping of the water column on and off the range would also provide insight into potential motivation of beaked whale behavior.

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ACRONYMS

ANOVA	Analysis of variance
AUTEC	Atlantic Undersea Testing and Evaluation Center
CI	Confidence interval
CLS	Collecte Localisation Satellites
CTCRW	Continuous time correlated random walk
ERL	Estimated received level
FFT	Fast Fourier Transform
GEBCO	General Bathymetric Chart of the Oceans
GPS	Global Positioning System
GVP	Group vocal period
IDDI	Inter-deep dive interval
LSE	Least squares error
MFAS	Mid-frequency active sonar
NOAA	National Oceanic and Atmospheric Administration
PAM	Passive acoustic monitoring
PMRF	Pacific Missile Range Facility
RHIB	Rigid-hulled inflatable boat
SCC	Submarine Command Course
SNR	Signal-to-noise ratio
SOAR	Southern California Offshore Acoustic Range
SUBEX	Submarine exercise
TDOA	Time difference of arrival
TOA	Time of arrival
ULT	Unit level training

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1. INTRODUCTION

Compared to chronic and acute noise exposures from increased global shipping traffic, Navy mid-training and testing activities that include mid-frequency active sonar (MFAS) generally occur in brief and discrete intervals and in discrete locations throughout the world’s oceans. An exception to this is on active Navy training ranges, where training and testing activity that may use MFAS occur with some regularity. These ranges create opportunities to conduct opportunistic behavioral response studies (BRS) on a variety of cetacean species (e.g., Harris and Thomas 2015; Harris et al. 2019; Durbach et al. 2021; Henderson et al. 2021; Henderson 2023), and to study resident populations of cetaceans to explore long-term demographics and potential impacts of repeated exposures to MFAS (e.g., Falcone et al. 2009, 2022; Curtis et al. 2021; Claridge 2013; Van Cise et al. 2021). While a variety of mysticete and odontocete species occupy these ranges, a species group of particular interest is the family of beaked whales (*Ziphidae*). Beaked whales have demonstrated an apparent behavioral sensitivity to MFAS, with a series of strandings in the late 1990s and early 2000s after several major multi-national Navy training exercises (Cox et al. 2006; D’Amico et al. 2009; U.S. Department of Commerce, U.S. Department of the Navy 2001; Filadelfo et al. 2009; Frantzis 1998; Simmonds and Lopez-Jurado 1991). These strandings may have occurred as a result of the way beaked whales respond to sonar when conducting their deep foraging dives, coupled with specific oceanographic and bathymetric features (D’Spain et al. 2006; D’Amico et al. 2009; Henderson 2023). By tagging beaked whales that reside on or near Navy ranges concurrently with Navy training and testing activity, behavioral responses to MFAS in real-word scenarios can be observed and quantified.

Joyce et al. (2020) examined the movement patterns of eight satellite-tagged Blainville’s beaked whales (*Mesoplodon densirostris*) on the Atlantic Undersea Testing and Evaluation Center (AUTEC) range in the Bahamas, also tagged prior to a Navy training event. Three of the animals were on the range when MFAS started; all three, plus a fourth animal near the range, moved away from the range 28 to 68 km. Another two animals slightly further from the range also moved away from the activity, but two more distant animals did not. Two of the tags also recorded dive data; both animals continued to conduct deep dives during the period of MFAS exposure, but one did not dive as deep as they had before the MFAS and conducted more mid-depth dives (Joyce et al. 2020). Falcone et al. (2017) combined data from 16 satellite tagged Cuvier’s beaked whales (*Ziphius cavirostris*) on the Southern California Offshore Acoustic Range (SOAR) to assess impacts of both high-powered, hull-mounted MFAS as well as lower power helicopter-dipping MFAS. Both deep and intermediate dive durations, as well as inter-deep dive interval (IDDI) durations, increased with proximity to the helicopter-dipping MFAS. IDDIs were also longer in the presence of hull-mounted MFAS, as were intermediate dives, but not as strongly as in the presence of helicopter-dipping MFAS, or in the presence of both sources combined (Falcone et al. 2017). Both of these ranges occur in deep basins adjacent to islands, where water depths reach 1800-2000 meters, but the deep waters are surrounded by ridges and seamounts. To move out of the ensonified basin, beaked whales must travel tens of kms and from deep waters into shallow waters, where they may encounter a shallow wave guide at the surface with the potential to capture and propagate sound (D’Spain et al. 2006). In contrast, the Pacific Missile Range Facility (PMRF) is located off the island of Kaua‘i in the Hawaiian Island archipelago. The seafloor forms a steep slope off the pinnacle island in all directions, and within 6-15 km from shore, waters reach 5400 meters in depth and remain deep. This very different underwater environment leads to a divergent soundscape at PMRF than at AUTEC or SOAR, which may lead to different behavioral responses than have been observed at the latter two ranges. Alternatively, beaked whale behavioral response to MFAS may be conserved such that it will be similar in all locations, regardless of the sound field, bathymetry, prey dynamics, or individual exposure histories. For example, if the reaction is an instinctive anti-predator response to a sound with similar properties to killer whale (*Orcinus orca*) whistles (e.g., Zimmer and Tyack 2007; Tyack et al. 2011, Aguilar de Soto et al. 2020) then the resulting behavior should remain the same.

While received levels and behavioral responses have been estimated for other odontocete species exposed to MFAS at PMRF (Henderson et al. 2021, Baird et al. 2017, 2019), beaked whales at PMRF have only been studied acoustically using passive acoustic monitoring (PAM) (Henderson et al. 2016; Jacobson et al. 2022; Manzano-Roth et al. 2016, 2023). This paper describes the movement and dive behavior of four Blainville's beaked whales satellite tagged prior to three biannual Submarine Command Course (SCC) training events conducted at PMRF that include the use of MFAS from multiple sources. This is the first time the additional sources of active sonobuoys and helicopter-dipping MFAS have been assessed for PMRF, in addition to hull-mounted MFAS. SCCs at PMRF are broken into five phases: Before; Phase A (a period of training activity that does not include these sources of MFAS or large surface ship activity); the Interphase between Phase A and B with no training activity, although vessels may still be present in the area; Phase B (a period of training activity that may include all three sources of MFAS and large surface ship activity); and After. Quantitative methods were applied to dive and movement data from the satellite tags to estimate behavioral responses. In addition, dives from the tagged animals were linked with acoustically detected group vocal periods (GVPs; a continuous period of echolocation pulses from one or more individuals, presumed to indicate a deep foraging dive) on the range for the first time, allowing for comparisons and correlations between the two data streams to fully understand the acoustic scene of Blainville's beaked whale foraging dives at PMRF.

2. METHODS

2.1 FIELD OPERATIONS

Tagging was undertaken from a 7.3-meter rigid-hulled inflatable boat (RHIB) during field operations conducted between Kauaʻi and Niʻihau in February 2014, August 2021, and August 2022. Field operations were timed to occur immediately prior to SCCs, to maximize the likelihood of data being obtained for periods before, during, and after the SCC. Beaked whales were tagged both on and off the Navy's hydrophone range at PMRF. For encounters on the range, acoustic detections from the array were used to direct the RHIB to the general area where beaked whales were acoustically detected, and information on the cessation of echolocation activity was used to predict when the animals were at or close to the surface, and thus potentially visually detectable. During encounters, information was recorded on group size, locations, start and end time (see Baird et al. 2013). Photographs of all individuals within the groups were taken for identification, determination of age (based on the degree of scarring and relative size) and sex (based on presence or absence of erupted teeth). Photos were compared to a long-term photo-identification catalog (McSweeney et al. 2007; Baird 2019) to assess sighting history and the potential for repeat tagging of individuals.

Tags included both location-only (SPOT5) and depth-transmitting SPLASH10-F tags (Wildlife Computers, Redmond, WA) in the Low Impact Minimally Percutaneous Electronic Transmitter configuration (Andrews et al., 2008). Tags were deployed with a Dan-Inject pneumatic projector and were attached with two 4.4-cm surgical grade titanium darts (see Schorr et al. 2009; Baird et al. 2011).

2.2 TAG PROGRAMMING

The SPOT5 tag was an Argos location-only tag, while SPLASH10-F tags also transmitted Fastloc®-GPS locations as well as summarized dive behavior data. Tags were programmed to transmit during the 14 or 16 hours of the day with the greatest density of satellite overpasses, based on Argos pass predictions obtained through Collecte Localisation Satellites (CLS). The SPOT5 tag deployed in 2014 and the SPLASH10-F tags in 2021 were programmed to transmit 16 hours per day, while the SPLASH10-F tag deployed in 2022 was programmed to transmit 14 hours per day. Transmitted dive data consisted of behavior logs recording the start and end time of dive and surface periods. All tags were programmed to record maximum dive depths and durations for dives greater than or equal to 50 meters and lasting longer than 30 seconds to reduce gaps in the behavior logs (Quick et al., 2019). Surface periods were considered any time when the animal did not dive below 50 meters. SPLASH10-F tags were programmed to obtain up to two Fastloc-GPS locations per hour, and 48 locations per day, with Fastloc-GPS locations set as high priority (three out of every four transmissions) and behavior logs and time series set as low priority (one out of every four transmissions). To maximize the likelihood of obtaining behavioral data before, during, and after each SCC, tags were recorded to collect behavior logs and Fastloc®-GPS locations starting three days prior to the start of the SCC and ending three days after the end of the SCC, and transmit behavior and Fastloc®-GPS data with a six-day buffer. Two shore-based Argos receivers (Wildlife Computers MOTEs), one on Niʻihau and one on Kauaʻi, were also used to increase data throughput when tagged animals were within range of the receivers (Jeanniard-du-Dot et al., 2017).

2.3 TAG DATA PROCESSING

Argos and GPS location data were processed following methods detailed in Kratofil et al. (2023). Briefly, Argos data were filtered through the Douglas-Argos Filter (Douglas et al., 2012) accessed through Movebank (Kranstauber et al., 2011) to remove erroneous locations. Fastloc-GPS locations were filtered based on residual error values (< 35; Dujon et al., 2014) and time errors (< 10 seconds), and were additionally processed through a general speed filter via Movebank (Kranstauber et al., 2011). Resultant Argos and GPS locations were combined, and subsequently fitted to a continuous time correlated random walk (CTCRW) model via the *crawl* package in R (Johnson et al., 2008; Johnson & London, 2018). Models were fit to each individual trajectory, and then used to predict locations at a five-minute interval for received-level analyses following Henderson et al. (2021). The CTCRW model allows for location prediction at user-defined intervals based on the modeled movement process while also directly incorporating known measurement error in Argos (error ellipses) and GPS (user-defined, see Henderson et al. 2021) locations (Johnson et al., 2008; McClintock et al., 2014). Predicted locations also include an estimated standard error (in meters) in both x and y directions (easting and northing), which was used to account for positional uncertainty in received-level analyses. Lastly, any locations on land were re-routed around land plus a 50-meter buffer using the *pathroutr* package (London, 2020).

Dive behavior data were examined prior to analyses to ensure that the tags operated as intended and experienced no malfunctioning that could invalidate the data. We assessed Depth and ZeroDepthOffset values in tag status files for indication of drift that could be associated with a pressure transducer failure. Those exceeding +/- 10 meters and +/ 9 meters, respectively, were flagged as potential pressure transducer failures. We also assessed data to identify extreme ascent or descent rates in recorded dives that could indicate tag malfunctioning by dividing twice the dive depth by the dive duration. Ascent/descent rates greater than 2-3 meters per second were flagged.

2.4 MFAS DETECTION AND LOCALIZATION

A custom computer-based recorder collected acoustic data from PMRF bottom-mounted range hydrophones at a 96 kHz sample rate with 16-bit samples. A total of 62 hydrophones were recorded in February 2014. Beaked whale clicks were detectable on all 62 hydrophones while MFAS transmissions were detectable on 47 hydrophones. Since the tag from February 2014 was not exposed to MFAS transmissions, this hydrophone configuration is not discussed further, although additional details are provided by Martin et al. (2015). In August 2021 and August 2022, a total of 63 hydrophones were recorded. Hydrophones that could detect beaked whale clicks and MFAS transmissions include thirty-one hydrophones with a frequency response from 50 Hz to 48 kHz and at depths of 2400 to 4800 m, and 5 hydrophones with a frequency response from 100 Hz to 48 kHz and at depths of 650 to 1750 m. The remaining 27 hydrophones could detect beaked whale clicks and had a frequency response from 8-48 kHz.

Detection of MFAS transmissions occurred in two frequency bands under 10 kHz. Due to security considerations, exact frequency bands cannot be provided, however, the lower frequency band detected surface ship hull mounted sonar (i.e., AN/SQS-53C) and helicopter dipping sonar (i.e., AN/AQS-22) while the higher frequency band detected sonobuoys (i.e., AN/SSQ-62). Raw time series data were processed with a 16,384-point fast Fourier transform (FFT) and 93.75% overlap. A long-term and short-term running average spectrum of the FFTs were computed in the two detection frequency bands to determine when the signal-to-noise ratio (SNR) exceeded a user defined threshold of 15 dB. If the number of user-defined consecutive detections was met (75 for the lower frequency band and 25 for the higher frequency band) or the SNR threshold was no longer met, a detection queue ended, and a 6-sec blanking time was initiated before resuming detection to avoid detecting multipath arrivals.

Model-based localizations of MFAS transmissions were performed under the same suite of C++ algorithms for whale calls described in detail by Martin et al. (2015, 2022) and summarized here. The onset times of automatic detections across multiple hydrophones were used as the measured time of arrival (TOA), and measured time difference of arrivals (TDOAs) were calculated by subtracting measured TOAs from each other. Modeled TDOAs were calculated from theoretical source locations determined by an iterative spatial grid search process that minimized the weighted least square error

(LSE) between measured and modeled TDOAs. The LSE was weighted by the order of TOAs with more weighting for earlier arrivals and was normalized by the number of hydrophones in a localization solution. In addition, candidate detections for a localization solution were required to have a start frequency within 12 Hz of each other and a slope of 0.5 frequency bins/time bin. Localizations with a weighted LSE < 0.15 seconds between measured and modeled TDOAs were used for this analysis.

2.5 ACOUSTIC PROPAGATION MODELING

The estimation of received levels on whales from MFAS transmissions utilized methods described in detail in Henderson et al. (2021) and are briefly summarized here. Propagation modeling was done with the Peregrine parabolic equation propagation model developed by Oasis Ltd (Heaney and Campbell, 2016), based on the range dependent acoustic model (RAM) (Collins, 1993). Bathymetry information with 3 arc-second resolution was obtained from the National Oceanic and Atmospheric Administration National Geophysical Data Center U.S. Coastal Relief Model (NOAA National Geophysical Data Center, 2011), and historical sound speed profiles were taken from the 2018 World Ocean Atlas (Locarnini et al., 2018; Zweng et al., 2018). Estimated received levels (ERLs) were calculated based on publicly available source levels of U.S. Navy sonars (NMFS, 2008) and modeled transmission losses. Nominal source levels at 1 meter distance for these three MFAS types are: hull-mounted sonar at 235 dB re 1 μPa, helicopter-dipping sonar at 214 dB re 1 μPa and sonobuoy 201 dB re 1 μPa.

The *crawl*-modeled x and y positional error from interpolated whale track locations were used to define a 95% confidence interval error ellipse to represent location uncertainty around each modeled whale location. The error ellipse was sampled with radial slices taken systematically in azimuth, and each radial slice associated with selected MFAS transmissions were a single propagation modeling run (see Henderson et al. 2021 for more details on this method). Modeling was performed across the full depth from 0 to 5400 meters, and the distance of the longest radial slice for an MFAS transmission was used for all radials from the same MFAS transmission. Peregrine output transmission loss calculations resulted in 600 depth bins with 9 meter spacing, and 1000 range bins with variable spacing based on the distance of the longest radial slice. To reduce constructive and destructive interference from modeling a single frequency of an MFAS transmission and to better characterize the bandwidth of the signal, 10 log-spaced frequencies across 200 Hz of bandwidth around an MFAS transmission (+/- 100 Hz) were modeled. Figure 1. illustrates a single radial slice from a ship through the maximum range of the error ellipse, including the area down to 5400 meters depth and 29.6 km from the source, color coded by the estimated receive level (ERL).

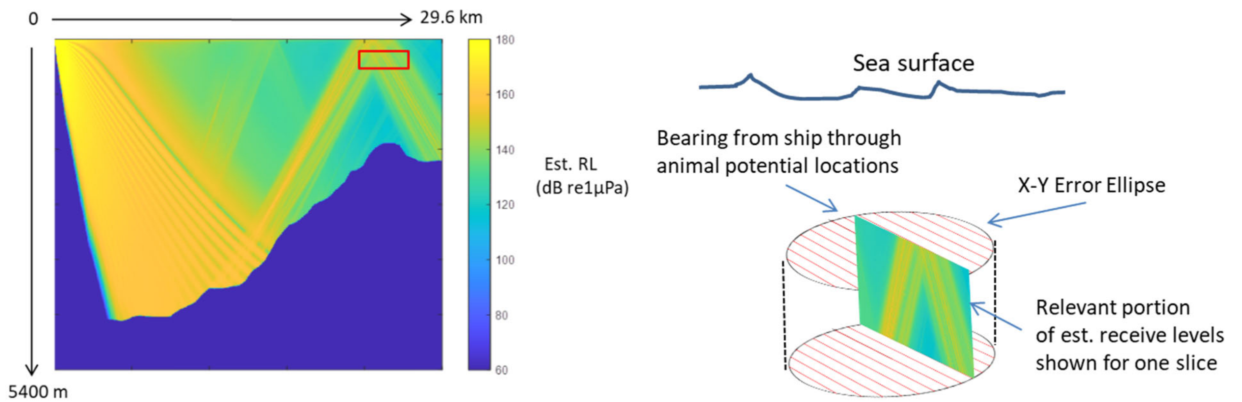


Figure 1. Left: Example of a single slice from ship MFAS source full depth maximum distance estimated received levels in units of dB re 1μPa. Dark color indicates the seafloor, highlighting the steep angle limitation close to a source. The red insert box illustrates the potential location in this slice of the animal location using the 95% CI ellipse and depth information. Right: The same red box depicted as one of the radial slices from the MFAS source through the error ellipse of the whale position, demonstrating how RLs are estimated for animals during a dive.

To estimate the probable 3D location of the animal at the time of MFAS transmissions requires utilizing the animal's location in the depth dimension over the 95% CI error ellipse. Animal depth was derived from the satellite tag data (see Dive Analysis section 2.8 for more details on how this was modeled). When no depth data were available for a 5-minute bin, two depth regimes were utilized to estimate receive levels. These included a shallow regime to represent exposures when the animal was within the upper 54 meters of the water column, and a dive depth regime that estimated depth bins between 54 and 1,125 meters; the latter value was derived from Baird et al. (2006) to be the typical depth for Blainville's beaked whale deep foraging dives. Tag positional update times, or times when tag position updates were attempted but failed, can be used as known times the animals were at the surface (see Dive Analysis section 2.8); these provide additional surface information for all three tagged whales when dive data were missing. When the satellite tags provided depth information, the modeled animal depth data corresponding to the time an MFAS transmission was received at the animal position was utilized, along with a percent of depth to represent uncertainties in depth. The percent of depth uncertainty used in this analysis varied with the depth regime: for shallow depths to 54 meters, each 9 meter depth bin from the surface to 54 meters depth were utilized; for depths from 54 meters to 100 meters, +/- 20% of the depth were utilized; for depths from 100 meters to 400 meters +/- 10% were used; and for depths > 400 meters +/- 5% were used. Figure 1. (left) shows a small red box indicating the estimated animal location for the propagation modeled single slice. Multiple slices for estimated animal locations contributed to the full 3D estimate for each exposure.

2.6 SHIP EXPOSURES

Each surface ship hull-mounted MFAS localization was joined to ship positional data from PMRF, nominally updated every second, if data were within one second and 400 meters. During a 5-minute interval, one transmission from each individual ship transmitting sonar and its azimuthal radials were selected for propagation modeling if it was closest in time (within +/- 2.5 minutes) and distance to a whale update. A similar approach was utilized by Henderson et al. (2021) with the exception that a single transmission with the absolute minimum time and distance to a whale update was selected for propagation modeling. The approach taken here requires more processing time for additional MFAS transmissions but provides a continuous exposure history for each transmitting ship. While the number of MFAS transmissions from all sources in a 5-minute bin is sensitive, a stoplight (red, yellow, and green) colorization of the median ERL is provided in ERL plots to indicate relative MFAS activity in each bin with green being low, yellow moderate, and red high.

2.7 TRACKING SONOBUOY AND HELICOPTER-DIPPING SONAR TRANSMISSIONS

Localized MFAS transmissions from sonobuoys and helicopter dipping sonar were automatically tracked with an adapted algorithm (Klay et al. 2015) that has been utilized to acoustically track whale calls at PMRF (e.g., Harris et al., 2019, Durbach et al., 2021, Martin et al., 2022). The automated tracking algorithm first filters localizations by quality indicator thresholds, then groups localizations by recursively examining time and distance between localizations. The following user-defined values were optimized for tracking sonobuoys and helicopter dipping sonar: a track required three or more localizations, a localization solution required automatic detections from eight or more hydrophones, the distance between localizations had to be within 0.012 decimal degrees in both latitude and longitude (1.3 km), the maximum time between localizations before ending a track had to be less than or equal to 300 seconds, and the frequency between localized MFAS transmissions could vary by hundreds of Hertz (exact values cannot be provided). An unknown compared to ship hull mounted sonars is the depth of the MFAS source. Sonobuoys have preset depth settings and the helicopter dipping sonar can be utilized at multiple depths. For this analysis we are assuming source depths likely used within operational parameters, since exact depths are unknown. This method was assessed and validated using data from a previous SCC; see Martin et al. (2023) for details on that analysis.

For each sonobuoy and dipping sonar track, a single transmission with the minimum number of error ellipse radials and closest in time and distance to a whale update was selected for propagation modeling. Due to the higher frequencies of these MFAS signals, the time to process a single radial was approximately 40 minutes. As described above there are multiple radials per animal location; therefore, it was not feasible to process one transmission from each sonobuoy and dipping sonar track in each 5-minute interval, as was done for surface ship transmissions. Since sonobuoys and helicopter dipping sonar typically transmit for shorter periods of time and have minimal movement during active periods, the modeled transmission loss from a single, mid-point transmission reasonably represents the rest of the transmissions that composed a sonobuoy or dipping sonar track. Selecting the transmission with the minimum number of error ellipse radials reduced processing time and provided modeled propagation estimates for exposures with the highest positional accuracy. Note that the number of tracks doesn’t necessarily represent the number of sources present since an individual source can be associated with multiple acoustic tracks. Finally, while the number of MFAS transmissions from all sources in a 5-minute bin is classified, we are providing a stoplight (red, yellow and green) colorization of the median ERL in plots to indicate relative MFAS activity in each bin with green being low, yellow moderate, and red high.

2.8 DIVE ANALYSES

2.8.1 Development of tag dive profiles

Three of the four satellite tags utilized in this study were capable of recording dive behavior log data, including start and end times of dives and surface periods, as well as maximum dive depths. Unfortunately, tag malfunctioning invalidated the behavior log on one of the whales, leaving only two tags with usable dive data (MdTag020 and MdTag021). Using these data, coupled with the smoothed crawl-modeled tracks in 5-minute intervals, full dive cycles were modeled in a custom Matlab program. First, minimum and maximum bottom times were estimated based on Wildlife Computer’s definitions of U, V, and Square-shaped dives (https://static.wildlifecomputers.com/Behavior-Log.pdf). Then, ascent and descent times were estimated based on the remaining time in the dive divided by two, and ascent and descent rates were determined by using the mean maximum depth provided divided by the estimated ascent and descent times. These values were bounded by the ascent and descent rates found in Baird et al. (2006) such that if the estimated rates were lower than the published minimum rate, or were higher than the published maximum rate, then the published minimum or maximum rate was used. These values (minimum and maximum bottom time, ascent and descent times, and ascent and descent rates) were estimated for all dives. The dive behavior logs and the MOTE transmission logs were also examined for completion in the record of surface and dive periods. If data were missing, these periods were noted as well, while times when tags attempted to update their positions were utilized as known surface times.

Next, dive durations were interpolated by 60 points per dive, leading to a timestamp approximately every 30 seconds for a deep (>300 meters) dive and approximately every 10 seconds for a intermediate (<300 meters) dive. Dive depths were modeled using the estimated ascent and descent rates at each interpolated timestamp, and these were combined with the surface crawl-modeled track for a full record for each whale. At each timestamp (either at 5-minute intervals when at the surface or at the finer interpolated intervals of the dives), it was also noted whether that timestamp occurred during a dive, was at the surface but interpolated, or was at the surface with either an Argos or GPS update or MOTE uplink. Finally, it was noted whether that timestamp occurred during a period of missing behavioral log data. In that case, it was assumed the animal was at the surface if the interpolated timestamp occurred within a minute of an Argos or GPS location.

The minimum, mean, median, and maximum durations of both intermediate (50–300 meters) and deep dives (> 300 meters), as well as surface periods, were estimated from the two tags with complete dive behavior logs (MdTag020 and MdTag021). Wildlife Computers SPLASH tags report a minimum and maximum bound for the dive depth and for the dive duration; these means of these values were taken for all analyses. Consecutive intermediate dives were also combined to get inter-deep dive periods and to estimate the durations of these IDDIs as well as the number of intermediate dives that occurred in each IDDI. For the two tags without dive data (MdTag017 and MdTag022) but with surface positions, the values of the known intermediate and deep dive durations were used to estimate dive vs. surface periods. If there were known surface times of less than one minute apart, the animal was assumed to be at the surface. If intervals between known surface times were 20 minutes or less the interval was assigned as a intermediate dive. And, if intervals between known surface times were 21-75 minutes, the interval was assigned as a deep dive. If the interval between known surface times was over 75 minutes, it was assumed to be a period of missing data.

Using bathymetry data from the General Bathymetric Chart of the Oceans (GEBCO) website (https://www.gebco.net), water depths were estimated at every interpolated 5-minutes surface position using the *ADEHabitat* package in R (Calenge et al. 2023). These were compared to deep dive depths to estimate the proximity of the foraging dives to the seafloor.

2.8.2 GVP Analysis

For the periods of time the Blainville's beaked whales were known to be over the PMRF range hydrophones, the locations of known deep dives for MdTag020 and MdTag021 and the assumed deep dive periods for MdTag022 and MdTag017 were compared to acoustically detected GVPs. First, any hydrophone with a GVP within 10 minute and 6 km of a crawl-modeled track location for all four whales were identified. These were further narrowed down to be only hydrophones with GVPs within 6 km of the full error ellipse from each crawl-modeled track position, to be certain that if the animal were truly located anywhere within the error ellipse it would still be detected on the hydrophone (a distance assumed to be 6 km based on McCarthy et al. [2011]). Next, the raw acoustic data from each hydrophone with detections from each of the selected GVPs were examined for echolocation pulse onset and cessation times. These times were compared to the tag dive start and end times. If the start and end times of the GVPs fell within the time period of the dive, then the GVP was assumed to belong to the tagged whale's group. Using the modeled dive profiles, the start and end depths of the GVPs were estimated.

2.9 Statistical Analyses

Correlation tests were run between the baseline variables of dive depth, dive duration, and time of day for individual deep and intermediate dives, and for intermediate dive counts and IDDI duration for the IDDI periods. To assess changes in dive behavior during MFAS exposures, percentile values were estimated for a variety of dive parameters including deep dive depth, deep dive duration, IDDI duration, mean IDDI intermediate dive duration, mean IDDI intermediate dive depth, and maximum IDDI intermediate dive depth. These values were then examined for the exposure dive data to evaluate how atypical they were from baseline dives. We considered these parameters to be atypical and indicative of a possible response if the exposure dive variables fell outside those occurring in 95% of the baseline data for each individual. Exposure dive parameters were considered atypical when they fell either below or above the 2.5 and 97.5 percentile values for baseline parameters, respectively.

To account for the impacts of diel patterns on diving behavior, the coverage of each tag based on time of day for each SCC Phase (Before, Phase A, Interphase, Phase B, After) was also calculated. Dive and surface periods were each assigned either as a day or night period based on when they started. The durations of surface periods that spanned more than one time of day were split. Surface periods that crossed multiple SCC phases had their durations split between phases. Due to their relatively short duration, dives did not need to be were split based on either phase or time of day as was done for surface periods. Coverage by time of day for each tag was calculated as the total duration of dive and surfacing periods within the time of day and SCC phase of interest, divided by the total duration of the time of day within that particular phase (e.g., the day total duration for Phase A would represent the sum of the duration of all days within Phase A). For the before and after periods, the total duration of the phase was calculated as three days prior to the start of Phase A, and three days following the end of Phase B, respectively. Metrics that were calculated for phases and times of day with sufficient coverage included the dive rate (number of dives per hour), percentage of time spent at the surface, median dive depth, and median dive duration among SCC phases and times of day for each tag to assess potential responses to MFAS exposure in their diving behavior while also accounting for known diel patterns (see Owen et al. 2019, Shaff & Baird 2021, West et al. 2018). Sufficient coverage for each phase and time of day was defined as having dive behavior data available for at least 50% of the total duration of each phase within that time of day. For all metrics, only three days of data following the end of Phase B were used where available. Kruskal-Wallis one-way ANOVA tests were conducted to identify significant differences in dive depth and duration among phases, and by night/day period, for the two whales with sufficient dive/surfacing coverage, and post-hoc Dunn's tests with a Benjamini-Hochberg correction were conducted to identify phases where pairwise significant differences were detected (e.g., statistical difference between Phase A and B; significance level for both tests = 0.05).

To assess changes in individual movement behavior, bearing, turning angle, step length (distance between track locations in meters), and travel speeds (in m/s) were calculated for each step along the crawl-interpolated tracks. This was done for the full tracks for all four animals to compare individual movement behavior in the full period before the first known exposure to periods of similar duration during and after exposures. The same analysis was conducted for MdTag021 and MdTag022, but with the periods of deep foraging dives excluded, therefore only comparing IDDI periods when most horizontal movement would be expected to occur. As these variables had non-normal distributions, Kruskal-Wallis nonparametric tests were performed to compare the baseline/before values for each variable to the during and after values, and multiple comparison tests were performed to determine which periods were statistically different from each other.

3. RESULTS

3.1 TAGGING AND PHOTO-IDENTIFICATION

Two Blainville's beaked whales were tagged in a group of five individuals during the 2014 field effort, but data were only obtained from one of the two tags (MdTag017), deployed on an adult male. Of the five individuals photo-identified in the group, none had been previously documented or have been photographed subsequently. Two individuals were tagged during the 2021 field effort in a group of seven individuals, one on an adult female (MdTag020) and one on an adult male (MdTag021). One individual was tagged out of a group of seven during the 2022 field effort, an adult female (MdTag022). Based on photo-identification, none of the individuals were tagged on more than one occasion. The adult male tagged in 2021 had previously been photo-identified off Kaua'i on two occasions, in March and June 2019 (Cascadia Research Collective, unpublished data). There were two individuals in common between the groups tagged in 2021 and 2022 (MdTag022 and a juvenile, presumably her offspring). Of the combined 17 individuals photo-identified in the three encounters, none have been documented off other islands.

3.2 LOCATION DATA AND SCCS

Location data was obtained for 8.0 (MdTag017), 13.3 (MdTag020), 9.0 (MdTag021), and 24.3 (MdTag022) days. The 2022 tag deployment experienced a pressure transducer failure early on in the deployment, and thus no dive behavior data were valid for further analyses. Dive behavior data for the two 2021 deployments passed all quality control assessments and were used in analyses. Dive behavior data coverage by SCC phase are provided in Table 1. . All times are presented in HST.

Table 1. Behavior data coverage by SCC phase.

Individual	Percentage of dive/surfacing data				
	Before	Phase A	Interphase	Phase B	After
MdTag020					
Duration overall (days)	0.3	1.7	3.8	2.4	0.9
Days surfacing/dive data	0.2 (NA)	1.7 (100%)	2.5 (65%)	0.6 (23%)	0.0 (NA)
Percentage behavioral coverage	96.0	100.0	65.3	22.9	0.0
MdTag021					
Duration overall (days)	0.2	1.7	3.8	2.4	5.2
Days surfacing/dive data	0.2 (NA)	1.7 (100%)	3.8 (100%)	1.0 (40%)	0.5 (NA)
Percentage behavioral coverage	95.7	100.0	99.7	40.4	6.9

- Behavior data coverage for the days of surfacing/dive data was calculated by summing the total duration of all dive and surfacing periods for each phase and calculating the percentage of those durations out of the total duration of each phase.
- These are reported in parentheses as percentages on the Days surfacing/dive data lines. These percentages are not shown for before and after as these are dependent on the start and end times of the deployment for each tag. The percentage of behavioral coverage is defined as the proportion of the duration of behavioral data relative to the duration of the tag within each phase.

The Blainville’s beaked whale MdTag017 was tagged at PMRF on 4 February 2014 at 12:42; this tag transmitted until 12 February 17:19. This individual remained within 5 km of the range for 3.5 days, spending time in the channel between Kauaʻi and Niʻihau, and only overlapped with the range hydrophones for 10 hours on 7 February before heading southwest away from the range along Niʻihau and west to Kaʻula Island (Figure 2). This animal left the area before the start of any training and so did not have any MFAS exposures (Table 2).

In 2021, two Blainville’s beaked whales were tagged in the same group on 11 August, the first (MdTag020) at 12:03 and the second (MdTag021) at 12:33; these animals were tagged a half day before the start of the SCC (Table 2). Phase A of the 2021 SCC was comprised of training activity but there were no active MFAS sources present. There was a four-day period between the two phases of training activity (Interphase, Table 2), and then Phase B, during which there were ships with hull-mounted MFAS as well as helicopter-dipping MFAS and active sonobuoys, which lasted three additional days. MdTag020’s tag stopped transmitting at 12:20 on 20 August, shortly after the end of Phase B, while MdTag021’s tag continued to transmit an additional five days until 18:52 on 24 August. The two animals appeared to remain in the same group for the nine days both tags were transmitting.

In 2022, the typical activities of Phase A and B were mixed together in both training phases, therefore the first week was called the mixed Phase A/B and the second week was called the mixed Phase B/A (Table 2). These lasted 3.5 days and 27 hours, respectively, with a 3.5-day interphase. The longest duration tag was deployed on 17 August 2022 at 14:09 on MdTag022 during the mixed Phase A/B and continued transmitting for 24.3 days until 10 September at 21:58. In contrast to the whale from 2014, the latter three Blainville’s beaked whales remained on or relatively near the range for the duration of their tag deployments (Figure 2), even during the SCC with active MFAS.

Table 2. SCC Phase Times and passive acoustic monitoring data durations (in HST). Note that only three days before and after the SCCs in 2021 and 2022 are given to correspond with the Before and After periods used in the behavioral response analyses. A ULT is a unit level test, a shorter duration training event that may include the use of MFAS. A SUBEX is a submarine exercise and does not include the use of MFAS. *The Interphase in 2021 included a unit-level training on 8/15 that did not include MFAS.

Phase	Start date	End date	Duration (hrs)
ULT	2/10/2014 0800	2/10/2014 1430	6.5
ULT	2/11/2014 1130	2/11/2014 1530	4
Post-ULT/Pre-SCC	2/11/2014 1530	2/12/2014 1800	26.5
Phase A	2/12/2014 1800	2/14/2014 2100	51
Interphase	2/14/2014 2100	2/17/2014 1900	70
Phase B	2/17/2014 1900	2/20/2014 1730	70.5
Post-SCC	2/20/2014 1730	2/20/2014 2230	6
Pre-ULT	7/31/2021 11:00	8/3/2021 10:57	72
ULT	8/3/2021 11:27	8/3/2021 16:42	5.3
Post-ULT/Pre-SCC	8/3/2021 16:45	8/11/2021 17:59	193.2
Phase A	8/11/2021 18:00	8/13/2021 22:20	40.3
Interphase	8/13/2021 10:21	8/17/2021 4:59	90.6
Phase B	8/17/2021 5:00	8/19/2021 14:30	57.5
Post-SCC	8/19/2021 14:31	8/22/2021 14:30	72
Pre-SUBEX	8/13/2022 2:30	8/16/2022 2:29	72
SUBEX	8/16/2022 6:01	8/16/2022 16:00	10.0
SCC A/B (mixed)	8/17/2022 6:30	8/20/2022 23:31	89.0
Interphase	8/20/2022 23:32	8/23/2022 12:50	73.3
SCC B/A (mixed)	8/23/2022 12:51	8/24/2022 15:53	27
Post-SCC	8/24/2022 15:54	8/27/2022 15:54	72

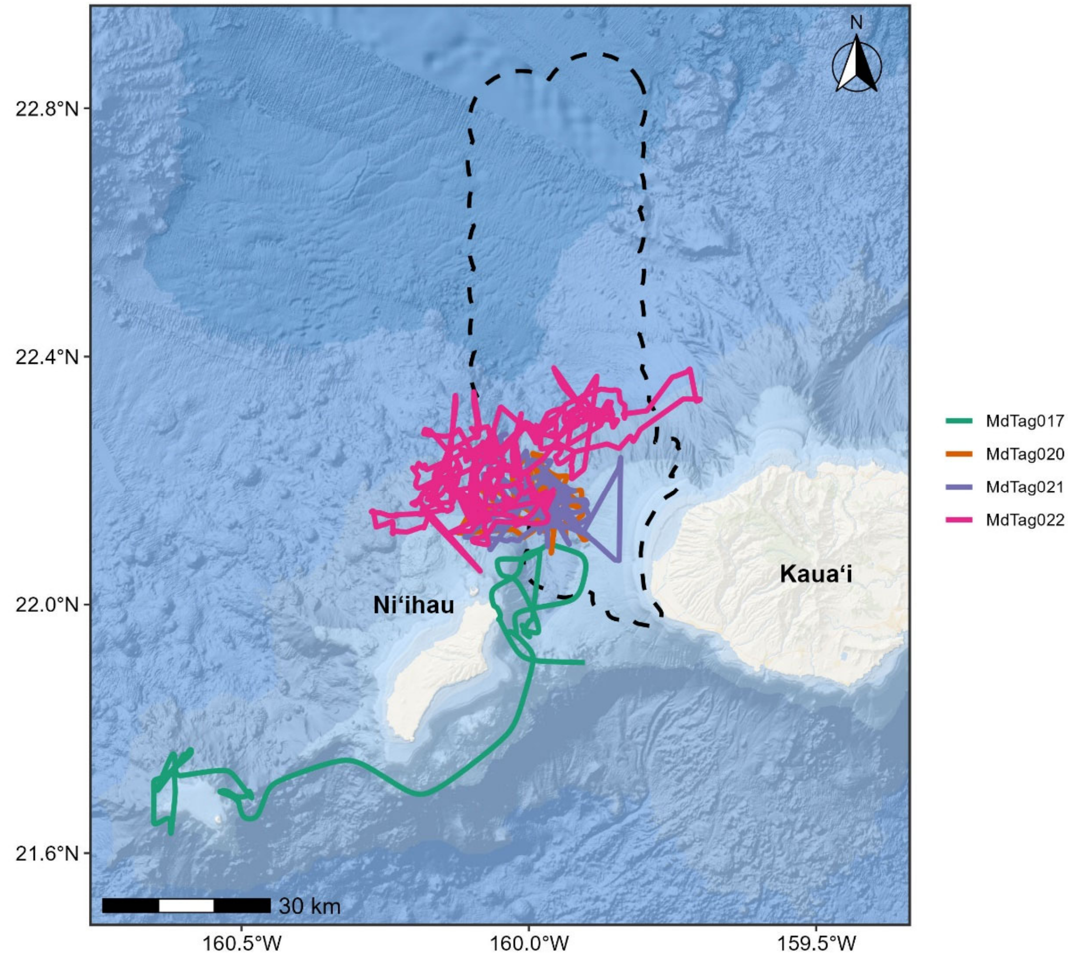


Figure 2. Tracks of tagged Blainville's beaked whales (2014, n = 1; 2021, n = 2; 2022, n = 1), with the outline of the PMRF range for reference.

3.3 BASELINE DIVE BEHAVIOR

The two tags from 2021 (MdTag020 and MdTag021) were the only deployments with valid dive behavior data (Table 3.) and were used to model the dive behavior for MdTag017 and MdTag022. The data from MdTag020 includes 175 dives, 45 (26%) of which were deep dives over 300 meters, and 130 (74%) were intermediate dives. This animal conducted three dives to depths of 303.5, 391.5, and 511.5 meters, which were deeper than the remainder of the intermediate IDDI dives but shallower than their deep dives. While these dives were unusual for these animals, they are part of the Blainville's beaked whale normal dive repertoire, although in small numbers and more typically during the day (e.g. Baird et al. 2008). The first two of these occurred during Phase A of the SCC, while the third occurred during Phase B. Excluding those dives, the minimum deep dive depth was 847.5 meters and the maximum deep dive depth was 1423.5 meters, with a mean deep dive depth of 1189.7 meters. The minimum deep dive duration was 23 min, while the maximum deep dive duration was 59.5 min, with a mean of 50.4 min. The majority of deep dives were U-shaped (78%), while only

12% were square-shaped, and none were V-shaped. For intermediate dives, the minimum depth was pre-set to be 50 meters, while the maximum depth was 231.5 meters and the mean was 113.5 meters. The minimum duration was less than a minute, the maximum duration was 24.2 minutes, and the mean duration was 10.5 minutes. U-shaped dives were still the most common shape for intermediate dives at 65%, but V-shaped dives were the next most frequently occurring shape at 20%, and Square-shaped dives were the least common at 15%.

The data from MdTag021 includes 249 dives, 59 (24%) of which were deep dives and 190 (76%) of which were shallow. MdTag021 performed one deep intermediate dive that was concurrent with MdTag020’s second deep intermediate dive, and to a depth of 375.5 m. During the first deep intermediate dive for MdTag020, MdTag021 only dove to 163.5 m and surfaced nine min sooner. For the third of MdTag020’s deep intermediate dives, there is a 2.63-hour period of missing data for MdTag021. However, based on known times that MdTag021 was at the surface, it does not appear that this individual conducted this dive (see the behavioral response section for more details). Excluding that dive, the minimum deep dive depth was 863.5, with a maximum depth of 1327.5 and mean of 1105.7 meters. Deep dive durations ranged from 39 to 71 minutes, with a mean of 50.7 minutes. Once again U-shaped dives were the most common dive shape for deep dives at 69.5%, with square-shaped dives performed 30.5% of the time and no V-shaped dives. Shallow dives ranged from the pre-set minimum depth of 50 meters to 255.5 meters with a mean of 102 meters, and durations ranged from 2.3 to 26.7 minutes, with a mean of 10.6 minutes. U-shaped dives remained the most common shape at 64.2%, but in this case square-shaped dives were the second most common at 18.9% and V-shaped dives were at a similar rate of 16.8%.

Table 3. Dive metrics for the combined dive record of MdTag020 and MdTag021. IDDI is the inter-deep dive interval.

	Median Duration (min)	Minimum Duration (min)	Maximum Duration (min)	Median Depth (m)	Minimum Depth (m)	Maximum Depth (m)	Minimum Shallow Dive Count	Maximum Shallow Dive Count
Deep Dive	50.7	13.8	71.0	1199.5	303.5	1423.5	--	--
IDDI	112.5	0.5	291.0	103.5	--	--	1	12
Shallow Dive	10.7	0.8	26.7	104.5	49.5	255.5	--	--

Since MdTag020 and MdTag021 were together for most of the period of MdTag020’s tag deployment, their dive data were very similar. In fact, other than in places where there is missing data for one of the tags, prior to the onset of sonar there are only two times where the deep dives differ between the two animals. The first is on August 11, 2021, at 19:15 shortly after the start of Phase A. Both animals went on a deep dive within a minute of each other, but MdTag020 surfaces at 19:47 only to immediately dive again to the same depth as MdTag021; both animals then surface together at 20:10. The second instance is the first aforementioned deep intermediate dive of MdTag020, which also occurred during Phase A. Both animals had completed a deep dive at 4:01 on August 13, 2021, with a subsequent intermediate dive to about 140 meters. Both animals dove again within a minute of each other at 5:35, but MdTag020 dove to 303.5 meters while MdTag021 only dove to 163.5 meters. MdTag021 surfaced at 5:54 and then did another intermediate dive at 5:57 to 119.5 meters; MdTag020 surfaced from their dive at 6:03 and MdTag021 surfaced at 6:06. They both performed 3 more intermediate dives, but out of time synchrony. At 7:10 MdTag021 began their next deep dive to 1103.5 meters, while MdTag020 didn't begin their deep dive until 7:32 and dove to 1327.5 meters. However, both animals surfaced synchronously at 8:21, dove again at 8:26, and performed the second anomalous intermediate dive together to 375.5 (391.5 meters) until 8:40 when they surfaced together again. Their dive synchrony is restored after this series of dives to once again diving and surfacing within a few minutes of each other for most of the remainder of the shared dive record.

In total, 41 synchronous deep dives were performed by these two animals over eight days. While in two deep dives the animals dove to the same depth, in most of the dives they were separated by 16 to 352 meters (mean 98.3 meters) while at the deepest point of their dives. The only time more than one deep dive was performed in a row without a typical IDDI were the three instances of a 300-500 meters dive being conducted immediately before or after a regular deep dive, and one instance when the pair conducted one deep dive, rested at the surface without diving for 123 minutes, then conducted another deep dive. This last instance occurred during a ULT that was conducted on August 15, 2021, during which no MFAS occurred (Table 2).

At least eight times for MdTag020 and six times for MdTag021, subsequent deep dives went to the exact same depth as the previous deep dive, and in a few cases this happened three deep dives in a row, possibly indicating a return to the same prey patch. This can be observed in the figures of dive depth for each animal (Figure 3 and Figure 4). Included on these figures are the bathymetric depths at each 5 minutes time interval of the crawl-modeled track. Deep dive depths were slightly correlated with bathymetric depth such that, as might be expected, deeper dives occurred in deeper water. Dive depths for MdTag020 occurred at a mean of 71% of the water column, ranging from 49.5% and descending all the way to the seafloor (100%). Deep dive depths were similar for MdTag021 although were generally a bit shallower (Figure 5), with dives occurring at a mean of 66% of the water column, ranging from 38% to 100%.

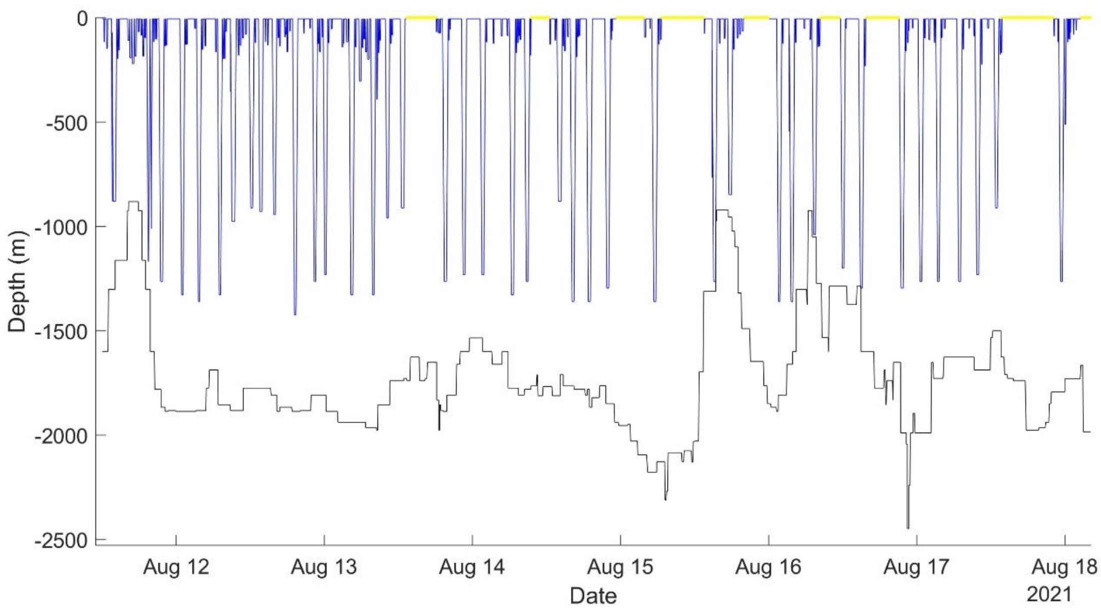


Figure 3. Dive profile for MdTag020 in blue plotted over the corresponding bathymetric depths in black at each 5-minute track position. Yellow bars indicate periods when there were no dive or surface data available.

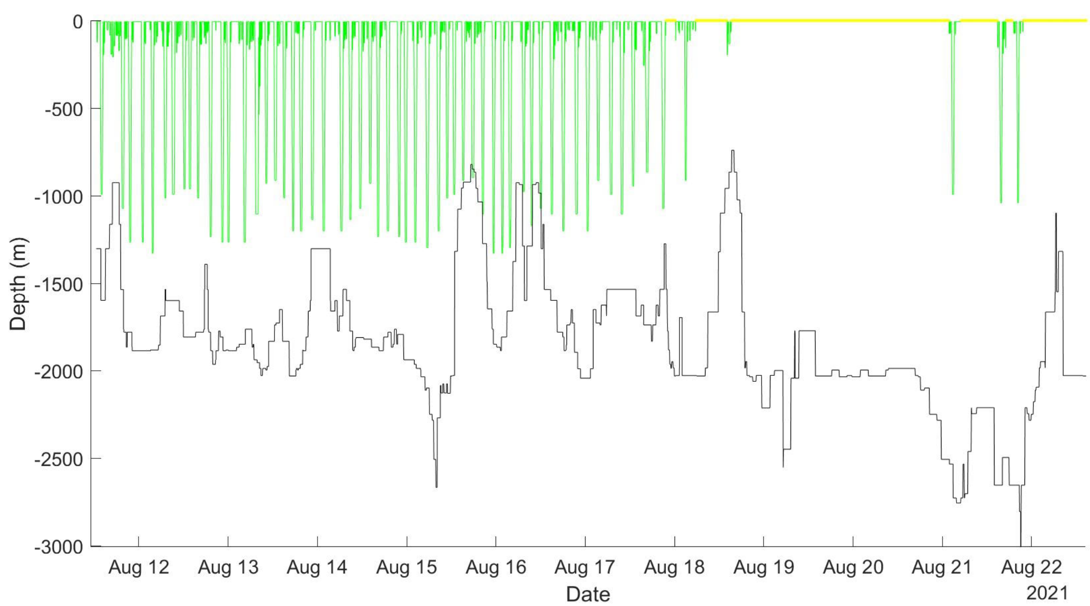


Figure 4. MdTag021 dive profile (in green) over the corresponding bathymetric depths in black throughout the track. Periods when there are no dive or surface data are highlighted in yellow.

For MdTag020 and MdTag021, IDDIs ranged in duration from 18.3 to 291 min (mean 115.6 min) and contained 1-12 dives. There were two brief IDDIs between consecutive deep dives that included 300-500 m deep intermediate dives. During one IDDI, MdTag020 remained at the surface for 131.5

min while MdTag021 conducted one shallow dive; and during another IDDI. Finally, both whales had the previously mentioned 123-minute IDDI where both animals remained on the surface the entire time.

3.3.1 Statistical analyses of baseline tag dive data

Pearson correlation tests were run against variables in the combined dive dataset as an initial look for diel patterns. As would be expected, significant correlations occurred between deep dive depth and duration ($R = 0.68$, $p= <0.001$), between intermediate dive depth and duration ($R = 0.5$, $p = < 0.001$), and between IDDI duration and number of intermediate dives per IDDI ($R = 0.63$, $p = <0.001$). There was also a significant correlation between the number of intermediate dives per IDDI and their average depth per IDDI ($R = 0.27$, $p = 0.006$; Figure 5.), such that intermediate dives that occurred in higher numbers per IDDI tended to be deeper on average (100–150 meters) while when fewer dives were performed they could be as intermediate as 50 meters on average. However, one of the deepest intermediate dives to 231.5 meters was performed as a single dive between two deep dives. Deep dive depth also correlated with time of day ($R = -0.21$, $p = 0.33$) such that slightly shallower deep dives were performed during the daytime, and slightly deeper dives were performed at night (Figure 6.). Intermediate dive duration was also significantly correlated with time of day ($R= -0.12$, $p = 0.04$), with slightly longer intermediate dives during the daytime, especially at dawn and dusk (Figure 6.). Coupled with this, IDDI duration ($R=-0.19$, $p = 0.048$) and the average intermediate dive depth during IDDIs ($R = -0.20$, $p = 0.038$) were also significantly correlated with time of day such that there were more intermediate dives during the day (Figure 6. Figure 6.) but IDDI durations were shorter during the day than at night (Figure 5.).

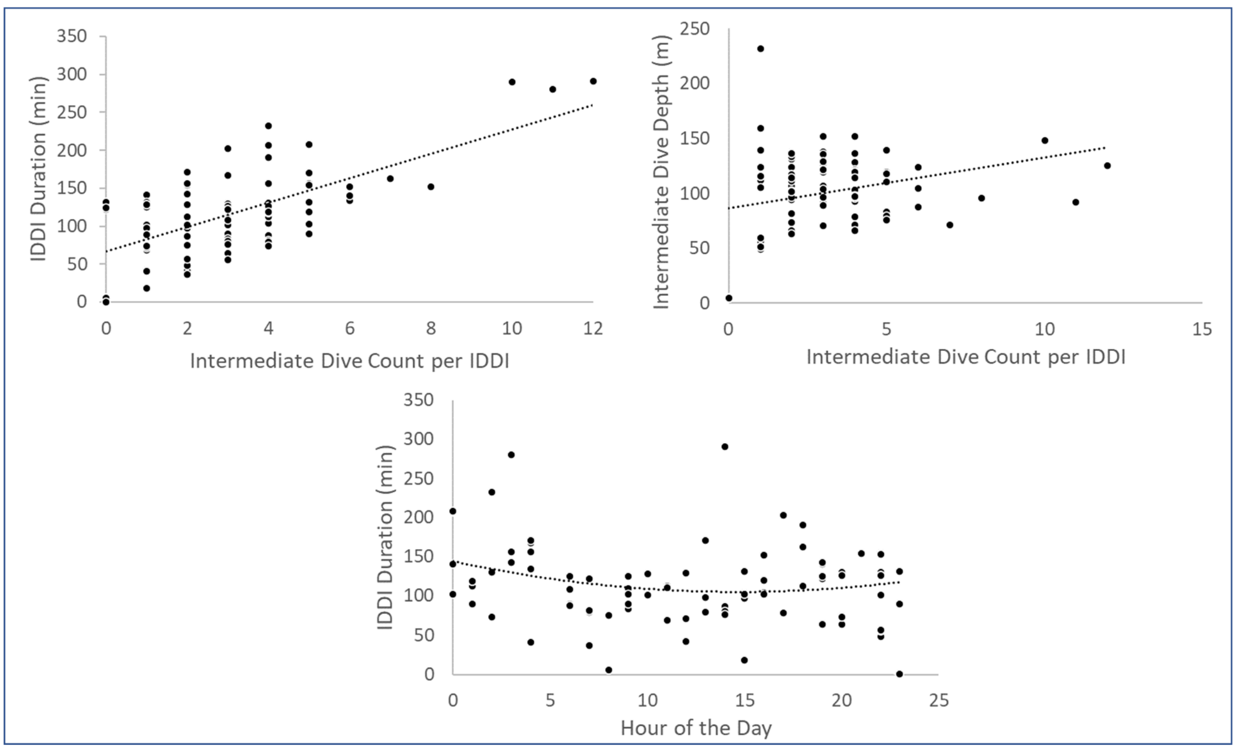


Figure 5. Top left: IDDI intermediate dive count compared to overall IDDI duration (minutes.). Top right: IDDI intermediate dive count compared to intermediate dive depth (m) and. Bottom: overall IDDI duration (min) compared to the hour of day.

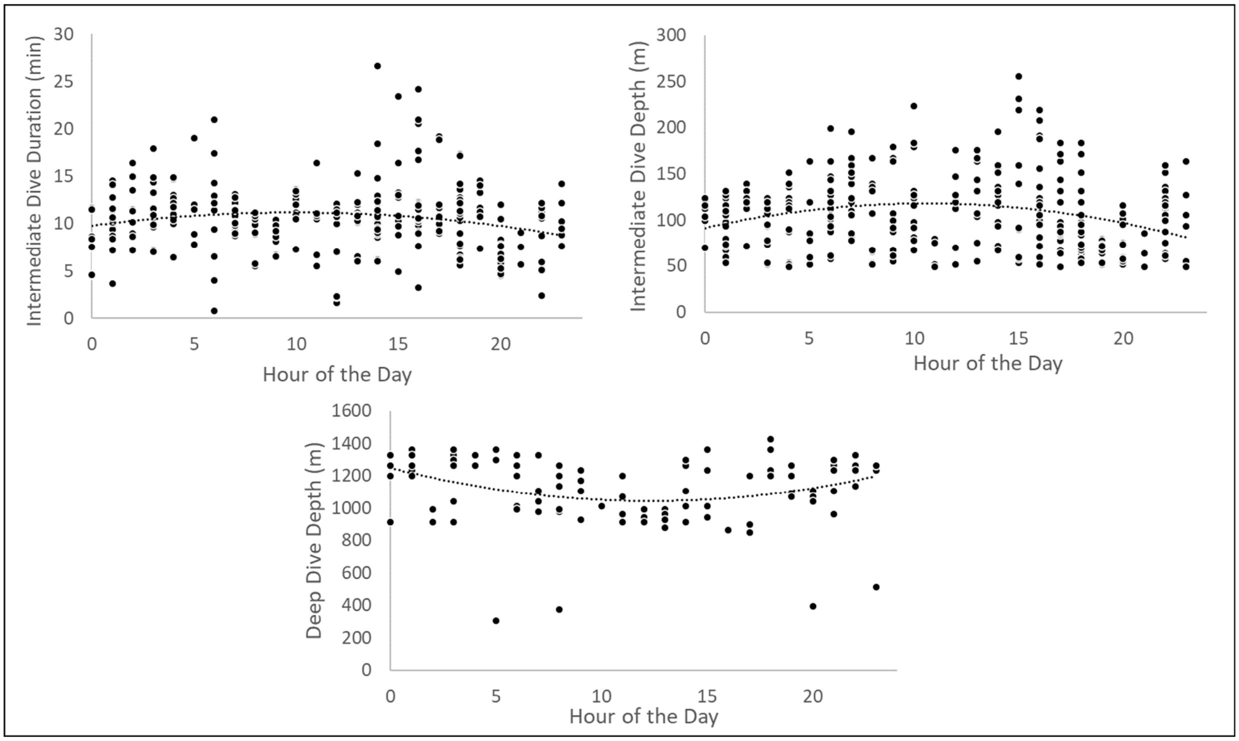


Figure 6. Top left: Intermediate dive duration compared to the time of day. Top right: intermediate dive duration compared to the time of day. Bottom: deep dive depth compared to the hour of day.

3.3.2 Modeled dive data

Using dive statistics derived from the data from MdTag020 and MdTag021, combined with the known times at the surface based on satellite and MOTE uplinks, dive behavior could be estimated for MdTag017 and MdTag022. First, if multiple uplink attempts occurred within a minute of each other, animals were assumed to be at the surface the entire time. If the time between known surfacings was less than 20 minutes, the whale was assumed to be conducting a intermediate dive, whereas if the time between surfacings was 20 to 75 minutes, the animals were assumed to be conducting a deep dive. If the period between known surfacings was longer than 75 minutes, the data was assumed to be lost and was not considered further. Using these values, MdTag017 was estimated to have conducted 26 deep dives (mean duration 42.5 minutes) and 261 intermediate dives (mean duration 4.0 minutes) over 73 IDDIs. The IDDIs were estimated to have between 0 and 5 intermediate dives and a mean duration of 14.1 minutes. Similarly, MdTag022 had 190 deep dives (mean duration 49.5 minutes) and 1076 intermediate dives (mean duration 8.6 minutes) over 264 IDDIs. There were estimated to be between 0 and 18 intermediate dives per IDDI, with a mean duration of 44.6 minutes.

3.3.3 GVPs and tag dives

For the period of attachment of MdTag021's tag from August 11 2021, at 12:00 to August 24, 2021 at 19:30 there were a total of 524 Blainville's GVPs detected across the PMRF range. There were 56 GVPs that fit the initial criteria for MdTag020, and 53 that fit the criteria for MdTag021. Of these, there were 11 and 15 GVPs that overlapped in time and space with MdTag020 and MdTag021 respectively, however, the tags did not have dive data during the times of the GVPs. This left 29 dives total with times that matched well with the GVPs. Of the remaining dives, 23 dives from both MdTag020 and MdTag021 met the temporal criteria of starting and ending around the echolocation period. While this is not conclusive evidence that the GVPs match the dives of the tagged whales, it is highly likely given the spatial and temporal overlap.

Of those likely matching dives, echolocation pulses were detected for 1.1 - 8.5 minutes (mean 5.7 minutes) after the whales dove, at estimated depths of 69.7 - 645.7 meters (mean 429.5 meters; Table 4). The echolocation pulses ceased 23.4 – 3.1 minutes (mean 12.7 minutes) before the animals surfaced. The clicks ended at depths from 253.8 meters down to the maximum depths of some dives, such that they may have ceased clicking before beginning their ascent in up to 10 dives. However, these longer periods without clicks tended to be detected on hydrophones along the edge of the range, and the animals may have continued to click but moved away from the range and were no longer detected. Alternately, the estimated ascent and descent rates for the dives could be incorrect, and therefore the animals could have actually started to ascend before ceasing to click. These dives were detected on 1 – 4 hydrophones per dive and occurred eight subsequent times on the same primary hydrophone or set of hydrophones. Additionally, it is important to note that when tagged there were seven individuals in this group, and thus it is possible that some of the detected echolocation pulses in these periods were of non-tagged whales in the same group.

Table 4. Tag dive start and end times compared against the acoustically detected Group Vocal Periods (GVPs) on the range, with estimates of the times when clicks started and stopped and the relative modeled depths at those times. The descent and ascent time differences are the offset in min between the tag dive start or end and the echolocation pulse detections start or end.

	Date	Tag Dive Start Time	Tag Dive End Time	Max Dive Depth	GVP Start	GVP End	Descent time diff	Ascent time diff	Click Start Depth	Click End Depth
MdTag020	8/12/2021	10:37:46	11:25:50	1327.5	10:42:31	11:08:56	4.75	16.90	403.6	1327.5*
MdTag021	8/12/2021	10:39:04	11:26:20	1263.5	10:42:31	11:08:56	3.45	17.40	283.8	1263.5*
MdTag020	8/12/2021	13:19:40	14:07:02	1359.5	13:25:14	14:03:51	5.57	3.18	491.6	281.1
MdTag021	8/12/2021	13:19:14	14:06:58	1327.5	13:25:14	14:03:51	6.00	3.12	513.4	266.7
MdTag020	8/12/2021	21:49:08	22:40:26	911.5	21:56:39	22:22:51	7.52	17.58	410.9	911.5*
MdTag021	8/12/2021	21:49:42	22:40:54	959.5	21:56:39	22:27:11	6.95	13.72	400.8	790.9
MdTag020	8/12/2021	23:21:00	0:07:16	927.5	23:28:42	23:54:54	7.70	12.37	617.4	927.5*
MdTag021	8/12/2021	23:22:24	0:07:52	959.5	23:28:42	23:54:54	6.30	12.97	531.8	959.5*
MdTag020	8/13/2021	4:52:54	5:44:36	1423.5	4:56:18	5:35:16	3.40	9.33	288.0	790.7
MdTag020	8/13/2021	--	--	--	--	--	--	--	--	--
MdTag020	8/13/2021	8:06:54	8:54:12	1263.5	8:10:13	8:35:30	3.32	18.70	272.6	1263.5*
MdTag021	8/13/2021	8:04:54	8:53:52	1263.5	8:10:13	8:35:30	5.32	18.37	422.1	1263.5*
MdTag020	8/13/2021	22:18:26	23:06:20	911.5	22:26:55	22:55:18	8.48	11.03	645.7	839.8
MdTag021	8/13/2021	22:19:24	23:07:08	911.5	22:26:55	22:55:18	7.52	11.83	574.1	903.9
MdTag020	8/14/2021	8:14:44	9:04:44	1231.5	8:20:13	8:58:17	5.48	6.45	540.2	635.5
MdTag021	8/14/2021	8:14:44	9:04:30	1135.5	8:20:13	8:58:17	5.48	6.22	500.4	567.4
MdTag020	8/14/2021	11:16:06	12:08:50	1231.5	11:21:56	11:54:33	5.83	14.28	419.2	1026.3
MdTag021	8/14/2021	11:16:00	12:08:44	1199.5	11:21:56	11:54:33	5.93	14.18	539.9	1199.5*
MdTag020	8/14/2021	16:00:26	16:59:14	1327.5	16:06:37	16:42:05	6.18	17.15	429.5	1191.3

MdTag021	8/14/2021	16:00:52	16:59:16	1199.5	16:06:37	16:42:05	5.75	17.18	363.4	1086.0

	Date	Tag Dive Start Time	Tag Dive End Time	Max Dive Depth	GVP Start	GVP End	Descent time diff	Ascent time diff	Click Start Depth	Click End Depth
MdTag020	8/14/2021	18:27:10	19:18:18	1263.5	18:33:54	19:13:08	6.73	5.17	511.9	392.8
MdTag021	8/14/2021	18:27:06	19:18:02	1135.5	18:31:02	18:58:23	3.93	19.65	269.8	1135.5*
MdTag020	8/15/2021	4:27:46	5:27:16	1359.5	4:34:47	5:08:45	7.02	18.52	493.3	1301.8
MdTag021	8/15/2021	4:30:28	5:27:26	1199.5	4:34:47	5:08:45	4.32	18.68	279.7	1199.5*
MdTag020	8/16/2021	11:18:08	12:08:48	1359.5	11:23:45	11:56:29	5.62	12.32	463.7	1016.9
MdTag021	8/16/2021	11:18:08	12:08:52	1327.5	11:23:45	11:56:29	5.62	12.38	452.2	997.0
MdTag020	8/16/2021	13:20:50	14:13:46	1359.5	13:27:09	14:02:15	6.32	11.52	499.2	910.1
MdTag021	8/16/2021	13:22:20	14:13:48	1295.5	13:27:09	14:02:15	4.82	11.55	485.0	1162.9
MdTag020	8/16/2021	17:01:04	17:51:10	1039.5	17:05:57	17:41:02	4.88	10.13	311.8	646.9
MdTag021	8/16/2021	17:04:52	17:51:30	975.5	17:05:57	17:41:02	1.08	10.47	69.7	673.7
MdTag020	8/16/2021	21:39:12	22:26:08	1199.5	21:44:23	22:13:21	5.18	12.78	407.6	1005.3
MdTag021	8/16/2021	21:40:18	22:26:32	1071.5	21:44:23	22:13:21	4.08	13.18	378.5	1071.5*
MdTag020	8/17/2021	--	--	--	--	--	--	--	--	--
MdTag021	8/17/2021	0:35:14	1:29:54	1103.5	0:39:29	1:06:30	4.25	23.40	264.0	1103.5*
MdTag020	8/17/2021	7:08:00	8:06:54	1295.5	7:12:55	8:03:09	4.92	3.75	332.7	253.8
MdTag021	8/17/2021	7:13:38	8:06:28	1103.5	7:12:55	8:03:09	0.72	3.32	5	277.1
MdTag020	8/17/2021	10:12:24	11:07:04	1263.5	10:19:05	10:54:25	6.68	12.65	475.3	899.6
MdTag021	8/17/2021	10:12:34	11:07:14	1199.5	10:19:05	10:54:25	6.52	12.82	440.0	865.3
MdTag020	8/17/2021	13:05:26	13:54:44	1263.5	13:11:29	13:42:41	6.05	12.05	477.1	950.2
MdTag021	8/17/2021	13:05:16	13:54:44	911.5	13:11:29	13:42:41	6.22	12.05	458.2	888.2

	Date	Tag Dive Start Time	Tag Dive End Time	Max Dive Depth	GVP Start	GVP End	Descent time diff	Ascent time diff	Click Start Depth	Click End Depth
MdTag020	8/17/2021	16:29:12	17:22:38	1263.5	16:37:15	17:11:14	8.05	11.40	585.7	829.4
MdTag021	8/17/2021	16:31:00	17:22:52	991.5	16:37:15	17:11:14	6.25	11.63	477.9	889.5
MdTag020	8/17/2021	19:25:12	20:20:46	1231.5	19:24:51	20:07:13	-0.35	13.33	NA	879.8
MdTag021	8/17/2021	19:25:02	20:20:42	1103.5	19:24:51	20:07:13	-0.18	13.29	NA	1036.6
MdTag020	8/17/2021	22:29:00	23:19:00	911.5	22:35:54	23:02:00	6.90	17.00	387.0	911.5*
MdTag021	8/17/2021	22:28:20	23:18:22	943.5	22:35:54	23:02:00	7.57	16.37	439.0	943.5*

Click end depths with an asterisk indicate that according to the modeled dive depths, at the time the clicks stopped the animals were still at their maximum dive depths. There is no dive data for one dive from MdTag020 and for one dive from MdTag021.

MdTag017 was on the range for a relatively short time, and only had five possible GVPs that occurred within 6 km of their track. Of those, they were known to be at the surface for at least one, leaving only four possible matches. MdTag022 was on the range for longer periods of time, coming and going at least three times between August 18-28, 2022. There were 14 GVPs that occurred within 6 km of their track; of these, at least four were highly unlikely based on known surface periods, leaving 10 possible matches.

3.4 MFAS EXPOSURES AND RECEIVED LEVELS

All three of the Blainville's beaked whales that overlapped spatially and temporally with SCCs had similar exposure paradigms and received levels. MdTag020 and MdTag021 were exposed to 15 periods of MFAS, ranging in duration from 2 minutes to 2.21 hours, while MdTag022 was exposed to 13 periods of MFAS, ranging in duration from 1 minute to 2.3 hours. All three whales were on the south-western edge of the range when MFAS began, and all moved away from the area of all three sources by 17.5-70.3 km.

3.4.1 MdTag020

MdTag020 was exposed to all three MFAS sources analyzed in this effort (hull-mounted, helicopter-dipping and sonobuoy). The first exposures were from sonobuoys on August 17, 2021, at about 17.5 km, with estimated received levels of 73 - 104 dB re 1 μPa (Figure 7). Distances to sonobuoys increased for these first sonobuoy pings, indicating the animal was moving away from the MFAS, even though levels were low at 105 dB re 1 μPa. Additional sonobuoy exposures occurred a few hours later at levels < 80 dB re 1 μPa, at the same time as the onset of hull-mounted MFAS. The majority of sonobuoy exposures occurred at distances of 35 to 55 km and received levels of 53 to 104 dB re 1 μPa.

The first helicopter-dipping sonar had a received level of 114 re 1 μPa; additional helicopter-dipping MFAS exposures had received levels of 116 – 122 dB re 1 μPa. The closest distance for helicopter-dipping sonar was 40 km. The maximum median estimated received levels for helicopter-dipping sonar exposures ranged from 101 to 122 dB re 1 μPa.

Hull-mounted MFAS exposures began on 17 August at around 140 dB re 1 μPa, with additional exposures on August 18 and 19, 2021 (Figure 7). Hull-mounted MFAS distances ranged from 24 to 60 km, with maximum median estimated received levels ranging from 124.3 to 145.7 dB re 1uPa. The whale was on the range for the first exposures to sonobuoys and helicopter-dipping MFAS, and for the first hull-mounted MFAS exposure, but then moved off the range for the second bout of MFAS (Figure 8). This whale remained just off the western edge of the range for the duration of their tag deployment.

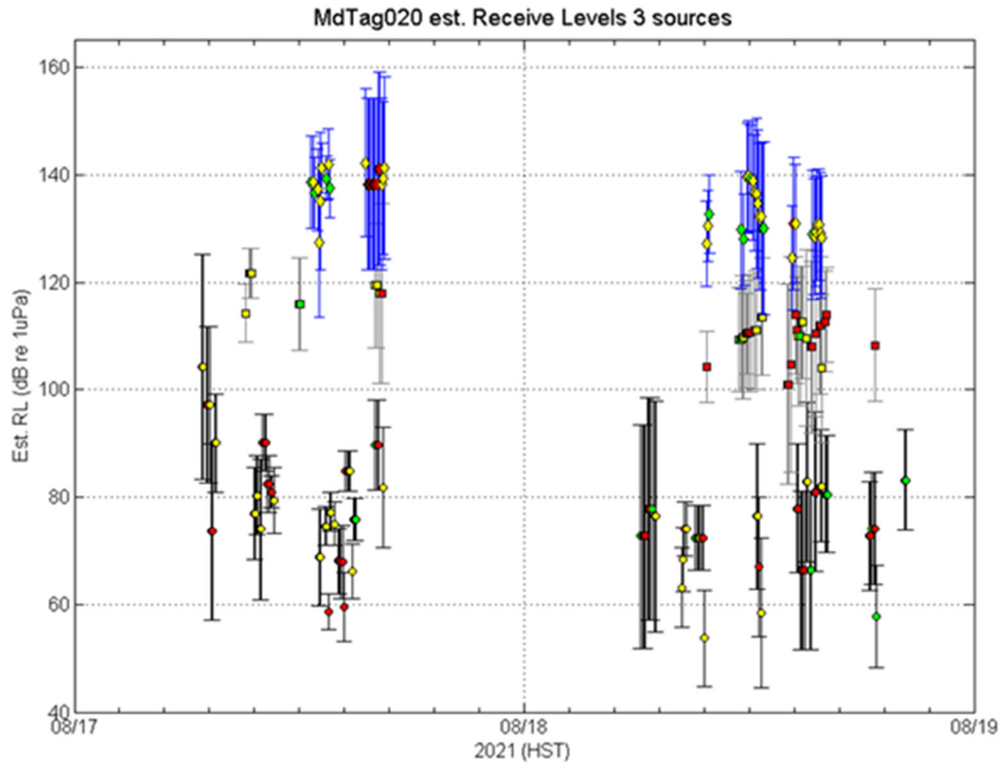
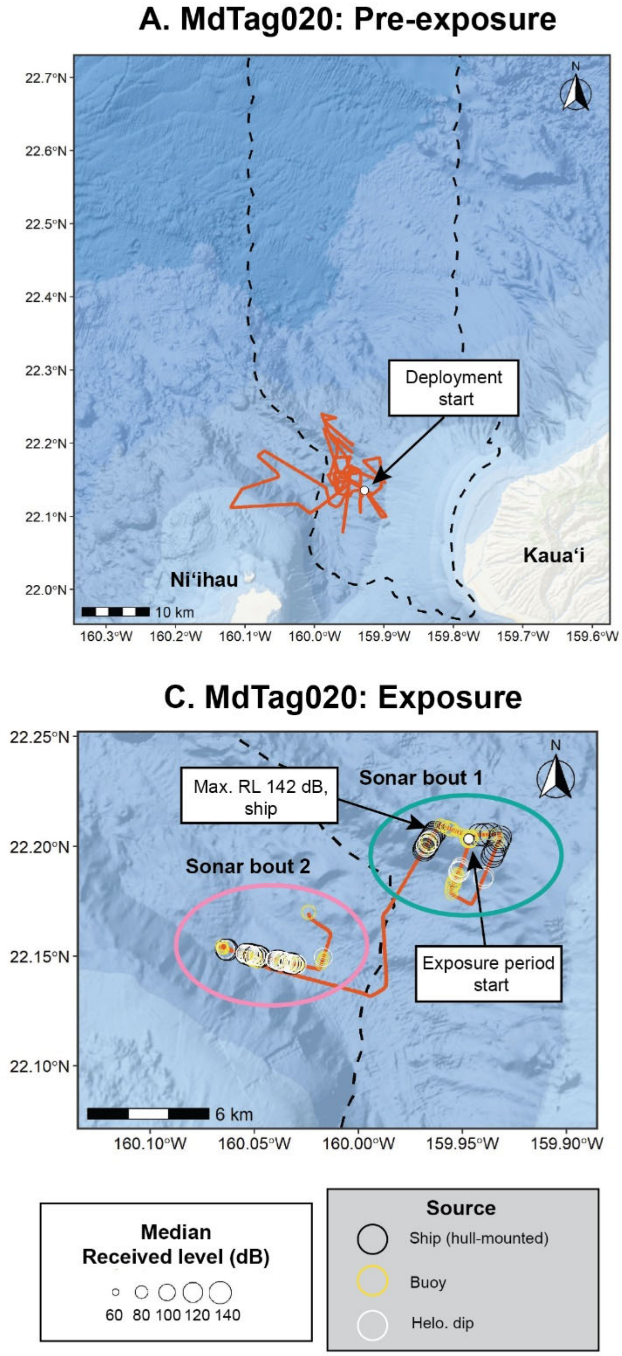


Figure 7. Estimated received levels for hull-mounted MFAS (blue) and helicopter-dipping (grey) and sonobuoy (black) MFAS for MdTag020 provided as maximum median +/- 2 standard deviations in 5 minute bins. The relative amount of sonar activity in each bin is indicated as a stoplight color coded symbol with green for lowest activity, yellow for moderate, and red for higher activity.



- Two bouts of sonar are shown for this particular exposure period; mean ship locations for blocks of sonar within each bout are shown in panel B, as well as closest helicopter dipping and buoy sonar positions. The PMRF is outlined by the dashed black line.

Figure 8. Movements of MdTag020 prior to, during, and after exposure periods, with corresponding median received levels (ERL) shown during the exposure period (panel C).

3.4.2 MdTag021

The estimated received level values for this whale were very similar to those for MdTag020 due to their synchronized movements. Exposures from sonobuoy and helicopter-dipping MFAS initially occurred on August 17, 2021 and continued through August 18, 2021 (Figure 9). The first hull-mounted MFAS exposure began on August 17, 2021, with received levels of 135 dB re 1 µPa. The closest distance between the whale and the ship was at the start of that first period of hull-mounted MFAS, estimated to be 19.5 km. MdTag021 was exposed to a maximum median received level of 142.3 dB re 1 µPa from hull-mounted MFAS, with the majority of received levels in the range of 125 – 140 dB re 1 µPa. Just like MdTag020, this animal was on the range for the first exposures to helicopter-dipping and sonobuoy MFAS, but after the first hull-mounted MFAS exposure they moved just off the range to the west (Figure 10), where they were exposed to their second bout of MFAS. The tag remained attached to MdTag021 longer than it did for MdTag020, so it can be observed that they moved back onto the range after the SCC.

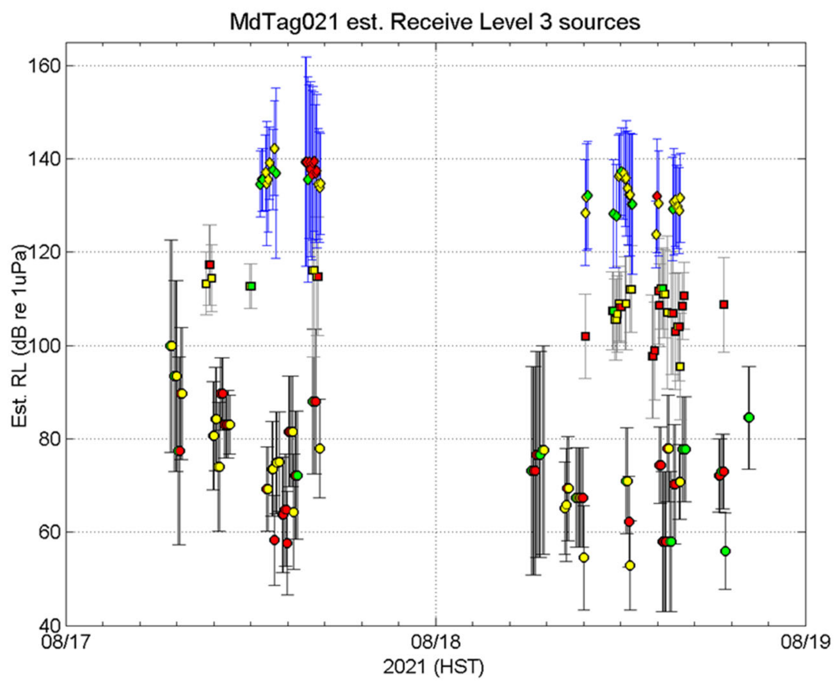
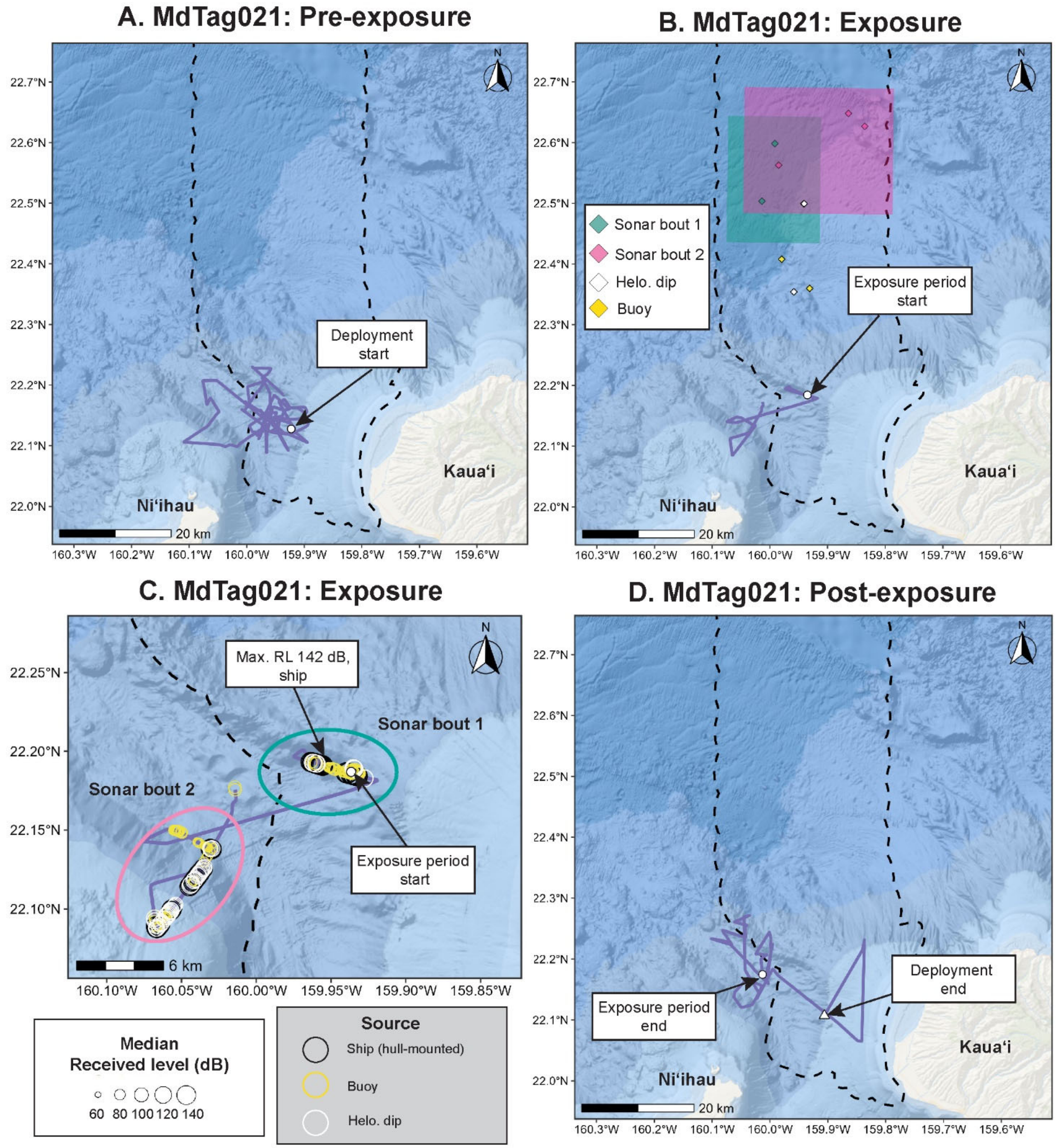


Figure 9. Estimated receive levels for hull-mounted MFAS (blue) and helicopter-dipping (gray) and sonobuoy (black) MFAS for MdTag021 provided as maximum median +/- 2 standard deviations in 5 min bins. The relative amount of sonar activity in each bin is indicated as a stoplight color coded symbol with green for lowest activity, yellow for moderate, and red for higher activity.



- Two bouts of sonar are shown for this particular exposure period; mean ship locations for blocks of sonar within each bout are shown in panel B, as well as closest helicopter dipping and buoy sonar positions. The PMRF is outlined by the dashed black line.

Figure 10. Movements of MdTag021 prior to, during, and after exposure periods, with corresponding median received levels (ERL) shown during the exposure period (panel C).

3.4.3 MdTag022

MdTag022 was exposed to both hull-mounted and sonobuoy MFAS in August 2022. The initial brief exposure was to an active sonobuoy on August 19, 2022, while the initial exposure to the first bout of hull-mounted MFAS began a few hours later and lasted for 20 minutes; this period had the highest estimated median received levels between 144 to 147.5 dB re 1 µPa with relatively low standard deviations (Figure 11). Distances for these first exposures were estimated to be about 34 km. Exposures to sonobuoys occurred at distances between 26.6 to 66.5 km, including 95% CI positions, and received levels were much lower than those of hull-mounted MFAS, with no sonobuoy MFAS median received level exceeding 100 dB re 1 µPa (Figure 11). MdTag022 had already moved just off the range to the west, to a very similar area that MdTag020 and MdTag021 occupied in 2021, when the first bout of MFAS began (Figure 12). They remained generally in this are for the rest of Phase B, although they did move further west at one point and then further south, so the second group of MFAS bouts had lower received levels (Figure 11). This animal also returned to the range after the SCC.

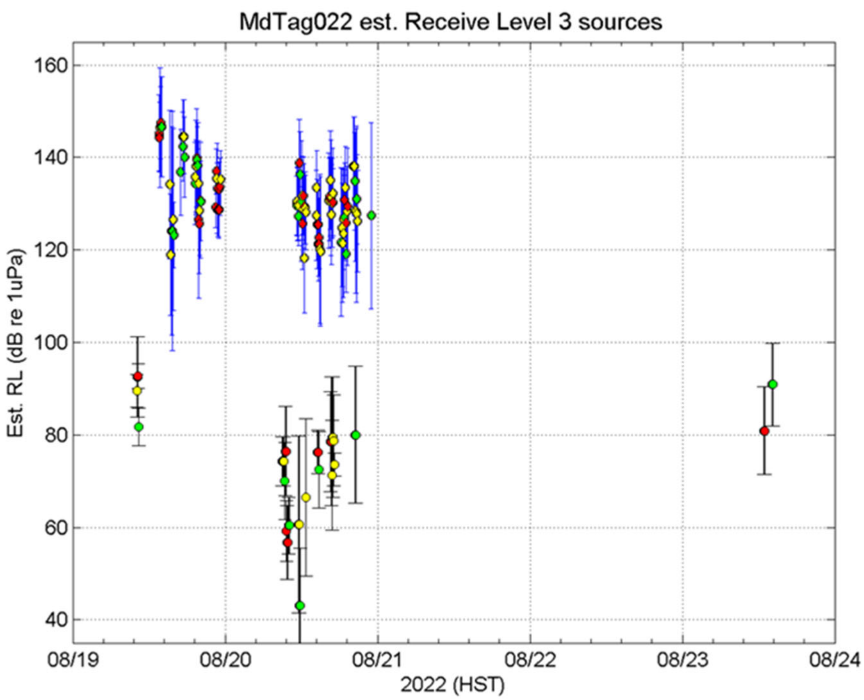
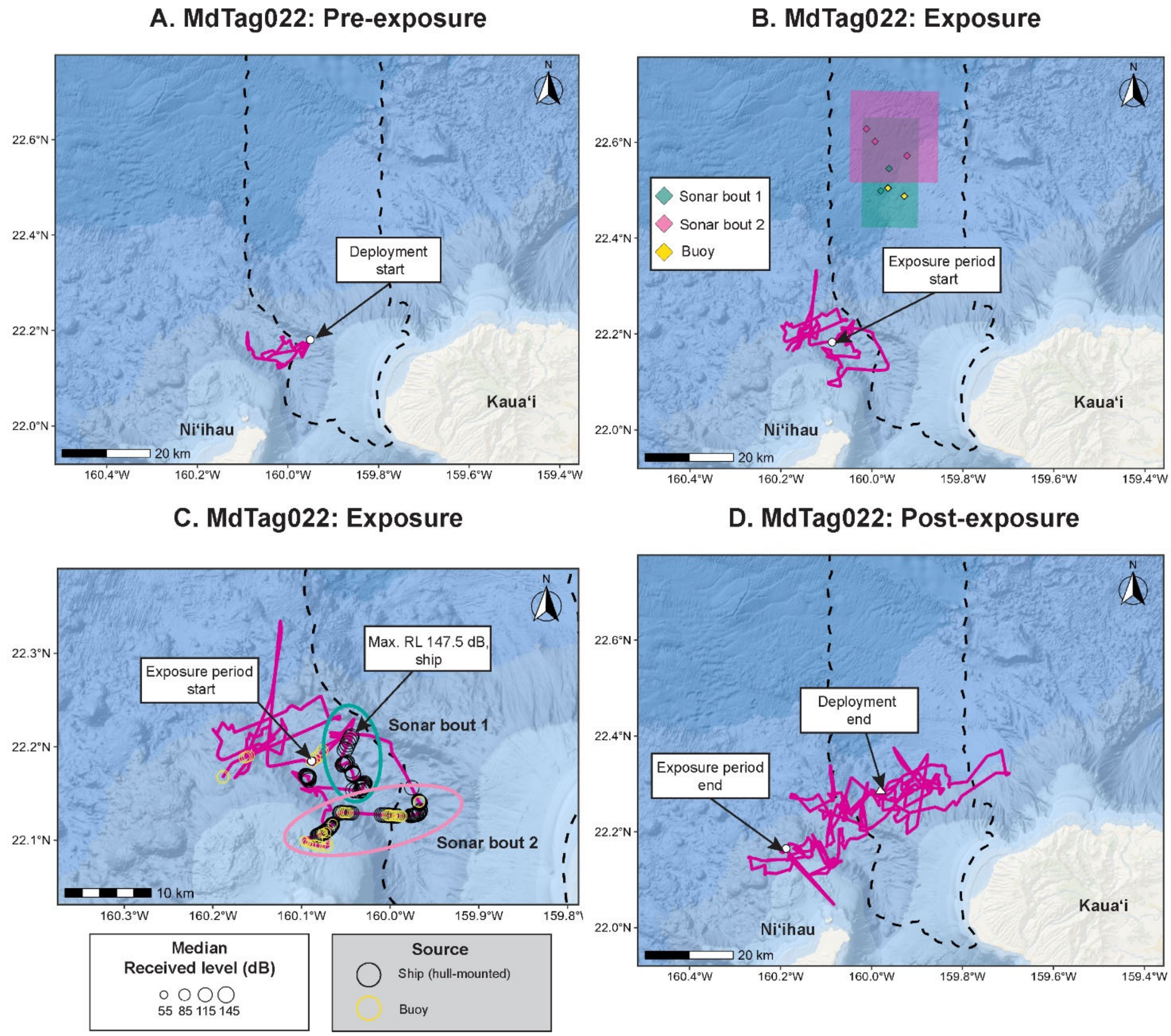


Figure 11. Estimated received levels for hull-mounted MFAS (blue) and sonobuoy MFAS (black) for MdTag022 provided as maximum median +/- 2 standard deviations in 5 min bins. The relative amount of sonar activity in each bin is indicated as a stoplight color coded symbol with green for lowest activity, yellow for moderate, and red for higher activity.



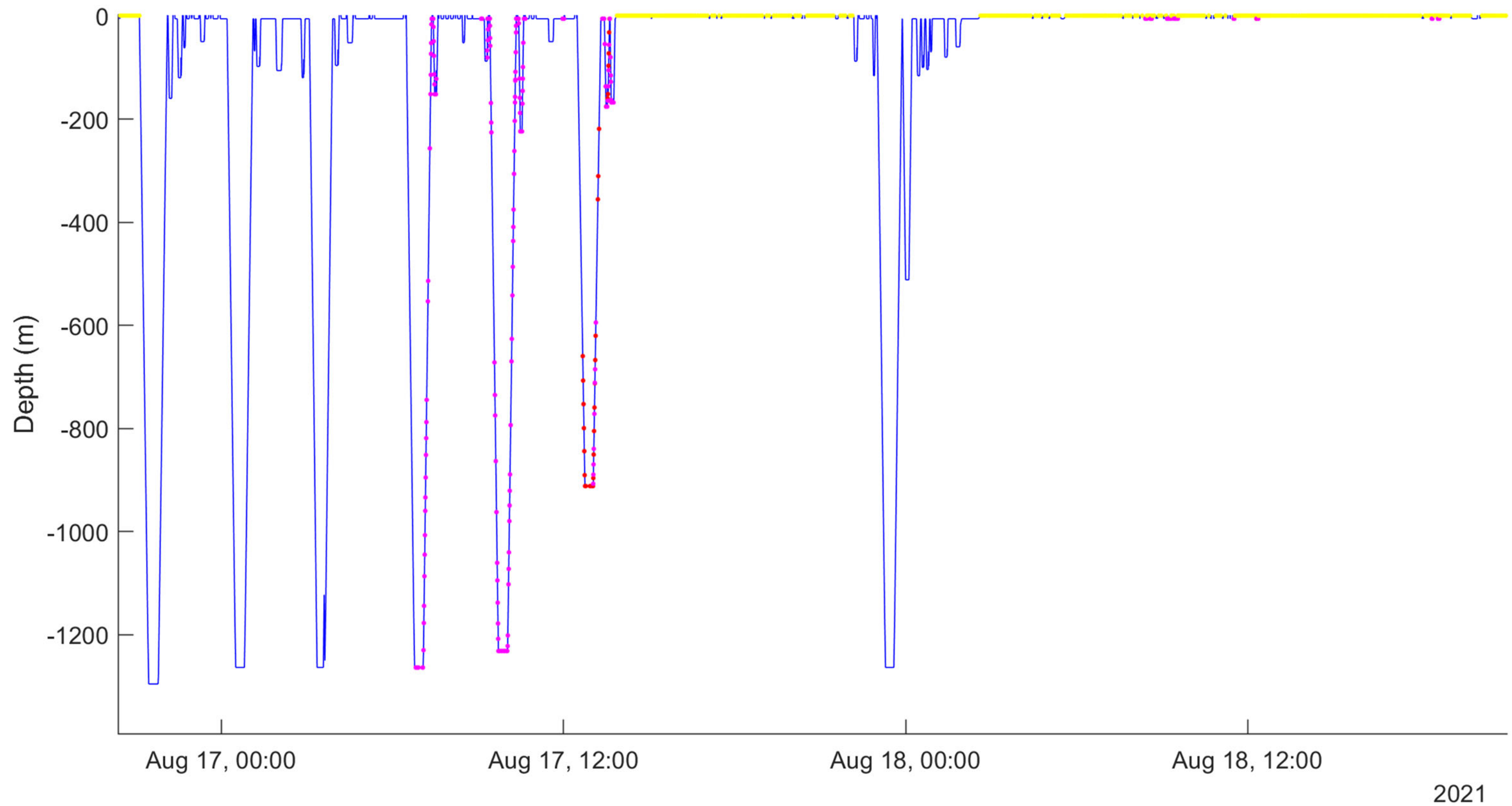
- Two bouts of sonar are shown for this particular exposure period; mean ship locations for blocks of sonar within each bout are shown in panel B, as well as closest buoy sonar positions. The PMRF is outlined by the dashed black line.

Figure 12. Movements of MdTag022 prior to, during, and after exposure periods, with corresponding median received levels (ERL) shown during the exposure period (panel C).

3.5 DIVE BEHAVIORAL RESPONSE ANALYSIS

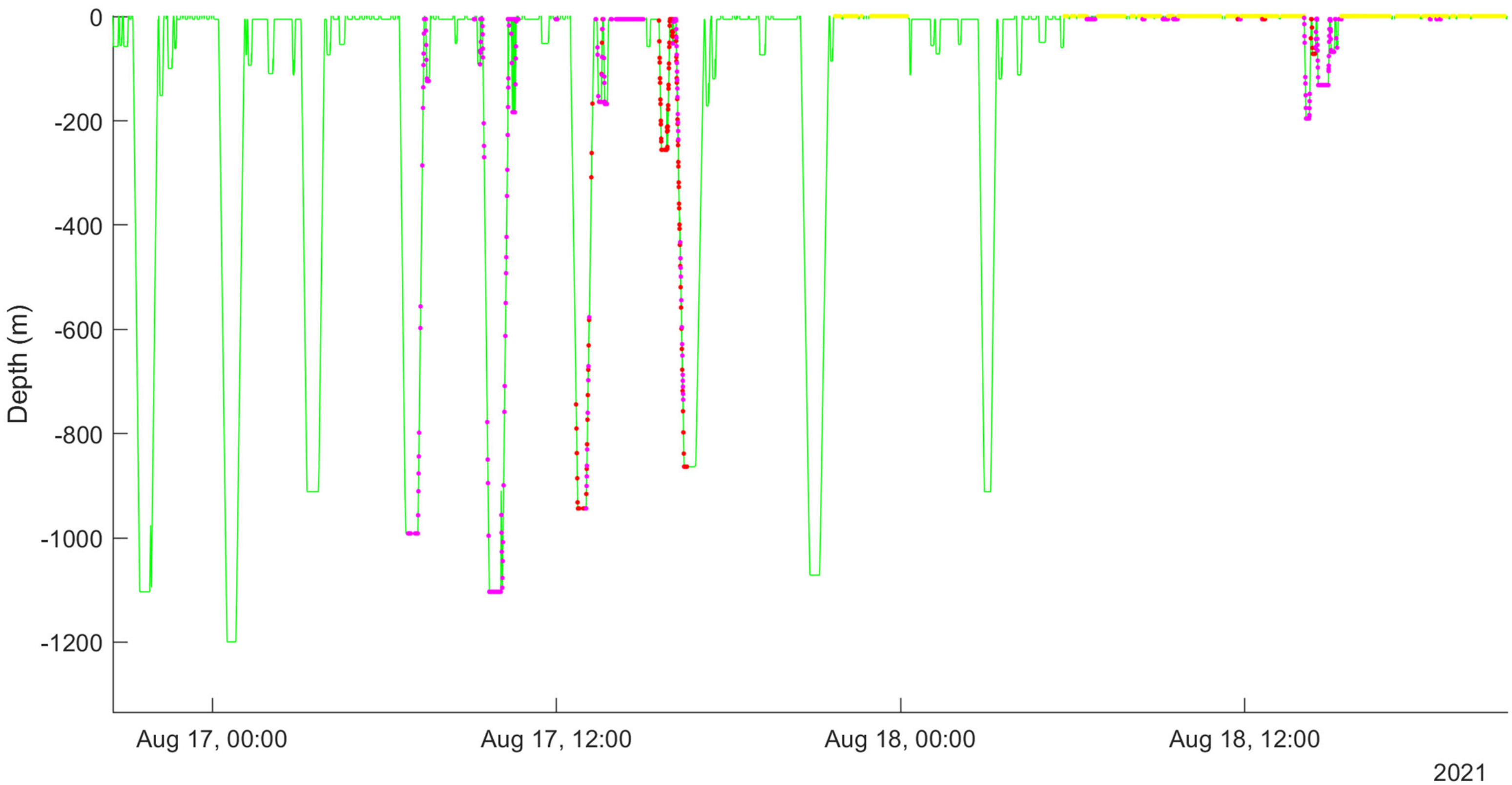
As described above, the first exposures for MdTag020 and MdTag021 were to sonobuoys dropped about 17.5 km away with received levels generally below 100 dB. As depicted in Figure 17 and Figure 18 these whales were apparently together and at the bottom of a deep foraging dive when the exposure period began. No apparent response or change in dive behavior was observed based on the data available and the percentile evaluation of dive parameters.

This dive matched to a GVP on the range and was a full foraging dive with no cessation of clicking. The sonobuoy exposure continued through the first intermediate dive, followed by a break in MFAS while the animals were at the surface. Then the whales conducted another deep foraging dive during a second exposure period that included MFAS from both sonobuoys and helicopter dips, although received levels were still low (Figure 7 and Figure 9). This dive may have matched a GVP on the range but started at the same time as the foraging clicks which would be unusual (clicks started at 19:24:51, tag dives start at 19:25:02 and 19:25:12), although other animals in the group could have dived sooner. An early onset of clicks could also possibly indicate a vocal response to maintain coordination. Finally, the third exposure period began when the whales were about 707 meters deep during their descent to what would be a 911.5 meters dive, which was considerably shallower than the previous five foraging dives but within the range of normal dive depths. This was the first exposure to hull-mounted MFAS, and as this dive also matched a GVP it appears they continued to forage throughout the dive, which lasted 50.0 min. Following this deep dive, the group conducted two intermediate dives, stayed at the surface for 79 min, then conducted three more intermediate dives for an IDDI lasting 170.7 min. The dive record for MdTag020 is missing during this period, but it is during this time that the dive records begin to differ between the two whales. MdTag021 conducted a deep dive to 863.5 meters for 59.1 min, but it is unknown whether MdTag020 conducted this dive or not (Figure 13 and Figure 14). Furthermore, this deep dive was off the range, so it is unknown whether it was an actual foraging dive or not. The whales may have split up during this period, based on their subsequent dive and movement behavior (see the next section), as both whales do conduct another deep dive each but at different times and to different depths.



- The yellow bar at the surface indicates periods of missing data, while blue dots at the surface are known times the animal was at the surface. Pink dots are 5-minute bins with sonobuoy or helicopter dipping MFAS exposures, red dots are 5-minute bins with hull-mounted MFAS exposures.

Figure 13. Dive record of MdTag020 starting August 16, 2021, at 21:00 HST through August 18, 2021, at 23:00 HST.



- The yellow bar at the surface indicates periods of missing data, while green dots at the surface are known times the animal was at the surface. Pink dots are 5-minute bins with sonobuoy or helicopter dipping MFAS exposures, red dots are 5-minute bins with hull-mounted MFAS exposures.

Figure 14. Dive record of MdTag021 starting August 16, 2021, at 21:00 HST through August 18, 2021, at 23:00 HST.

Most of the deep foraging dive metrics during and after the exposures fell between the 25 and 75 percentiles of the baseline dive data (Table 5). Two deep dives were slightly longer in duration, but shorter than the 97.5 percentile duration. The deep dive at the onset of hull-mounted MFAS was shallower than the 25th percentile, but deeper than the 2.5 percentile depth. There was one unusually long IDDI (202 min) after the longest (59.1 min), shallowest (863.5 meters) deep dive with MFAS but only for MdTag021, and all three metrics were still within the 95th percentile of baseline behavior.

In contrast, metrics were higher than the 75th percentile for many of the IDDI metrics during and after exposure periods (Table 5). Mean intermediate dive durations were longer than median values from baseline data, with longer mean intermediate dives than the 75th percentile in four out of five exposure/post-exposure periods for MdTag021. Mean intermediate dive depths were over the 75th percentile range of baseline data during two of the three IDDIs for MdTag020 and for two of the five IDDIs for MdTag021. Similarly, the maximum intermediate dive depths were generally deeper during and after exposure periods. In the same two IDDIs for MdTag020 the maximum intermediate dive depths exceeded the 75th percentile. This effect was even stronger for MdTag021, where in four of the five IDDIs the maximum intermediate dive depths exceeded the 75th percentile of baseline dives and one exceeded the 97.5th percentile.

Table 5. (A) Percentile values of dive metrics for MdTag020 and MdTag021 during baseline and before exposure periods. (B) Actual metrics for the five dive cycles during exposure periods.

A		Deep dive duration	Deep dive depth	(IDDI) duration	# Int. dives following	Mean int. dive duration	Mean int. dive max depth	IDDI max depth
2.5%	MdTag020	17.3	349.7	3.2	0.0	4.0	56.7	62.0
	MdTag021	35.9	830.5	39.0	0.0	4.9	51.3	51.3
25.0%	MdTag020	47.4	955.5	74.7	2.0	8.3	97.5	119.5
	MdTag021	46.8	991.5	81.4	1.5	8.7	76.5	107.1
50.0%	MdTag020	51.1	1263.5	108.6	3.0	10.3	110.3	135.5
	MdTag021	50.3	1103.5	110.6	3.0	10.3	101.5	123.5
75.0%	MdTag020	54.6	1327.5	137.8	4.0	11.2	130.8	163.5
	MdTag021	53.0	1231.5	132.1	4.0	11.4	117.5	147.5
97.5%	MdTag020	59.2	1389.9	256.9	7.7	15.9	193.8	225.8
	MdTag021	61.3	1327.5	237.1	8.4	14.1	140.3	209.0
B		Exposure deep dive duration	Exposure deep dive depth	Exposure IDDI duration	Exposure # int. dives	Exposure mean int. dive duration	Exposure mean int. dive max depth	Exposure IDDI max depth
8/17/21 16:29	MdTag020	53.43	1263.5	122.20	3	8.19	96.83	151.5
	MdTag021	51.87	991.50	122.17	3	8.39	88.83	123.5
8/17/21 19:25	MdTag020	55.57	1231.5	128.37	2	10.80	136.50	223.5
	MdTag021	55.67	1103.50	128.33	2	13.70	117.50	183.5
8/17/21 22:29	MdTag020	50	911.5	30	2	11.05	*171.5*	175.5
	MdTag021	50.03	943.50	170.70	5	11.71	139.10	*255.50*
8/18/21 2:09	MdTag020	--	--	--	--	--	--	--
	MdTag021	59.07	863.50	201.97	3	12.43	121.50	171.50
8/19/21 0:04	MdTag020	--	--	--	--	--	--	--
	MdTag021	NA	NA	75.63	5	12.98	105.10	195.5

- Note that MdTag020 is missing data for the last two exposure periods, and that the final period for MdTag021 is missing data before and after that period, so the IDDI data may be truncated. Values outside of the 25th to 75th percentiles of baseline data are highlighted in bold, and the values outside of the 2.5 or 97.5th percentiles are also italicized.

Less can be said about MdTag022 as there was no dive record for this animal. However, they were at the surface when their first exposure period began. They may have immediately gone on one or more deep dives without IDDIs, as they were below the surface for 52.4 minutes, briefly at the surface, then below the surface for another 89.7 minutes, briefly at the surface one more time, then below the surface for another 64.1 minutes. It is not known to what depths the animal dove during those periods, but they were likely not at the surface since the tag would have been detected on one of the MOTEs during those intervals, given the proximity to the MOTEs. However, during the second and third exposure periods, they were at the surface for the first 32.3 minutes, down for 36 minutes, then at the surface on and off (e.g., in an IDDI) for 137.9 minutes.

3.5.1 Diel Dive Analysis

For the diel analysis of the dive data across SCC phases, day and night dive metrics were available for only Phase A and the Interphase for both tags. Day dive rates decreased between Phase A and the Interphase for both tags, and the percentage of surface time during day hours concurrently increased (Table 6, Figure 15). Night dive rates also decreased between Phase A and the Interphase for both tags, and the percentage of surface time during night hours increased by roughly the same degree that it did during the day hours. Dive depths and durations did not vary significantly between phases for either the day or night.

- A comparison of daytime and nighttime diving parameters from Blainville's beaked whales exposed to MFAS for phases that meet the required coverage cutoff. None of the statistical tests were significant comparing dive depths or durations across SCC Phases.

Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Day dive rate (dives/hour)							
MdTag020	NA	1.90	1.50	NA	NA	-	
MdTag021	NA	1.94	1.59	NA	NA	-	
Night dive rate (dives/hour)							
MdTag020	NA	1.43	1.11	NA	NA	-	
MdTag021	NA	1.34	1.13	NA	NA	-	
% time in surface periods at day							
MdTag020	NA	38.02	45.83	NA	NA	-	
MdTag021	NA	35.50	47.75	NA	NA	-	
% time in surface periods at night							
MdTag020	NA	52.74	59.62	NA	NA	-	
MdTag021	NA	53.78	58.11	NA	NA	-	
Median dive depth day (m)							
MdTag020	NA	149.50	131.50	NA	NA	0.9669	NA
MdTag021	NA	127.50	117.50	NA	NA	0.5205	NA
Median dive depth night (m)							
MdTag020	NA	135.50	111.50	NA	NA	0.1426	NA
MdTag021	NA	123.50	107.50	NA	NA	0.1063	NA
Median dive duration day (min)							
MdTag020	NA	12.10	11.22	NA	NA	0.5223	NA
MdTag021	NA	12.23	10.85	NA	NA	0.0986	NA
Median dive duration night (min)							
MdTag020	NA	12.87	11.08	NA	NA	0.5801	NA
MdTag021	NA	11.57	12.00	NA	NA	0.9958	NA

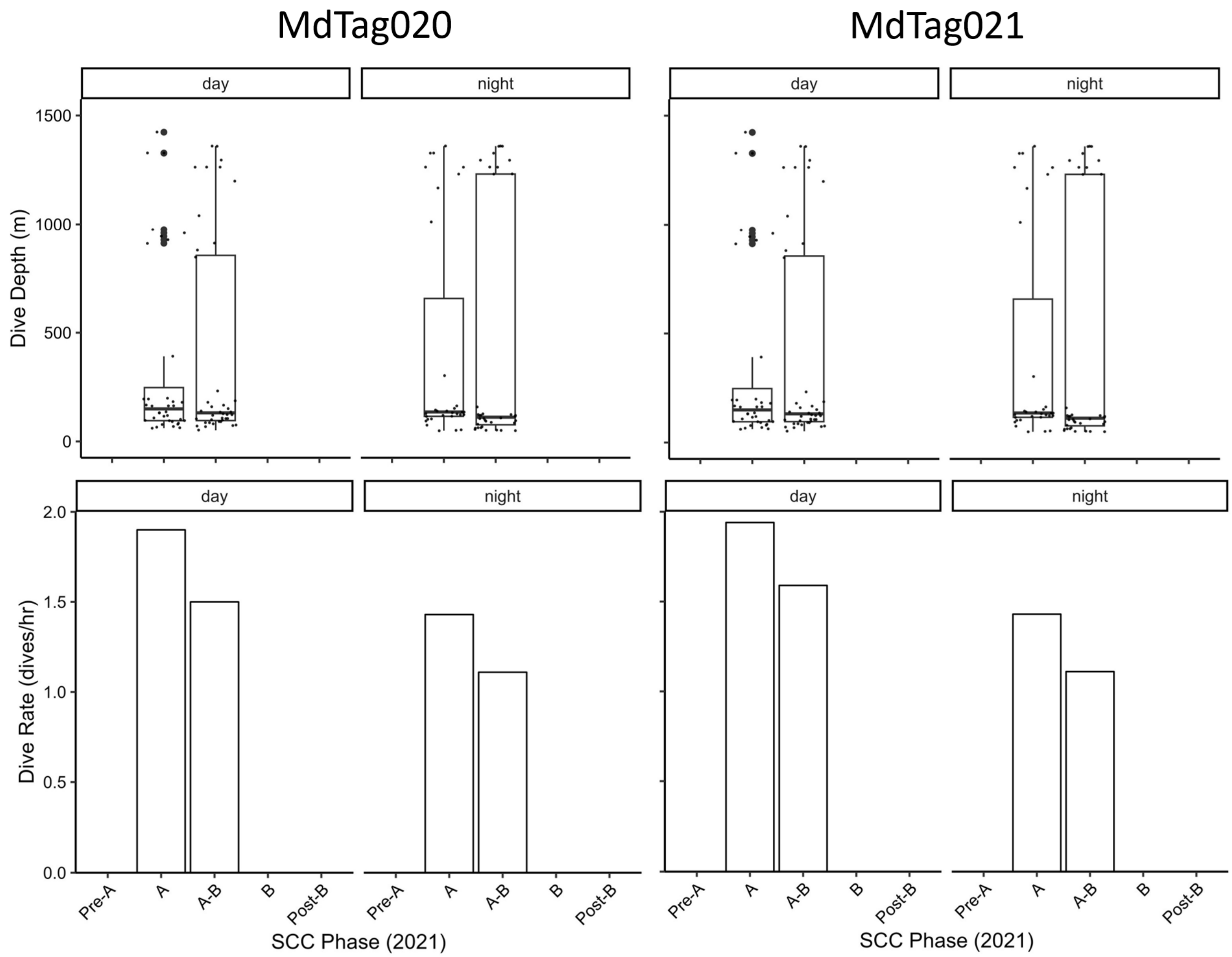


Figure 15. Top left: Boxplot showing dive depths of MdTag020 by SCC Phase and time of day. Bottom left: Barplot showing dive rates of MdTag020 by SCC Phase and time of day. Top right: Boxplot showing dive depths of MdTag021 by SCC Phase and time of day. Bottom right: Barplot showing dive rates of MdTag021 by SCC Phase and time of day.

3.6 MOVEMENT BEHAVIORAL RESPONSE ANALYSIS

MdTag020 and MdTag021 were tagged in the same group in 2021, and generally remained associated over the overlapping period of tag attachment. Information was available on movement patterns for Before (0.3 and 0.2 days), Phase A (1.7 days), the Interphase period (3.8 days), Phase B (2.4 days) and the After phase (0.9 and 5.2 days, truncated to 3 days for analysis). Both individuals remained on or in close proximity to the range throughout the duration of the SCC. Information on movement patterns for MdTag022 in 2022 was available for the A/B Mixed Phase (3.4 days), the Interphase period (3.5 days), the B/A Mixed Phase (1.2 days), and the After phase (17.3 days, truncated to 3 days).

Four variables of whale spatial (horizontal) movement behavior were calculated for the full smoothed crawl-modeled tracks from the four tagged Blainville's beaked whales: track bearing between steps, step length, turning angle, and speed (m/s). These parameters were compared for the five SCC phases described above. The entire track for MdTag017 is considered baseline behavior, given its timing relative to MFAS events, while the baseline (before) periods for the other three whales were the time before the onset of MFAS. It is important to note that all three whales were tagged just before or concurrent with Phase A, so there is little to no true baseline data for these animals prior to Phase A or Phase A/B. These movement variables were analyzed across phases within each individual, and then were compared across all four animals to examine inter-animal differences in potential responses.

Due to the frequent multi-hour intervals between GPS or Argos positional updates, the crawl-smoothed track could become artificially straight between longer intervals, leading to erroneous assumptions about the movement parameters during different phases. Therefore, the analysis was repeated two more times; first, with intervals greater than 3 hours plus deep dive intervals removed; and second, with intervals greater than 1 hour plus deep dive intervals removed. The resulting statistics were then compared to assess whether changes in movement behavior across phases is robust across different sampling schemes and therefore could likely be linked to potential behavioral responses (Table 6). While the magnitude of the Chi-square and p-values changes across each of these sampling paradigms, the values that are significant remain so for all paradigms, as do the patterns in behavioral changes. Therefore, only the results of the 1-hour intervals are included herein (Figures 16 – 19).

The Before periods for MdTag020 and MdTag021 had very little data once intervals between positions longer than 1 hour were removed, and MdTag022 had no Before data; thus, MdTag017 becomes the best baseline for all the movement metrics. They moved in all different directions with a slight majority of movement towards the southwest and northwest as they moved around Ni'ihau and Ka'ula Island. Their MdTag017's mean step length was 94 meters with a mean speed of 0.4 m/s, and moved in a fairly directed manner with turning angles largely between -1 and 1. For the other whales, these variables were all significantly different between at least two of the SCC periods with the exception of turning angle for MdTag022 which was never significantly different (Table 6). Travel direction (bearing) varies by phase for all three whales; for MdTag020 and MdTag021 the After bearing is significantly different from the other phases except Before, while for MdTag022 it is Phase A that is different from the other phases, significantly so for the Interphase and After. For MdTag020 and MdTag021, step length and speed increased from baseline to Phase A and were very comparable between Phase A and Phase B, were actually highest during the Interphase, and then After the SCC went back to similar levels as before (Figures 12 and 13); for both animals, the After values were significantly different than the Interphase values for both variables. The turning angles for these two whales were most tightly centered around 0 (i.e., more directed movement) during Phase A, Phase B, and the Interphase (Figure 17). The Interphase was significantly different from

Before, Phase A, and After for MdTag021, while only the Before phase was significantly different from the other phases for MdTag020. While given the reduced amount of data in the Before period when positional intervals greater than 1 hour were removed, these values should be taken with caution, the same statistical trends hold for the other track sampling methods so the underlying patterns are likely valid. Interestingly, the patterns for MdTag022 are different from the other whales. Their step lengths and speeds were significantly higher during Phase A and After and were reduced during the Interphase and Phase B (Figures 18 and 19). In contrast their turning angles were lower (more directed) during Phase A and then broadened slightly during the Interphase, Phase B, and After (Figure 17), with only the values between Phase A and After being significantly different.

Table 6. Chi-square (top) and p-values (bottom) from the Kruskal-Wallis nonparametric tests that examined track movement variables in the SCC Phases Before, Phase A, Interphase, Phase B, and After for the tracks with intervals less than one hour. Significant p-values are in bold.

	MdTag020	MdTag021	MdTag022
Bearing	43	51.2	31.5
Step Length	**<0.001**	**<0.001**	**<0.001**
Turning Angle	32	49	19.6
Speed	**<0.001**	**<0.001**	**0.0002**

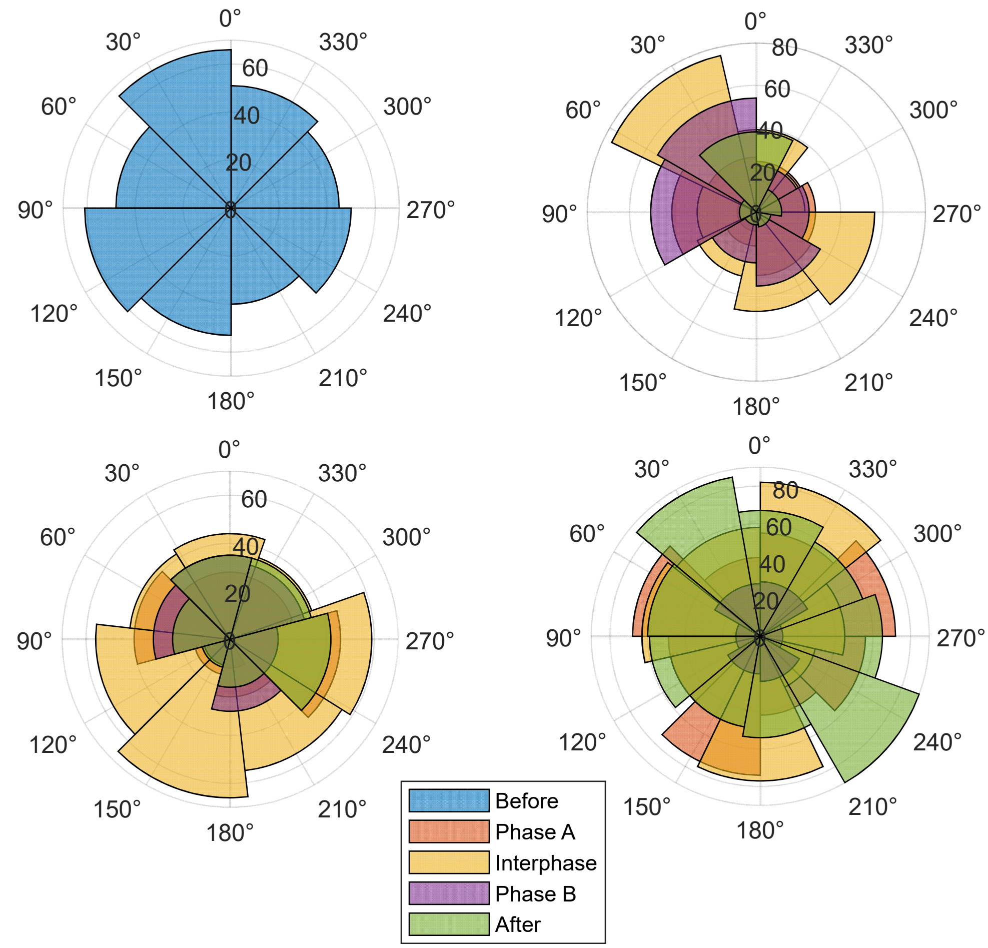


Figure 16. Top left: Track bearing values between 5-minute crawl-modeled track steps, with all of MdTag017 being baseline data, while the data for the other three whales is broken down by baseline/before, during, and after exposure periods. Top right: MdTag020. Bottom left: MdTag021. Bottom right: MdTag022.

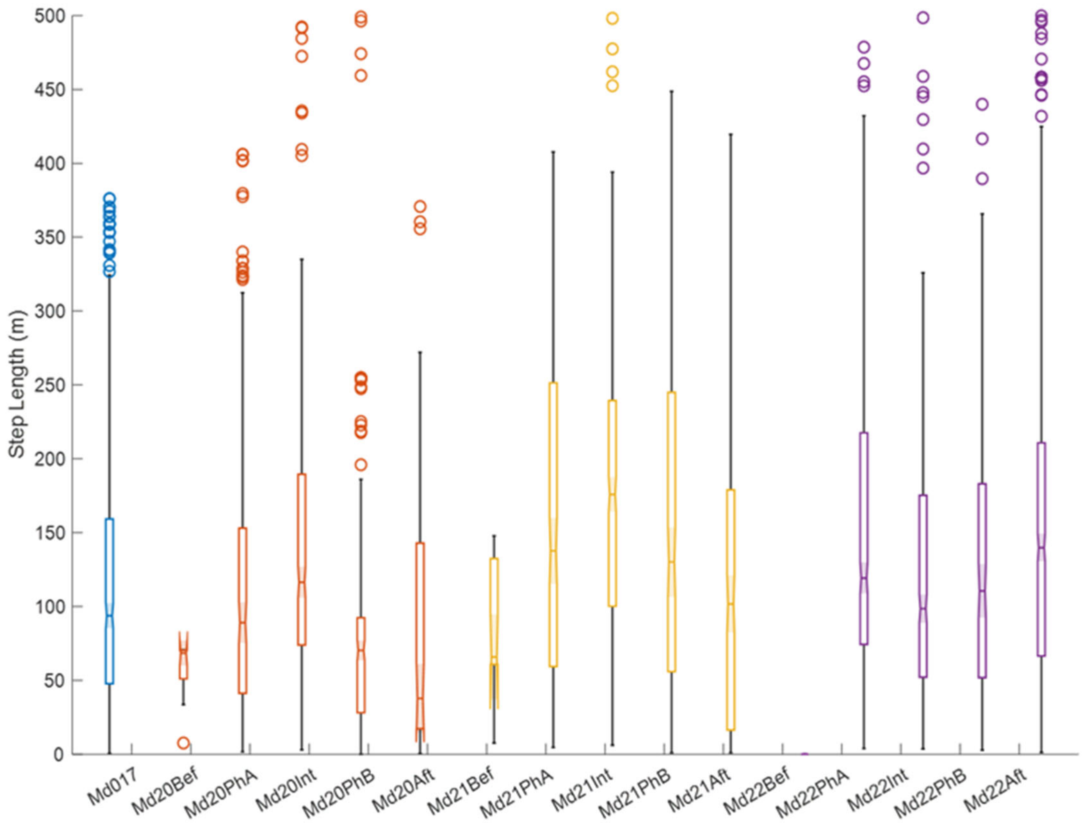


Figure 17. Track step length values between 5-minute crawl-modeled track steps, with all of MdTag017 being baseline data, while the data for the other three whales is broken down by baseline/before, during, and after exposure periods.

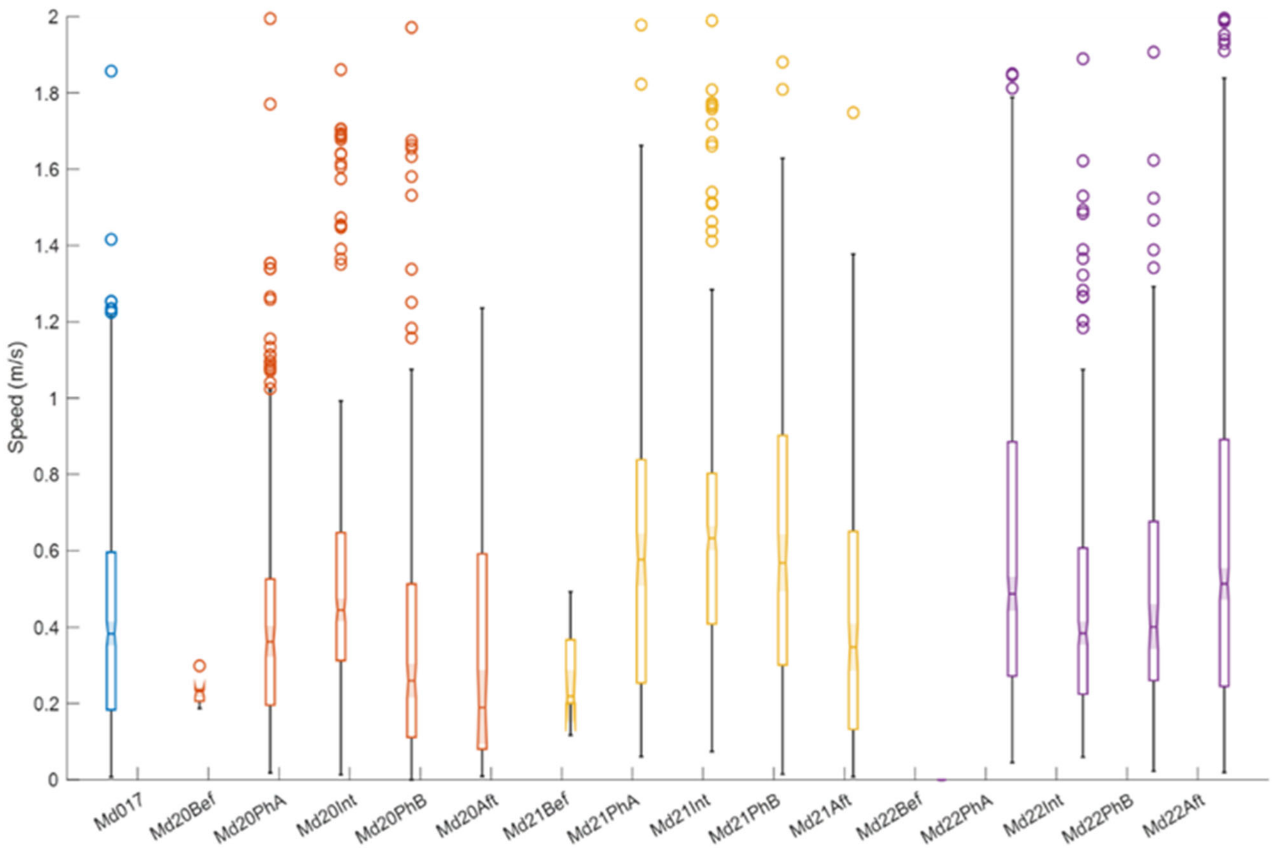


Figure 18. Track speed values between 5-minute crawl-modeled track steps, with all of MdTag017 being baseline data, while the data for the other three whales is broken down by baseline/before, during, and after exposure periods.

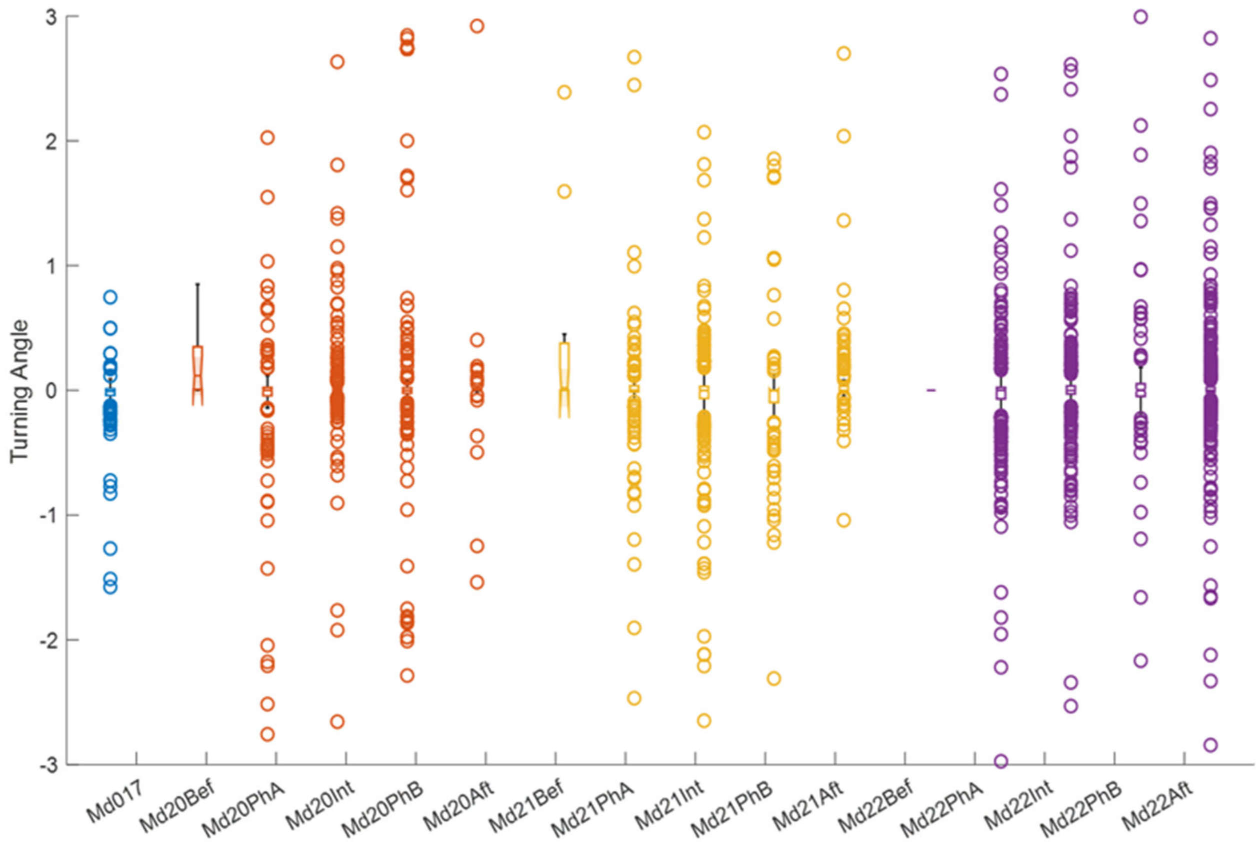


Figure 19. Track turning angle values between 5-minute crawl-modeled track steps, with all of MdTag017 being baseline data, while the data for the other three whales is broken down by baseline/before, during, and after exposure periods.

4. DISCUSSION

Our results provide insights into how Blainville's beaked whales respond to different sources of MFAS. While the movement behavior of MdTag017 can only act as baseline behavior, it is interesting to note that MdTag017 was the only animal tagged in February and moved well away from the range prior to the onset of MFAS. It is possible that this individual/group was part of an open-ocean population (see Baird et al. 2011), rather than an island-associated group. In contrast, the three animals tagged in August (2021 and 2022) remained relatively close to the range throughout the MFAS activity. All three whales moved away from the training activity; at their furthest point the whales were 61.4, 67.5, and 48.9 km away from the nearest active ship, and 20-48 km away from the nearest hydrophone on the range. However, all three animals remained in the Kaulakahi Channel between Ni‘ihau and Kaua‘i and west of the range. These differences may be indicative of prey abundance and location at different times of year and may begin to elucidate why animals may remain in the area and presumably forage even during repeated periods of MFAS. While the sample size is very small, they provide the first information on dive behavior of Blainville's beaked whales at PMRF, particularly relative to the regularly recorded acoustic data. In addition, the analyses conducted on these data are simplified quantitative ways to describe the data and to detect changes in dive and spatial movement behavior across periods.

In Cuvier's beaked whales (Ziphius cavirostris), high levels of dive synchrony have been observed in male pairs for periods of days to weeks, while levels of synchrony between an adult male and an animal of another sex or age class was much lower (Cioffi et al. 2021). In this instance, MdTag020 was a female and MdTag021 a male, indicating that long duration associations with high dive synchrony can occur across sex classes in Blainville's beaked whales. MdTag020 tended to dive deeper than MdTag021 on their synchronous dives (Figure 5), and often initiated a deep dive before MdTag021 (e.g., Table 4). Dive synchrony was also observed in another tagged male-female pair of Blainville's beaked whales off the island of Hawai‘i (Baird 2019), with the female sometimes deeper and sometimes shallower than the male on deep foraging dives as well as during the intermediate dives. Tight synchrony while diving but spatial separation at depth has been observed in other tagged pairs of both Blainville's and Cuvier's beaked whales (Aguilar de Soto et al. 2020; Alcázar-Treviño et al. 2021), and may prevent individuals in a group from competing for specific prey items while at depth. Also off the island of Hawai‘i, Blainville's beaked whales were recorded diving to median depths of 1099 meters during the day (896-1409 meters) and 1052 meters (872-1182 meters) at night for dives deeper than 800 meters, with a maximum depth of 1599 meters. Their deep dive durations lasted a mean of 54.4 minutes (51-60 minutes) during the day and 51.3 minutes (43-58 minutes) at night, with maximum durations of 68 minutes during the day and 83 minutes at night (Baird et al. 2008). These values are comparable to what was found off Kaua‘i, although the median deep dive depth was deeper at 1113 meters and the maximum depth was slightly shallower at 1424 meters. Median deep dive duration off Kaua‘i was 51 minutes (range 14-71 minutes).

The Blainville's beaked whales off Hawai‘i appear to be a resident population that co-occur with a resident population of Cuvier's beaked whales (McSweeney et al. 2007; Baird 2019). It seems as though the two species have partitioned their environment and prey resources, such that the Cuvier's beaked whales dive more deeply and are found in deeper water depths (generally but not always further offshore), while the Blainville's beaked whales occur in slightly more shallow waters (Baird 2019). Although Cuvier's beaked whales have never been visually detected at PMRF (Baird 2016) there are occasional acoustic detections in deep water, along with Longman's (Indocetus pacificus) and the Cross Seamount beaked whale (McCullough et al. 2024, Martin et al. 2023); the spatial relationship and habitat use of the range complex can be examined for these four species to determine if similar spatial partitioning is occurring off Kaua'i as well. This is also the first time that tagged whale dives have been linked to acoustically detected GVPs, and so the first time click start and end times and depths have been estimated for satellite tag data. These linked dives provide insight on the use of the range habitat by the same groups. For example, this is the first time it can be said with some certainty that repeated dives on a cluster of hydrophones was in fact the same group of animals. This kind of information can facilitate density estimation using spatially explicit capture-recapture (SECR) methods, as we can begin to quantify repeated dives on-range by the same animals (e.g., Marques et al 2012). These data can also be compared to acoustic studies of Blainville's beaked whales at PMRF. Previous observations of Blainville's beaked whale GVPs before, during, and after SCCs have noted that GVPs are reduced both at the start of and throughout Phase A, with some recovery over the Interphase, and then are further reduced during Phase B (Manzano-Roth et al. 2016; Henderson et al. 2019, Jacobson et al. 2022). The movements away from the range and into the adjacent Kaulakahi Channel between Kaua'i and Ni'ihau both support these findings and provide evidence that the animals are in fact moving off the range, rather than ceasing to forage and echolocate, but that they remain in the area and likely continue to forage. Similarly, the habitat that the tagged whales utilized on and off the range was the same habitat where GVPs are typically detected (Henderson et al. 2016), with steep slopes and water depths generally 1500-2000 meters.

In 2021, there were three sources of MFAS present during the SCC: hull-mounted, helicopter-dipping, and sonobuoy. Figure 10 and Figure 13 visually depict the tracks of MdTag020 and MdTag021 during periods before, during, and after MFAS exposures, and demonstrate the relative proximity of the different sources to the animals' locations. Although the sonobuoy exposures were closer in distance, their lower source level led to very low received levels, below 100 dB re 1 mPa (Figure 9 and Figure 12). The first bout of helicopter-dipping MFAS had slightly higher received levels, up to median values of 120 dB re 1 mPa. While the whales continued to dive in synchrony and conduct at least one or two more foraging dives as detected on the range hydrophones, a few possible responses may have occurred. First, the second deep dive that occurred during the sonobuoy and helicopter-dipping MFAS exposure (Figure 17 and Figure 18) began almost exactly at the same time as an acoustically detected GVP. It is possible that the GVP belongs to a different group, but that would indicate that the deep dive conducted by the tagged animals was not a foraging dive, as that GVP was the only one in the area at the time. Alternatively, if the GVP does belong to the tagged animals' group, then either some of the group began diving sooner than the two tagged animals, or the group began echolocating immediately upon initiating the dive, possibly as a means of communication during the low-level MFAS exposure.

Another possible response to these two sources of MFAS was the deep intermediate dive that occurred immediately after that second dive, which was deeper than 75% of their baseline intermediate dives and was within 2 meters of the 97.5th percentile depth for MdTag020. However, the two animals initiated a third foraging dive that did match an acoustically detected GVP, although it was shallower than 25% of their baseline deep foraging dives. After these three dives with MFAS, MdTag020 and MdTag021 appear to change their behavior and split up. There is evidence of this split in both their tracks (Figure 10C and Figure 13C) and their dive behavior (Figure 17 and Figure 18). Both were highly correlated from 11 through 17 August, but after the dive with hull-mounted MFAS, their tracks appeared to separate and their dive behavior began to differ, although this is also when the dive data begins to fail in both tags so it is not entirely clear if MdTag020 does the subsequent deep dive that is conducted by MdTag021. It is likely that the animals have already split at this point, as MdTag020's track begins to head southwest off the range during the time that MdTag021 is conducting the dive. This dive is preceded by the deepest intermediate dive conducted by MdTag021 to 255 meters, deeper than the 97.5th percentile of their baseline dives. The deep dive by MdTag021 is also one of their shallowest "deep" dives to 863.5 meters. While this dive was done on the range, it does not align with a GVP and therefore was likely not an active foraging dive. They do continue to stay relatively near each other for the remainder of MdTag020's tag deployment (Figure 10D and Figure 13D), but it is difficult to tell if their tracks realign. It may be that some of the differences in travel speed and step length between the two animals during and after the exposure periods is due to the fact that they have split up and are responding differently to subsequent exposures. MdTag020's tag deployment ends shortly after this, but MdTag021's tag continues to transmit for six more days, and the whale remains in the area west of the range, possibly continuing to forage as three additional deep dives are recorded by the tag during this time. MdTag021 does return to the range for the last 29 hours of the tag deployment, but there is no dive data to match with GVPs to determine if or when they return to foraging on the range.

MdTag022 only had exposures to hull-mounted MFAS and active sonobuoys in 2022. This beaked whale was already to the west of the range when the exposures began with the distance to the activity about 34 km away, and their initial exposure to hull-mounted MFAS resulted in received levels between 144 and 147.5 dB re 1 μPa. They changed their direction of travel 180 deg at the onset of this first exposure, turning to head southwest away from the area of activity on the range. Subsequent received levels were lower as MdTag022 continued to move largely west and south during and after the exposure periods (Figure 16), down to median values around 120 dB re 1 μPa. However, they did begin to move east during the last few bouts of MFAS with a concurrent slight increase in received levels (Figure 14). Received levels from sonobuoys remained low throughout, with median levels never exceeding 92 dB re 1 μPa. Much like MdTag020 and MdTag021, the horizontal movement of MdTag022 became more directed during and after the exposure periods, but also traveled faster during the exposure periods.

By looking at simplified metrics of dive and horizontal movement behavior before, during, and after periods of exposure to different sources of MFAS, as well as comparing diel dive statistics across broad SCC phases, these data provide evidence that Blainville's beaked whales respond to MFAS by changing their behavior.. It should be noted that all three whales were tagged just before or during Phase A, during which there was training activity being conducted on the range. There were no MFAS sources present during Phase A in 2021, while during the 2022 SCC, the typical activity of Phase A and Phase B were mixed, therefore MdTag022 had MFAS exposures within two days of tag attachment. That said, there did not appear to be strong responses evidenced in the dive behavior of MdTag020 and MdTag021; while many of the dive metrics measured during the exposures were outside of the 75th (or 25th) percentiles of baseline data, only the maximum intermediate dive depth during an IDDI exceeded the 95th percentile of baseline data. This potential response was only observed for hull-mounted MFAS; there didn't appear to be as strong of a response to the sonobuoy or helicopter-dipping MFAS exposures. Dive rates both during the day and at night were reduced from Phase A into the interphase, but not substantially. Similarly, while there were deeper dives both day and night in the interphase compared to during Phase A, the median depths were the same and there were no statistical differences. Median durations were also the same across phases both day and night. Since there weren't enough dive data during Phase B to do these analyses, it is possible some differences would have been detected. The only other noticeable change in dive behavior were the three deeper intermediate dives that took place during that period. However, dives to depths between 300 and 600 meters are within the dive repertoire of Blainville's beaked whales (Baird et al. 2008). The only unusual part is that two of the three took place during the day, whereas they are normally conducted most often at night.

While the Before periods for MdTag020, MdTag021, and MdTag022 were either short or non-existent, the horizontal movement behavior was still very similar to that of MdTag017, which provides some indication that their behavior during that period was relatively normal. In contrast, there were statistically significant differences in bearing, step length, and speed for all three beaked whales during Phase A, the Interphase, and Phase B, in turning angle for two of the three whales. Interestingly, these metrics varied by individual, indicating there wasn't a consistent response across all animals. It should be noted that the long diving behavior of beaked whales limits the frequency of location transmission at the surface, thus limiting our ability to capture their true continuous movements throughout the deployment. In addition, there were frequent long intervals between positional updates, leading to possible spurious track smoothing between those intervals, and furthermore this analysis was conducted on a single version of a crawl-modeled track, thereby not carrying forward the error from each position. While we attempted to account for this by removing long foraging dives from this analysis, as well as removing intervals longer than 3 hours and 1 hour, the horizontal movement metrics computed here should be interpreted with a level of caution in consideration of the data limitations of using smoothed tracks.

In another opportunistic behavioral response studies like this one, where tagged Blainville's beaked whales were exposed on a Navy range to real world training activity, the whales moved away from their locations on or near the range by 28-68 km, although more distant whales did not avoid the area (Joyce et al. 2020). The estimated received levels for the exposed whales were 145 to 172 dB re 1 μPa, and the animals returned to the range within two to four days (Joyce et al. 2020). The whales in this study did not move as far off the range post-exposure, but median estimated received levels never exceeded 150 dB re 1 μPa. In another range-based opportunistic study of Cuvier's beaked whales on SOAR that also looked at both hull-mounted and helicopter-dipping MFAS, data from 16 animals were aggregated to model changes in dive behavior relative to the different sources. For the lower source level helicopter-dipping sonar, closer proximity of the source led to increased durations of both intermediate and deep dives, even more so than for hull-mounted MFAS, and longest when both sources were present (Falcone et al. 2017). Both intermediate and deep dives were also slightly longer at PMRF during exposures to all source types (Table 6), but never exceeded the 95th percentile baseline values. In contrast to what was found at PMRF for Blainville's beaked whales where intermediate dives during exposures were the deepest recorded, the Cuvier's beaked whales on the SOAR range conducted shallower intermediate dives during MFAS exposures. Finally, both surface intervals and IDDIs were longer during exposures, especially at closer distances (Falcone et al. 2017); IDDIs were only slightly longer for two of the dive cycles and only for hull-mounted MFAS. Interestingly, this study also observed four unusually short and intermediate deep dives, similar to the three intermediate deep dives recorded in this study. The Cuvier's beaked whales were often much closer to the helicopter-dipping sonar at SOAR than the Blainville's beaked whales in this study were to either helicopter-dipping or sonobuoy MFAS; this may be why a response was observed for the former population to that lower powered source and less so in the latter population. Falcone et al. (2017) hypothesized that the stronger reactions observed for the lower powered source was due to the "random" nature of exposure, where the source appeared suddenly and then disappeared, unlike a ship that could be heard approaching or moving away. Future opportunistic studies at PMRF should continue with both beaked whales and other cetacean species to estimated received levels to these additional sources of MFAS, in order to determine if closer proximity may elicit a behavioral response.

Little is known about the population of Blainville's beaked whales that occupy the waters off Kaua'i, but there are known to be resident beaked whale populations off the island of Hawai'i. There are certainly Blainville's beaked whales present year-round at PMRF so it is likely that even if there is not an island-associated population, members of the Hawaiian population may have been exposed at least once, and possibly multiple times. If these animals are resident, they are likely exposed to Navy training activity and the use of MFAS with some regularity and may have habituated to the sounds. Alternately, foraging needs may drive their behavior regardless of anthropogenic activity, and therefore they continue to forage off the range during exposures because that is where their prey is located. Due to the pinnacle structure of Kauaʻi there may be limited habitats where the mesopelagic prey of Blainville’s beaked whale are concentrated. Additional tagging and photo-identification studies are critical for these Blainville’s beaked whales to understand their habitat use and residency in this area, and to be able to assess the potential impact of repeated exposures to MFAS. Prey mapping of the water column on and off the range would also provide insight into potential motivations and drivers of beaked whale behavior. However, these tag data, coupled with the linked GVPs on the range, begin to provide some of this insight into both baseline habitat use and behavioral response of potentially resident animals to Navy training and multiple sources of MFAS.

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