Naval Information Warfare Center PACIFIC

TECHNICAL REPORT 3353
AUGUST 2024

Received Level Estimation, Behavioral Response, and Diel Behavior Analyses for Delphinids Tagged at the Pacific Missile Range Facility in 2021–2022

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

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Administrative Notes:
This report was approved through the Release of Scientific and Technical Information (RSTI) process in February 2024 and formally published in the Defense Technical Information Center (DTIC) in August 2024.

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

ADMINISTRATIVE INFORMATION

The work described in this report was performed by the Whale Acoustic Reconnaissance Project Lab in the Environmental Readiness Branch (Code 56720) of the Intelligence, Surveillance, and Reconnaissance Division at the Naval Information Warfare Center (NIWC) Pacific San Diego, CA.

Released by
Mark Xitco, Division Head
Reconnaissance and Interdiction Division

Under authority of
Nicole Stone, Department Head
Intelligence, Surveillance, and
Reconnaissance Division

ACKNOWLEDGMENTS

We would like to acknowledge Julie Rivers at Commander, U.S. Pacific Fleet (COMPACFLT) for funding this effort, and thank the team at the Pacific Missile Range Facility, including Jim Hagar, Jon Winsley, Eliseo Bolison, Bryson Kurokawa, and Bruce Comisap, whose support allows us to do this work. We would also like to thank Colin Cornforth, Kimberly Wood, Shannon Vasquez, Jordan Lerma, Jana Phipps, and Mark Mohler for help in the field efforts, Kristen Ampela/HDR for administering CRC funding, and Nancy Dimarzio, Susan Jarvis, Alex Muniz, and Stephanie Watwood for acoustic support in locating groups.

Editor: MGK

EXECUTIVE SUMMARY

This report summarizes the results of satellite-tagging efforts conducted before Submarine Command Course (SCC) training events in August 2021 and 2022, at the Pacific Missile Range Facility (PMRF) off the island of Kauaʻi. Researchers tagged 21 delphinids to observe their behavior before, during, and after the SCCs, to estimate received levels (RLs) of mid-frequency active sonar (MFAS).

Fifteen of the tagged individuals remained in the area or had direct acoustic paths between their locations and surface ship hull-mounted MFAS sources, allowing received level estimation through propagation modeling. This group included:

- 6 short-finned pilot whales (*Globicephala macrorhynchus*)
- 1 false killer whale (*Pseudorca crassidens*)
- 5 melon-headed whales (*Peponocephala electra*)
- 1 rough-toothed dolphin (*Steno bredanensis*)
- 2 common bottlenose dolphins (*Tursiops truncatus*)

Henderson et al. (2021) developed the analytical methods that were applied to this data. These methods involved smoothing animal tracks at 5-minute intervals using the R-package *crawl*, calculating a 95% confidence error ellipse for each step location, and modeling transition loss along multiple radials from the sea surface to the seafloor. Dives were modeled using tag behavior logs to account for animal depth during each transmission to estimate RLs in three dimensions. The median RL for each 5-min bin was calculated, along with a range of possible exposure values based on two times the standard deviation (± 2*SD).

The study analyzed dive behavior within the diel period (dawn, day, dusk, and night) and across SCC phases (Before, Phase A, Interphase, Phase B, and After) to determine if dive behavior changed due to training activities or MFAS.

For all animals, the maximum median received sound pressure levels ranged from 73 to 148 dB re 1 μPa. Eight animals moved out of the area before the onset of MFAS, resulting in maximum median RLs at or below 100 decibels (dB) re 1 μPa. The remaining seven were near the range during MFAS and had higher estimated RLs, although none exceeded 156 dB re 1 μPa (including +2*SD). Observed behavior differences include: changes in dive depth and duration between SCC phases, dive rates, and time spent at or near the surface. However, no consistent behavior changes were observed either within or across species. No changes in horizontal movement were observed relative to periods of MFAS.

All tagged animals were compared to Cascadia Research Collective's photo-identification catalog; most matched existing animals in the catalog. One new bottlenose dolphin and two new rough-toothed dolphins were added. The false killer whale, three pilot whales, two bottlenose dolphins, and one rough-toothed dolphin belonged to known Hawaiian and Kauaʻi-specific population.

These data, aggregated with previously tagged or photo-identified animals from Kauaʻi and the other Hawaiian Islands, build the basis for understanding the long-term consequences of MFAS exposure at the population level and may identify impacts of repeated exposures.

As most tagged animals in this study are island residents, it is possible they have been exposed to MFAS previously. Since none of the animals demonstrated consistent or overt responses, they may have habituated to, or at least tolerate, MFAS and other training-associated sounds. Continued improvements in analytical methods for satellite tag data could enable the use of these aggregated data in finer-scale behavioral response analyses, potentially addressing some of these uncertainties.

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1. INTRODUCTION

Satellite tagging of cetaceans provides valuable information on habitat use, movement patterns, and dive behavior over potentially long periods and large areas, and with repeated efforts on focal species, population-level information can be developed. For example, Cascadia Research Collective (CRC) has conducted 20 years of vessel-based surveys in the Hawaiian Islands, using photo-identification capture-recapture and satellite tagging methods (e.g., Baird et al., 2009; 2012; 2013). Through these studies, CRC identified resident and offshore populations of multiple odontocete species (e.g., Baird et al., 2008a, 2008b, 2022), established biologically important areas for many species (Baird et al., 2015a; Kratofil et al., 2023), and assessed their behavioral responses to anthropogenic activities, including fisheries interactions, tourism, and Navy sonar (Baird et al., 2009, 2015b, 2020; Thorne et al., 2012; Van Cise et al., 2021). Due to the presence of a Navy testing and training range in the Hawaiian Islands, the Pacific Missile Range Facility (PMRF), not only can behavioral responses to Navy testing and training activity be assessed, but received levels of mid-frequency active sonar (MFAS) can be estimated for the tagged animals in three-dimensional space (Baird et al., 2014, 2017; Henderson et al., 2021; Martin and Manzano-Roth, 2012). Similar long-term studies of cetacean populations have been conducted for other species in other areas where Navy ranges are present, such as fin (Balaenoptera physalus) and goose-beaked whales (Ziphius cavirostris) in southern California (Falcone et al., 2009, 2017, 2022; Schorr et al., 2017), and Blainville's beaked whales (Mesoplodon densirostris) in the Bahamas (Claridge 2013; Claridge and Dunn 2013; Joyce et al., 2020). These long-term, multi-modality studies document reactions to actual training scenarios and assess effects beyond a single exposure level for one animal. They estimate the impacts of repeated and long-term exposures on populations. These long-term, multi-modality studies record exposures and responses to real-world training scenarios and can be used to assess effects beyond a single exposure level for an individual animal, including an estimation of the effects of repeated exposures and the impacts of long-term exposures at the population level.

Continuing this work, CRC returned to the PMRF range in August 2021 and August 2022 to tag odontocetes prior to and during a two-week biannual training event, the Submarine Command Course (SCC). Personnel from the Naval Underwater Warfare Center (NUWC) Newport and the Naval Information Warfare Center (NIWC) Pacific supported CRC by directing it to locations of acoustic detections within the range of odontocete species of interest. Potential focal species included short-finned pilot whales (Globicephala macrorhynchus), false killer whales (Pseudorca crassidens), pygmy killer whales (Feresa attenuata), melon-headed whales (Peponocephala electra), common bottlenose dolphins (Tursiops truncatus), rough-toothed dolphins (Steno bredanensis), and, when possible, Blainville's beaked whales and killer whales (Orcinus orca). The goals of this work were to build on the existing species' databases of home range and habitat use, estimate the received levels of MFAS, and assess any potential behavioral responses to the MFAS. This report focuses on movement patterns, estimated received levels of mid-frequency active sonar, and behavioral responses of delphinid odontocetes tagged in 2021 and 2022. Similar information on beaked whales tagged during the same field efforts is reported separately (Henderson et al., 2024).

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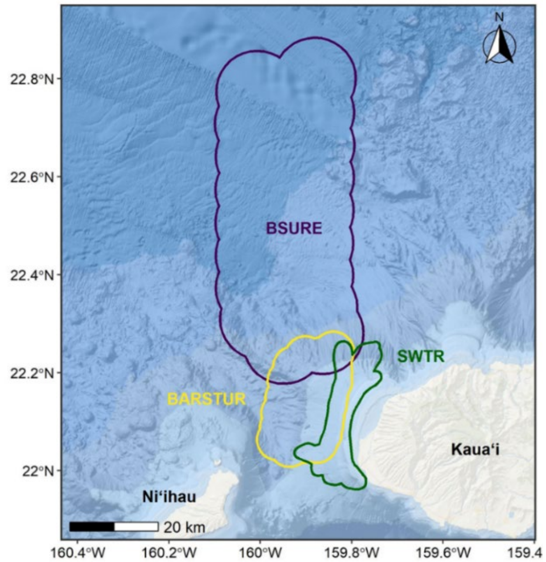
2. METHODS

2.1 FIELD OPERATIONS

Field operations were undertaken between Kaua‘i and Ni‘ihau in August 2021 and August 2022, with tagging conducted from a 7.3-m rigid-hulled inflatable boat (RHIB). To maximize the likelihood of data being obtained for periods before, during, and after biannual SCCs, survey efforts occurred immediately prior to each SCC. SCCs are broken out into five phases for analysis: Before, Phase A (a period of training activity that does not include hull-mounted MFAS from surface ships), an Interphase without training activity but during which sources may still be present on the range, Phase B (a period of training that includes surface ship hull-mounted MFAS along with other sources of MFAS), and After. Odontocetes were located 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 odontocetes were acoustically detected. During encounters, information was recorded on group size, start and end times, and locations (see Baird et al., 2013). To identify individuals and to determine age (based on the degree of scarring and relative size) and sex (based on species-specific characteristics like sexual dimorphism, when possible), photographs of all individuals within the groups were taken. For all species except for melon-headed whales, photos were compared to long-term photo-identification catalogs (Baird et al., 2008, 2009; Mahaffy et al., 2015, 2023) to assess sighting history and the potential for repeat tagging of individuals.

Tags used included both location-only (SPOT6) and depth-transmitting SPLASH-10 or SPLASH10-F tags (Wildlife Computers, Redmond, WA) in the Low Impact Minimally Percutaneous Electronic Transmitter configuration (Andrews et al., 2008). SPLASH10-F tags also transmitted Fastloc®-GPS locations. Tags were deployed with a Dan-Inject pneumatic projector and were attached with two gas-sterilized surgical grade titanium darts (see Schorr et al., 2009; Baird et al., 2011). For smaller species (i.e., bottlenose dolphins, rough-toothed dolphins, melon-headed whales), 4.4-cm darts with one row of backward-facing petals were used, while for larger species (i.e., short-finned pilot whales, false killer whales) 6.7-cm darts with two rows of backward-facing petals were used.



- The Barking Sands Underwater Range Expansion (BSURE) is outlined in purple, the Barking Sands Tactical Underwater Range (BARSTUR) is outlined in yellow, and the Shallow Water Training Range (SWTR) is outlined in green. Ship activity primarily occurs on BSURE, but animals are considered to be on the range if they overlap with any portion of the range (taken from Henderson et al., 2021).

Figure 1. The Barking Sands Underwater Range.

2.2 TAG PROGRAMMING

SPOT6 and SPLASH10 tags were Argos location-only tags, while SPLASH10-F tags also transmitted Fastloc®-GPS locations. Tags were programmed to transmit between 11 and 16 hours per day (depending on tag type and species; see Table 1), with transmissions prioritized during hours of the day with the greatest density of satellite overpasses, based on Argos pass predictions obtained through CLS. For SPLASH tags, transmitted dive data consisted of behavior logs recording the start and end time of dives and surface periods, and some tags were also programmed to transmit time series data every sixth day (see Table 1). All SPLASH tags were programmed to record 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 m. For each dive greater than the 50-m dive depth threshold, the maximum dive depth and duration were recorded, with the start and end of the dives determined [by the wet/dry sensor; by when the animal dove below 3 m]. 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 the SCC, tags were recorded to collect behavior logs and Fastloc®-GPS locations starting approximately three days prior to the start of the SCC and ending approximately three days after the end of the SCC and transmit behavior and Fastloc®-GPS data with a 6-day buffer. There were two shore-based Argos receivers (Wildlife Computers MOTEs) on Ni'ihau and Kaua'i that were also used to increase data throughput when tagged animals were within range of the receivers (Jeanniard-du-Dot et al., 2017), and an Argos goniometer was used during all small-boat operations to potentially obtain additional behavior data, times when animals were known to be at the surface, and Fastloc®-GPS locations from SPLASH10 and SPLASH10-F tags.

Table 1. Summary of tag programming regimes by species, year, and tag type.

Species	Year	Tag type	Data	# Hours transmitting per day
Gm	2021	SPLASH10-F	Argos, Fastloc, Behavior	16
Pe	2021	SPLASH10-F	Argos, Fastloc, Behavior	16
Pc	2021	SPLASH10-F	Argos, Fastloc, Behavior	16
Sb	2021	SPLASH10	Argos, Behavior, Time Series (1 min 15 sec)	11
Sb	2021	SPOT6	Argos	15
Tt	2021	SPLASH10-F	Argos, Fastloc, Behavior	16
Gm	2022	SPLASH10-F	Argos, Fastloc, Behavior, Time Series (5 min)	14
Pe	2022	SPLASH10-F	Argos, Fastloc, Behavior, Time Series (5 min)	14
Pe	2022	SPLASH10-F	Argos, Fastloc, Behavior	16
Sb	2022	SPLASH10	Argos, Behavior, Time Series (5 min)	14
Tt	2022	SPLASH10	Argos, Behavior, Time Series (5 min)	14

- When there are multiple programming regimes for a single tag type and species within the same year, each regime is given a separate line.
- Gm = pilot whale (Globicephala macrorhynchus).
- Pe = melon-headed whale (Peponocephala electra).
- Pc = false killer whale (Pseudorca crassidens).
- Tt = common bottlenose dolphin (Tursiops truncatus).
- Sb = rough-toothed dolphin (Steno bredanensis).

2.3 DATA PROCESSING

Argos and GPS location data were processed following the methods detailed in Kratofil et al. (2023). To summarize, the Douglas-Argos Filter (Douglas et al., 2012), accessed through Movebank (Kranstauber et al., 2011), was used to filter Argos data to remove erroneous locations. Residual error values (< 35; Dujon et al., 2014) and time errors (< 10 seconds) were used to filter Fastloc-GPS locations; these were additionally processed through a general speed filter via Movebank (Kranstauber et al., 2011). Resultant Argos and GPS locations were combined and then 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; subsequent models were then used to predict locations at 5-minute intervals used to estimate received levels following Henderson et al. (2021). The CTCRW model directly incorporates 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) while allowing for location prediction at user-defined intervals based on the modeled movement process. Predicted locations at the user-defined 5-minute intervals also include estimated standard errors (meters) in both x and y directions (easting and northing), which were used to account for positional uncertainty in received-level analyses.

Finally, any locations on land were re-routed around land plus a 50-meter buffer using the *pathroutr* package (London, 2020).

To verify that the tags operated as intended and experienced no malfunctioning that could invalidate dive data, the dive behavior data were examined prior to analysis as described in Henderson et al. (2021). To ascertain whether there might have been a pressure transducer failure, we assessed Depth and ZeroDepthOffset values in tag status files for indication of drift. Those exceeding +/- 10 meters and +/ 9 meters, respectively, were flagged as potential pressure transducer failures. We also assessed data to identify and flag extreme ascent or descent rates (greater than 2-3 meters per second) in recorded dives that could indicate tag malfunctioning by dividing twice the dive depth by the dive duration.

2.4 DIVE ANALYSIS

The SPLASH10 and SPLASH10-F tag data included a dive behavior log, which reported start and end times of dives and surface periods, as well as maximum dive depths. Using these data, coupled with the smoothed crawl tracks in 5-min intervals, full dive cycles were modeled in a custom Matlab program. For pilot whales, estimated ascent and descent rates were derived from pre-existing TDR tag data (see Henderson et al., 2021 for more details). For the other odontocete species, minimum and maximum bottom times were estimated based on Wildlife Computer's definitions of U, V, and square-shaped dives. 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 (minimum and maximum bottom time, ascent and descent times, and ascent and descent rates) were estimated for all dives. The dive behavior logs, MOTE transmission logs, and goniometer files 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 were detected by the MOTE, Argos, or goniometer, even if no locations were available, were utilized as known surface times.

Next, dive durations were interpolated by 30 points per dive, leading to a timestamp approximately every 30 seconds for a deep dive and approximately every 10 seconds for a shallow (<300 m) dive. Dive depths were modeled using the estimated ascent and descent rates at each interpolated timestamp, and these were combined with the surface crawl track for a full record for each whale. At each timestamp (either at 5-min 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.

2.5 ACOUSTIC DATA, MFAS DETECTION, AND LOCALIZATION

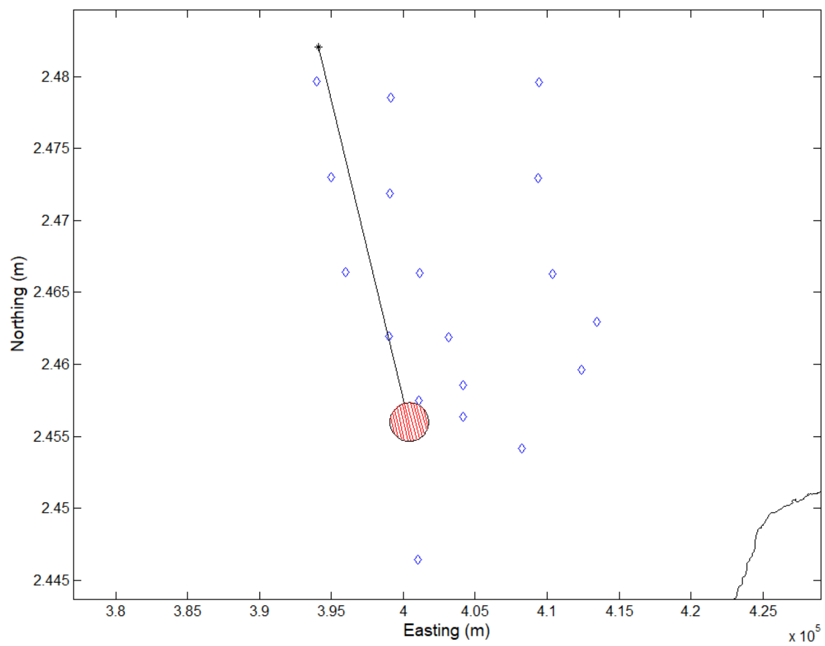
Acoustic data were recorded for 63 of the PMRF bottom-mounted range hydrophones in August 2021 and August 2022. Of the 63 hydrophones recorded, 36 had the broadband frequency response required for detecting MFAS transmissions. Thirty-one of these hydrophones had a frequency response from 50 Hz to 48 kHz and were at depths of 2400 to 4800 m, and the remaining 5 hydrophones had a frequency response from 100 Hz to 48 kHz and were at depths of 650 to 1750 Hz (Martin et al., 2015). The remaining 27 hydrophones had a frequency response of 8–48 kHz and therefore were sufficient to detect most delphinid vocalizations. A custom computer-based recorder collected data at a 96 kHz sample rate with 16-bit samples.

The detection of MFAS transmissions occurred in the mid-frequency band of 1–10 kHz. Raw timeseries data were processed with a 16,384-point fast Fourier transform (FFT) and 93.75% overlap. Both long-term and short-term running average spectra of the FFTs were computed in the two detection frequency bands. These were used to determine when the signal-to-noise ratio (SNR) exceeded a user-defined threshold of 15 dB. To determine if an MFAS transmission was the first arrival (e.g., not multi-path), the maximum signal level had to be greater than one-half and one-third of the detected signal frequency to exclude the second and third harmonics as detections. 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 5-second blanking time was initiated before resuming detection to avoid detecting reverberations.

Model-based localizations of MFAS transmissions were performed using the suite of C++ algorithms originally developed for whale calls, described in detail by Martin et al. (2015, 2023). Briefly, the onset times of automatic detections across multiple hydrophones were used as the measured time of arrival (TOA), and measured TOAs were subtracted from each other to calculate the time difference of arrivals (TDOAs). A weighted least square error (LSE) between measured and modeled TDOAs was minimized by calculating modeled TDOAs from theoretical source locations determined by an iterative spatial grid search process. 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 of 0.15 seconds between measured and modeled TDOAs were used for this analysis.

2.6 ACOUSTIC PROPAGATION MODELING

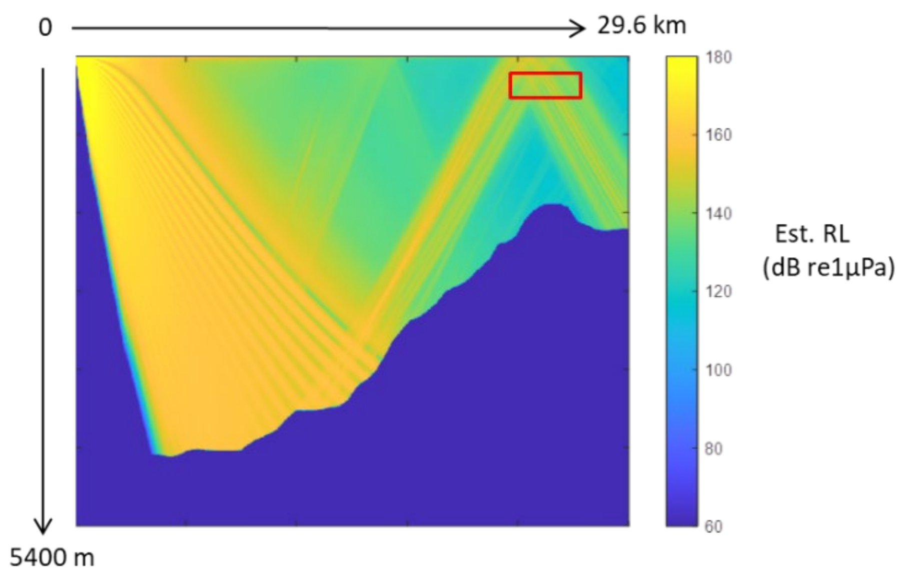
The process of estimating received levels on whales from MFAS transmissions utilizes methods described in detail in Henderson et al. (2021). To summarize, propagation modeling was done with the Peregrine parabolic equation propagation model developed by Oasis Ltd. (Heaney and Campbell, 2016), based on the range-dependent acoustic model (RAM) (Collins, 1993). The National Oceanic and Atmospheric Administration National Geophysical Data Center U.S. Coastal Relief Model (NOAA National Geophysical Data Center, 2011) was used to obtain bathymetric data with 3 arc-second resolution, and the 2018 World Ocean Atlas (Locarnini et al., 2018; Zweng et al., 2018) was consulted for historical sound speed profiles. Received levels were calculated based on publicly available source levels of U.S. Navy sonars (NMFS, 2007) and modeled transmission losses. Nominal source levels at 1 m distance for hull-mounted sonar (53C) are 235 dB re 1 µPa. The *crawl*-modeled x and y positional errors from interpolated whale track locations (described in Data Processing) were used to define a 95% confidence interval error ellipse to represent 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 was a single propagation modeling run (Figure X; also see Henderson et al. 2021 for more details on this method).



- Blue diamonds approximate the location of hydrophones for MFAS detection. The lower right shows a portion of the Kaua‘i coastline.

Figure 2. Example of radial slices from a ship through the error ellipse of a tag location.

Modeling was performed across the full depth range from 0 to a maximum of 5400 m, and the distance of the longest radial slice for an MFAS transmission was used for all radials from the same MFAS transmission for ease of analysis. Peregrine output transmission loss calculations resulted in 600 depth bins with 9 m 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 3 illustrates a single radial slice from a ship through the maximum range for an exposure over 5400 m depth and 29.6 km distance, color coded by the estimated receive level (RL).



- Dark color indicates the seafloor, highlighting the steep angle limitation close to source. The red insert box illustrates potential location in this slice of the animal location using the 95% CI ellipse and depth information.

Figure 3. Example of single slice from ship MFAS source full depth maximum distance estimated receive level in units of dB re 1µPa.

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 full water column of the 95% CI error ellipse. Animal depths were derived from the satellite tag data (see Dive Analysis section for more details on how this was modeled). For SbTag024, there was no depth data recorded with the SPOT6 tag; therefore, two depth regimes were utilized to estimate received levels. These included a shallow regime to represent exposures when the animal was within the upper 30 m of the surface and a dive depth regime that estimated depth bins between 30 and 400 m; the latter value was derived from Shaff and Baird (2021) to be the maximum depth for rough-toothed dolphin deep dives. Tag positional update times, or times when tag position updates were attempted but failed, can be used as known times the animals are at the surface (see Dive Analysis section); these provide additional surface information for all tagged delphinids for periods 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 m, each 9 m depth bin from the surface to 54 m depth was utilized; for depths from 54 m to 100 m, +/- 20% of the depth was utilized; for depths from 100 m to 400 m, +/- 10% was used; and for depths > 400 m, +/- 5% was used. Figure 2 shows a small red box indicating the estimated animal location for the propagation-modeled single slice. Multiple slices of estimated animal locations contribute to the full 3D estimate for each exposure.

Figure 4 illustrates the concept of utilizing radial azimuthal slices in a 3D manner. Each radial slice's contribution to the 3D volume is considered. Given that the acoustic propagation model computes the full field, this allows us to utilize all available elements of the estimated RL (three dimensions plus time along the track). Figure 5 illustrates a histogram of all available (19,872 in this example) individual depth-range elements within an animal's estimated 3D location at the time of an MFAS transmission.

The distribution is not nicely Gaussian in nature; although there is an estimated median received level of 129.3 dB, the histogram demonstrates the relatively high uncertainty in the actual exposure value for this MFAS transmission. This is also evident in Figure 3, where it is evident how multipath arrivals can contribute to stronger estimated received levels while much of the ensonified area has relatively lower estimated received levels. Therefore, the estimated received level needs to be defined by a single metric and accompanied by a metric for the variation of the received level. Following Henderson et al. (2021), we will provide the median RL +/- twice the standard deviation. Furthermore, while the number of MFAS transmissions in a 5-min bin is sensitive, we are providing a stoplight (red, yellow, and green) colorization of the median RL in plots to indicate relative MFAS activity in the bin, with green being low, yellow moderate, and red high.

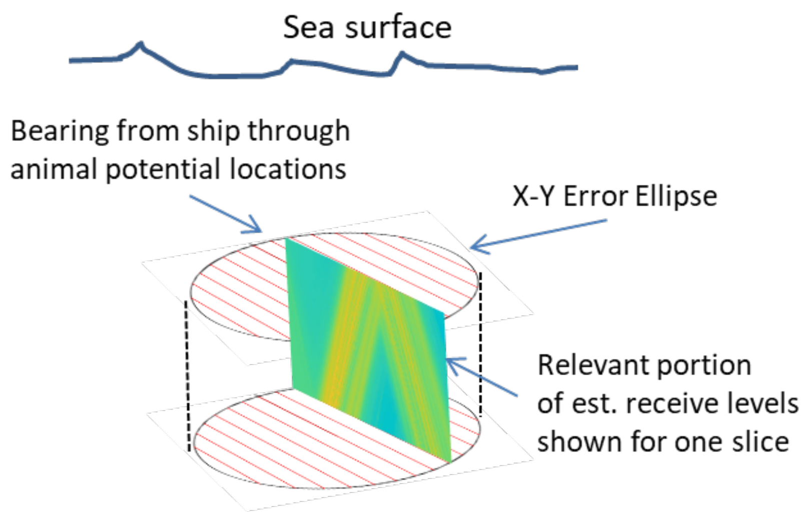
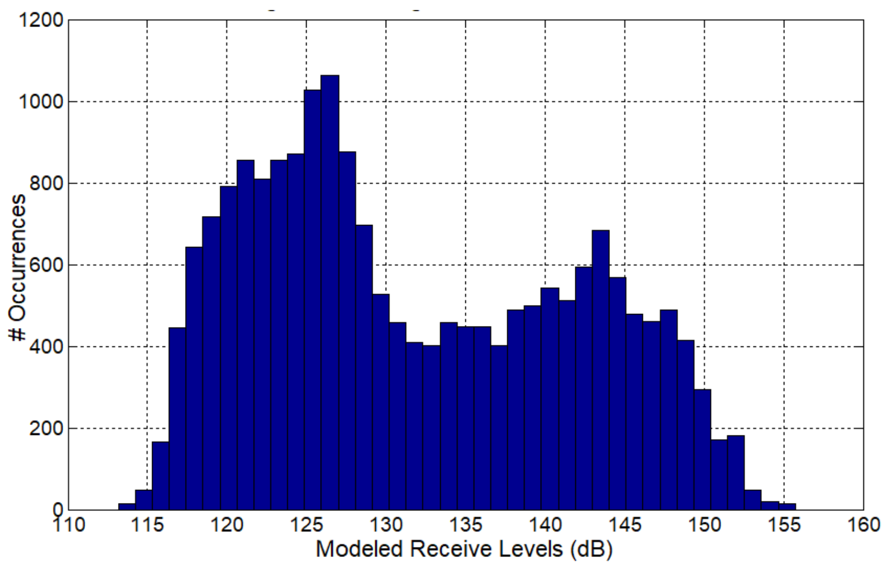


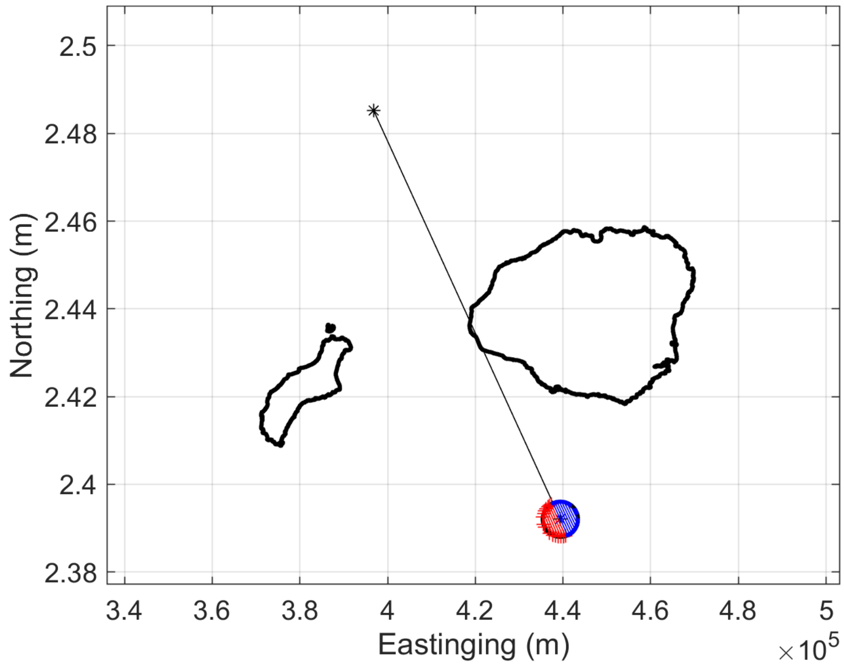
Figure 4. 3D concept utilizing multiple radials from MFAS source through an animal's estimated location in 3D space, using the red box insert from Figure 3.



- Example of all estimated receive levels for a single MFAS transmission via 25 slices from the MFAS ship to one estimated possible 95% CI location in three dimensions.

Figure 5. Estimated receive levels.

There are also diagnostic metrics available to account for the loss of propagation-modeled received level elements due to a variety of situations, such as some of the possible animal locations being impossible. This could be for a variety of reasons: 1) a portion of the animal's error ellipse is shadowed from the MFAS source due to bathymetry or a land mass; 2) the estimated water depth is less than the animal's modeled foraging dive depth; or 3) if the animal's error ellipse is within a few hundred meters of the source, the steep angle limitation precludes providing estimates. A single metric, termed the Probability of Exposure, is 1.0 for exposures with all of the 3D elements being represented in the propagation model; when this metric is < 1.0, it flags exposures that might not have been fully possible (e.g., a majority of the animal's error ellipse is shadowed from the MFAS source by, for example, the islands). Figure 6 illustrates an example of this for one position from GmTag235, where a portion of the error ellipse has an acoustic path to a ship (in red), while the remainder of the ellipse is shadowed by land (in blue).



- Plan view of exposure geometry for one location, illustrating the situation where the animal may, or may not, have been exposed to MFAS depending on where it actually was within its 95% confidence interval location uncertainty. To account for this, an estimated probability of exposure metric is included for all estimated exposures to MFAS.

Figure 6. Plan view of exposure geometry.

2.7 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 m. 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 in that analysis, 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 radials but provides a continuous exposure history for each ship. This method also allows for the interpolation of all pings that occurred between the propagation-modeled exposures for each ship participating in the training activity.

2.8 BEHAVIORAL RESPONSE AND DIEL ANALYSIS

The timing and general locations of tagged animals were first assessed in relation to the timing and general location of both Phase A and Phase B to determine whether additional assessments of potential behavioral responses were warranted. If tags ceased transmitting prior to the start of Phase A, if tagged individuals were in the acoustic shadow of Kaua‘i or Ni‘ihau during Phases A and B, or if tagged individuals had moved >100 km from the general area of the SCC, they were not considered in the behavioral analyses. For each tag with dive behavior, the coverage of dive and surfacing data during each phase was first evaluated to provide an indication of the robustness of comparisons among phases. To do this, the duration of all dive and surfacing periods within each phase was summed up, then divided by the total durations of the respective phases.

Any dive or surface periods that spanned more than one phase had their durations split (e.g., a surfacing period beginning in Phase A and continuing into the interphase would have its duration split between the two periods based on when the interphase begins). Because not all tags were transmitted for the full duration of each phase, coverage relative to the duration of each tag was evaluated. To do this, the duration of all dive and surfacing periods within each phase was summed up, with those that occurred over multiple phases split as before, and divided by the total duration of tag transmission during each phase. This allows for an assessment of gaps in the behavioral data that might influence the likelihood of detecting potential behavioral responses.

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 was also calculated. Dive and surface periods were each assigned a time of day based on when they started, defined as either dawn, day, dusk, or night. Dawn was defined as the period before and after sunset, with solar angles between 6° below and above the horizon. Day was defined as the period after sunrise and prior to sunset with solar angles > 6° above the horizon. Dusk was defined as the period prior to sunset with solar angles between 6° below and above the horizon. Night was defined as the period after sunset and prior to sunrise with solar angles >6° below the horizon. The durations of surface periods that spanned more than one time of day were split (e.g., such that a surface period beginning at dawn and continuing into day would have its duration split between the two times of day based on when day begins). As before, surface periods that crossed multiple SCC phases (e.g., Phase A to Interphase) had their durations split between phases. Due to their short duration, no dives were split based on either phase or time of day. 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 dawn total duration for Phase A would represent the sum of the duration of all dawns within Phase A). For the Before and After periods, the total duration of the phase was calculated as 3 days prior to the start of Phase A and 3 days following the end of Phase B, respectively.

Metrics calculated 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). For all metrics, only 3 days of data following the end of Phase B (i.e., After) 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 each tagged individual with sufficient dive/surfacing coverage (SPLASH10 tags only), 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 phases A and B; significance level for both tests = 0.05).

These statistical procedures were not applied to summaries on dive rates (dives per hour) or percentages of time at surface due to the nature of how these values were calculated (i.e., only single values for each SCC phase). Sufficient coverage for each phase was defined based on species and time of day to account for species-level variation in diving behavior, with those species that have the longest dive durations requiring a higher level of coverage during the dawn and dusk periods for inclusion in statistical tests (Table 2). Additionally, due to their relatively short durations, the dawn and dusk times of day had higher coverage requirements to ensure that data from these times of day were providing an accurate representation of diving behavior.

Table 2. Coverage requirements for each phase. Coverage requirements for each phase by time of day and species for inclusion in statistical comparisons between phases.

Species	Dawn % coverage required for inclusion in statistical testing	Day % coverage required for inclusion in statistical testing	Dusk % coverage required for inclusion in statistical testing	Night % coverage required for inclusion in statistical testing	Notes
Gm	80	50	80	50	Due to their longer dive durations, the dawn and dusk coverage requirements for this species are set at 80%.
Pe	NA	NA	NA	50	As this species dives almost exclusively at night (West et al. 2018), only night is statistically tested for this species.
Pc, Tt, Sb	70	50	70	50	

- Gm = pilot whale (Globicephala macrorhynchus).
- Pe = melon-headed whale (Peponocephala electra).
- Pc = false killer whale (Pseudorca crassidens).
- Tt = common bottlenose dolphin (Tursiops truncatus).
- Sb = rough-toothed dolphin (Steno bredanensis).

3. RESULTS

3.1 TAGGING AND PHOTO-IDENTIFICATION

A summary of individuals that were tagged, including their tag duration, overlap with SCC phases, and maximum estimated RL, is given in Table 3. The false killer whale tagged in 2021 (PcTag074) was identified as HIPc364, a member of Cluster 3 (cf. Mahaffy et al., 2023) of the endangered main Hawaiian Islands population. This individual had previously been documented off Hawaiʻi Island (2009, 2014) and Oʻahu (2017, 2021), but had not been previously documented off Kauaʻi. All six of the tagged short-finned pilot whales from 2021 and 2022 had been previously documented. The three individuals tagged in 2021 were from two different social clusters (see Mahaffy et al., 2015). GmTag232 and GmTag233 (HIGm0242 and HIGm1166, respectively) are members of Cluster W11, known to be part of the western community (cf. Baird, 2016; Van Cise et al., 2017). These individuals have been previously documented off Kauaʻi in 2005 (HIGm0242) and 2008 (both individuals), and off Oʻahu in 2009 (HIGm1166). GmTag234 was identified as HIGm0205 and a member of Cluster W8, previously documented off Oʻahu in 2003 and 2009 and off Kauaʻi in 2012. All three individuals tagged in 2022 (GmTag235, GmTag236, and GmTag237; individuals HIGm2222, HIGm2213, and HIGm0768, respectively) are members of Cluster H14. This group has not been linked by association with any other group, and thus its community membership is unknown. Sighting history of the tagged individuals (HIGm0768 off Hawaiʻi Island in 2006 and 2013, HIGm2213 off Hawaiʻi Island in 2013, and Oʻahu in 2016, HIGm2222 off Hawaiʻi Island in 2013 and 2014) suggests they are not part of the resident communities and are likely an offshore group. None of these individuals had been previously tagged.

Two of the three tagged bottlenose dolphins (TtTag040 and TtTag041) had previously been documented off Kauaʻi, while the other (TtTag039) had not been previously identified. While TtTag039 had not been previously documented, it was linked by association with the resident, island-associated population through other individuals in the encounter. TtTag040 was identified as HITt0740 in the photo-identification catalog and had been photographed on six different occasions in three different years (first in 2011). TtTag041 was identified as HITt1474 in the photo-identification catalog and had been photographed once previously (in 2018). Both HITt0740 and HITt1474 are known to be part of the island-associated resident community (Baird et al., 2009). Only one of the three tagged rough-toothed dolphins had been previously documented. SbTag024 was identified as HISb1474 and documented on six different occasions in four different years (first in 2008) and is known to be part of the island-associated resident population (Baird et al., 2008). The other tagged rough-toothed dolphin from 2021 (SbTag023, HISb2743 in the photo-identification catalog) was in the same encounter as HISb1474, and thus is linked by association with the resident, island-associated population. The individual tagged in 2022 (SbTag025, HISb2744 in the catalog) had not been encountered previously, but at least one other distinctive individual in the encounter was known to be part of the resident, island-associated community, and thus this individual was considered a member by association. None of the individuals of either species had been previously tagged. Although Cascadia has a melon-headed whale photo-identification catalog (Aschettino et al., 2012), the catalog has not been substantially updated since 2011. Given the size of the catalog (~2000 individuals) and the rate of mark change, it is unlikely that matches to tagged individuals would be found without also updating the catalog with photos available in the intervening years. Finally, three Blainville's beaked whales were also tagged, two in 2021 and one in 2022, but their results are discussed in a separate paper (Henderson et al., 2024) and will not be mentioned further in this report.

Table 3. Tag deployment data for 2021 and 2022 satellite tags.

Tag ID	Tag type	Deployment Date/time (GMT)	End Date/time (GMT)	Duration (days)	Overlap with SCC Phases	Max RL (dB re 1 μPa)
GmTag232	SPLASH10-F	2021-08-08 21:32	2021-08-22 21:11	14.0	A, B	80.4
GmTag233	SPLASH10-F	2021-08-10 18:36	2021-08-26 21:30	16.1	A, B	81.2
GmTag234	SPLASH10-F	2021-08-10 19:01	2021-09-03 20:23	24.1	A, B	72.6
PcTag074	SPLASH10-F	2021-08-08 16:35	2021-08-20 17:42	12.0	A, B	90.5
PeTag029	SPLASH10-F	2021-08-01 17:56	2021-08-14 08:11	12.6	A	147.7
PeTag030*	SPLASH10-F	2021-08-09 18:59	2021-08-09 18:59	0	NA	NA
PeTag031	SPLASH10-F	2021-08-11 19:21	2021-09-01 09:04	20.6	A, B	136.6
PeTag032	SPLASH10-F	2021-08-13 19:24	2021-08-30 05:31	16.4	B	135.5
SbTag023	SPLASH10	2021-08-09 20:23	2021-08-22 20:12	13.0	A, B	141.9
SbTag024	SPOT6	2021-08-09 20:54	2021-08-14 09:19	4.5	A	NA
TtTag039	SPLASH10-F	2021-08-12 21:00	2021-08-25 16:10	12.8	A, B	100.0
TtTag040	SPLASH10-F	2021-08-14 19:44	2021-08-30 16:30	15.9	B	100.5
SbTag025	SPLASH10	2022-08-24 20:17	2022-09-01 08:30	7.5	B/A Mixed	NA
GmTag235	SPLASH10-F	2022-08-17 17:43	2022-09-03 21:09	17.1	A/B Mixed, B/A Mixed	129.2
GmTag236	SPLASH10-F	2022-08-17 20:00	2022-08-21 21:16	4.1	A/B Mixed	128.8
GmTag237	SPLASH10-F	2022-08-17 20:27	2022-10-02 08:42	45.5	A/B Mixed, B/A Mixed	128.8
PeTag033	SPLASH10-F	2022-08-18 18:20	2022-08-29 21:24	11.1	A/B Mixed, B/A Mixed	70.1
PeTag034	SPLASH10-F	2022-08-18 19:00	2022-08-22 21:57	4.1	A/B Mixed	72.6
PeTag035	SPLASH10-F	2022-08-24 19:24	2022-09-12 03:05	18.3	B/A Mixed	NA
PeTag036	SPLASH10-F	2022-08-24 19:49	2022-09-04 05:03	10.4	B/A Mixed	NA
TtTag041	SPLASH10	2022-08-21 20:36	2022-09-07 19:49	17.0	B/A Mixed	NA

- *Tag failed upon deployment.
- An “NA” in the maximum received level column indicates that there was no overlap between the specified tag and MFAS blocks.
- Max RL = Maximum estimated received level.

In 2021, there was a two-day Unit Level Test (ULT) prior to the SCC, and then the SCC was conducted in a typical fashion, with Phase A (no surface ship or MFAS activity) occurring for three days, then a three-day break, and then Phase B (which includes surface ships and MFAS) occurring for another four days. The ULT did include MFAS, which was modeled in the same manner as the MFAS in Phase B. A three-day Before and a three-day After period are also included in Table 4 for reference. In 2022, there was a one-day submarine exercise (SUBEX) prior to the SCC. There was no MFAS during the SUBEX. In this case, the SCC was conducted slightly differently than is typical, with components of Phase A and B occurring in both weeks. The first four-day portion is referred to in this report as Phase A/B, indicating it takes place during the typical Phase A period, while the second period only occurred for one day and is referred to in this report as Phase B/A, indicating it was conducted during the typical Phase B period. Any MFAS that occurred during either Phase A/B or Phase B/A was analyzed in the same manner as the MFAS in 2021. There was also the usual 5-day break in between the two training phases (Interphase) and a 3-day Before and 3-day After period included in Table 4 as well.

Table 4. SCC phase times and passive acoustic monitoring data durations.

Phase	Start date	End date	Duration (hrs)
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/Before	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
After	8/19/2021 14:31	8/22/2021 14:30	72
Before	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	8/24/2022 10:29	73.3
SCC B/A (mixed)	8/24/2022 10:30	8/24/2022 15:53	5.4
After	8/24/2022 15:54	8/27/2022 15:54	72

- Times given in HST.

3.2 BEHAVIORAL RESPONSE, DIEL ANALYSIS, AND RECEIVED LEVEL ESTIMATION

The following sections document data available for behavior analyses, as well as movements and estimated RLs for short-finned pilot whales, false killer whales, melon-headed whales, rough-toothed dolphins, and bottlenose dolphins across two separate SCC training events, following the format from Henderson et al. (2021).

Of the 21 animals tagged at PMRF in 2021 and 2022, 15 animals remained in the area during the phases of the SCCs during which MFAS is used (Phase B in 2021, Phases A/B and B/A in 2022). Only the hull-mounted MFAS was modeled for received level estimation in this report; however, in 2021 there was also helicopter-dipping and active sonobuoy MFAS present, and in 2022 there was helicopter-dipping MFAS present. The source levels of the latter two sources are much lower than those of hull-mounted MFAS, and they are typically deployed in the same area of the range as the hull-mounted MFAS activity, so they are not expected to be large contributors to the MFAS soundscape experienced by these whales. For all of these animals, the median estimated RL per 5-minute bin (associated with a *crawl*-smoothed track location) is reported along with the ± 2 standard deviation (SD) values for those bins. As a reminder, wide ± 2 SD on the RL figures indicate a larger error ellipse on the *crawl*-smoothed track location (e.g., on the 4th to last ping on Figure 5). Bouts or blocks of MFAS are considered to be periods of MFAS separated by at least 30 minutes, and there are multiple blocks per phase (Phase B or B/A). Širović et al. (2013) determined that ambient noise levels are about 60 dB re 1 µPa at 1 kHz; noise levels would be even lower in the mid-frequency band of 1–10 kHz. Using this value as the noise floor and following what has been done previously at PMRF (Baird et al. 2019) and the recommendation of Schick et al. (2019), any estimated received levels below 60 dB re 1 µPa will be included in figures but will otherwise be reported as “NA.”

Summary tables and figures are only included for individuals with exposures and statistically significant differences among phases; the remaining tables and figures are included in the Appendix. Sections are organized by species and within species in the following order: summary tables, followed by narratives for each individual or group, including estimated RLs, maps for those specific animals, dive behavior narratives for each individual or group, and applicable dive behavior figures.

3.2.1. Short-finned pilot whales

Six short-finned pilot whales were tagged three in 2021 in one group, and three in 2022 in another group. Summary statistics are presented below in Table 5, Table 6, and Table 7 for all animals.

Table 5. Percentage of surfacing/dive data by phase for short-finned pilot whales.

Individual	Percentage of surfacing/dive data				
	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After
GmTag232					
Duration overall (days)	3.3	1.7	3.8	2.4	2.9
Days surfacing/dive data	3.3	1.7	3.8	2.3	1.7
Percentage behavioral coverage	100.0	100.0	99.2	95.0	58.4
GmTag233					
Duration overall (days)	1.4	1.7	3.8	2.4	6.9
Days surfacing/dive data	1.4	1.4	3.1	2.3	3.2
Percentage behavioral coverage	100.0	80.4	81.5	95.8	46.1
GmTag234					
Duration overall (days)	1.4	1.7	3.8	2.4	14.8
Days surfacing/dive data	1.2	1.5	3.5	2.4	3.2
Percentage behavioral coverage	89.8	88.7	93.7	99.6	21.4
GmTag235					
Duration overall (days)	NA	3.7	3.5	0.2	9.8
Days surfacing/dive data	NA	3.6	3.3	0.2	4.8
Percentage behavioral coverage	NA	97.5	95.1	100.0	49.4
GmTag236					
Duration overall (days)	NA	3.6	0.5	0.0	0.0
Days surfacing/dive data	NA	2.8	0.0	0.0	0.0
Percentage behavioral coverage	NA	78.4	8.2	0.0	0.0
GmTag237					
Duration overall (days)	NA	3.5	3.5	0.2	38.3
Days surfacing/dive data	NA	3.2	3.4	0.2	5.0
Percentage behavioral coverage	NA	91.2	98.0	100.0	13.1

- 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.

Table 6. A comparison of dawn diving parameters from short-finned pilot whales exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dawn dive rate (dives/hour)							
GmTag232	1.99	1.12	2.15	2.31	NA	-	
GmTag233	NA	NA	0.56	2.33	1.90	-	
GmTag234	NA	2.25	2.32	2.14	1.50	-	
GmTag235	NA	NA	2.60	NA	1.27	-	
GmTag237	NA	NA	2.70	NA	1.71	-	
% time in surface periods at dawn							
GmTag232	39.67	72.19	37.17	43.64	NA	-	
GmTag233	NA	NA	93.07	52.78	54.62	-	
GmTag234	NA	38.33	43.35	41.24	53.42	-	
GmTag235	NA	NA	33.90	NA	61.22	-	
GmTag237	NA	NA	23.23	NA	45.47	-	
Median dive depth dawn (m)							
GmTag232	751.50	663.50	655.50	623.50	NA	0.6202	NA
GmTag233	NA	NA	99.50	647.50	623.50	0.1576	NA
GmTag234	NA	903.50	719.50	655.50	599.50	0.1942	NA
GmTag235	NA	NA	679.50	NA	735.50	0.1474	NA
GmTag237	NA	NA	719.50	NA	687.50	0.8638	NA
Median dive duration dawn (min)							
GmTag232	18.97	14.95	16.90	14.60	NA	0.1195	NA
GmTag233	**NA**	**NA**	**7.47**	**13.10**	**14.27**	**0.0147**	**B-After**
GmTag234	NA	16.70	17.28	16.20	18.48	0.1596	NA
GmTag235	**NA**	**NA**	**14.95**	**NA**	**18.43**	**0.0278**	**Inter-After**
GmTag237	**NA**	**NA**	**17.63**	**NA**	**19.03**	**0.0202**	**Inter-After**

- Kruskal-Wallis one-way ANOVA: significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

Table 7. A comparison of nighttime diving parameters from short-finned pilot whales exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Night dive rate (dives/hour)							
GmTag232	2.97	2.72	2.71	2.51	2.42	-	
GmTag233	NA	4.67	3.80	3.70	2.78	-	
GmTag234	NA	2.75	2.91	3.11	2.59	-	
GmTag235	NA	3.63	3.47	NA	3.02	-	
GmTag236	NA	3.53	NA	NA	NA	-	
GmTag237	NA	3.56	3.25	NA	3.20	-	
% time in surface periods at night							
GmTag232	34.82	37.18	29.86	37.48	38.31	-	
GmTag233	NA	29.11	33.85	33.35	39.83	-	
GmTag234	NA	32.35	33.73	36.71	36.25	-	
GmTag235	NA	26.55	28.98	NA	31.84	-	
GmTag236	NA	25.57	NA	NA	NA	-	
GmTag237	NA	23.56	30.96	NA	27.27	-	
Median dive depth night (m)							
GmTag232	**403.50**	**504.50**	**527.50**	**591.50**	**543.50**	**NA**	**Inter-Before; B-Before; After-Before**
GmTag233	**NA**	**227.50**	**233.50**	**255.50**	**559.50**	**<0.0001**	**Inter-After; A-After; B-After**
GmTag234	**NA**	**575.50**	**543.50**	**511.50**	**591.50**	**0.0040**	**Inter-A; A-B; Inter-After; B-After**
GmTag235	NA	323.50	387.50	NA	391.50	0.4695	NA
GmTag236	NA	319.50	NA	NA	NA	NA	NA
GmTag237	NA	271.50	295.50	NA	335.50	0.8859	NA

Table 7. A comparison of nighttime diving parameters from short-finned pilot whales exposed to MFAS for phases that meet the required coverage cutoff. (Continued)

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Median dive duration night (min)							
GmTag232	**14.12**	**13.07**	**15.13**	**15.17**	**15.67**	**0.0188**	**No significant adjusted p-values**
GmTag233	**NA**	**8.93**	**10.32**	**10.97**	**13.53**	**<0.0001**	**Inter-A; A-B; Inter-After; A-After; B-After**
GmTag234	**NA**	**14.67**	**13.97**	**12.42**	**14.87**	**0.0002**	**Inter-B; A-B; Inter-After; B-After**
GmTag235	**NA**	**12.08**	**12.50**	**NA**	**13.93**	**0.0003**	**Inter-After; A-After**
GmTag236	NA	12.82	NA	NA	NA	NA	NA
GmTag237	NA	12.60	12.57	NA	14.20	0.0641	NA

- Kruskal-Wallis one-way ANOVA: significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

3.2.1.1 GmTag232, GmTag233, GmTag234

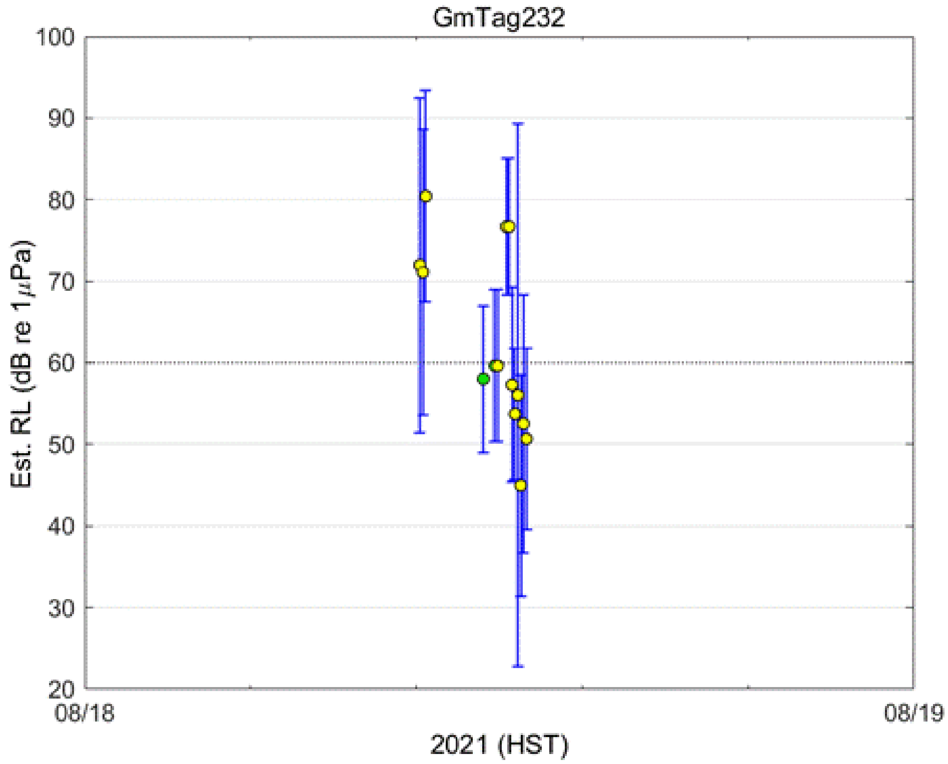
These three individuals were tagged within the same group in 2021 and generally remained associated over the overlapping period of tag attachment. Information was available on movement patterns for Before (1.4–3.3 days), Phase A (1.7 days), the interphase period (3.8 days), Phase B (2.4 days), and After (2.9–14.8 days; Table 5). All three of these individuals remained off the range for the entire duration of the SCC, though they remained in close proximity to Kaua‘i (e.g. within 10s of kms; Figure 10).

After tag deployment south of the range, all three individuals moved along the southern coast of Kaua‘i and remained in this general area throughout Phase A. After Phase A, they remained in the area for the few days of the interphase period and then moved along the eastern coast of Kaua‘i before returning to the southern coast at the start of Phase B. These individuals remained in this same area during Phase B and were largely out of range of MFAS exposure throughout Phase B, except for a handful of exposures ranging between 47 and 81 dB re 1 µPa. After Phase B, these individuals remained in the same general area for a short period of time and then moved back up along the east coast of Kaua‘i. Because these individuals remained associated during their shared deployment period and had highly similar exposure levels, only one individual was mapped here (Figure 10).

GmTag232 was exposed to three different bouts of hull-mounted MFAS, although, as described, they were off the range and behind the island of Kaua‘i for most of the SCC. They did have a few exposure bins with a probability of 1, but others were as low as 0.2 (e.g., only a portion of the error ellipse for that track location could have been exposed). In addition, distances were all longer than 72 km, and all median RL values were less than 82 dB re 1 µPa (Table 8, Figure 7). In fact, 9 of the 14 track locations that had some MFAS exposure had RLs below the ambient noise floor of 60 dB re 1 µPa.

Table 8. Estimated received levels, cumulative sound exposure levels, and ship CPA for GmTag232.

Minimum median RL value (± 2 SD) dB re 1 µPa	NA
Maximum median RL value (± 2 SD) dB re 1 µPa	80 (68, 93)
CPA of ship (km)	72
Maximum overall cSEL dB re 1 µPa^2	85



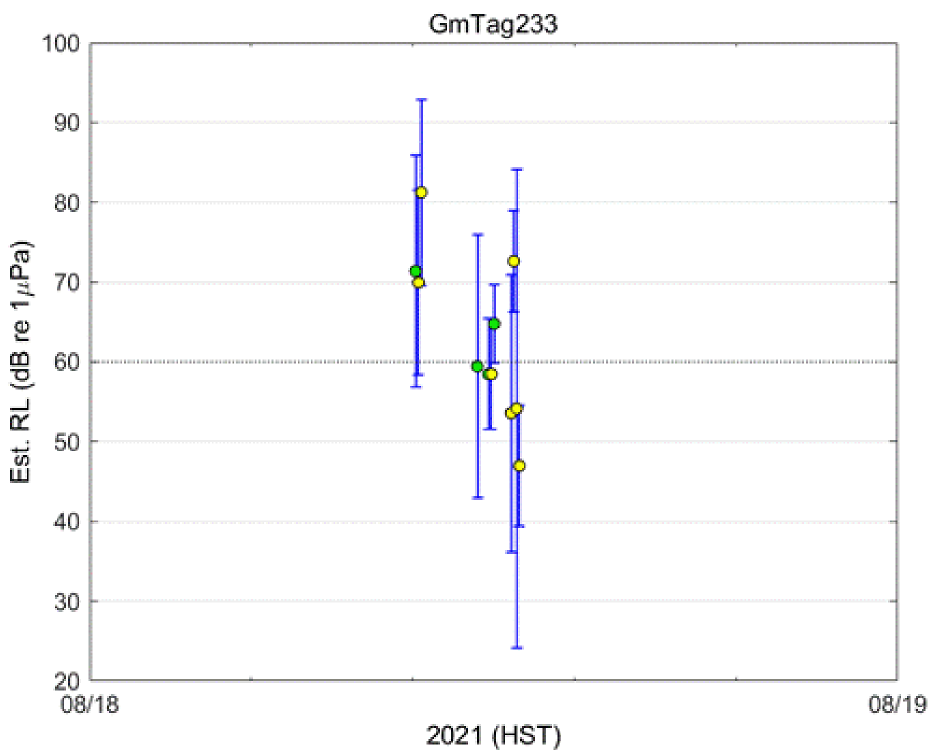
- Median RLs for GmTag232 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 7. Median RLs for GmTag232.

GmTag233 had similarly low estimated RLs and long distances for their two exposure periods (Table 9, Figure 8). Six of the 11 locations with exposures had RLs below ambient noise levels, and eight of the 11 locations had less than a probability of one exposure.

Table 9. Estimated received levels, cumulative sound exposure levels, and ship CPA for GmTag233.

Minimum median RL value (± 2 SD) dB re 1 µPa	NA
Maximum median RL value (± 2 SD) dB re 1 µPa	80 (70, 93)
CPA of ship (km)	73
Maximum overall cSEL dB re 1 µPa^2	87



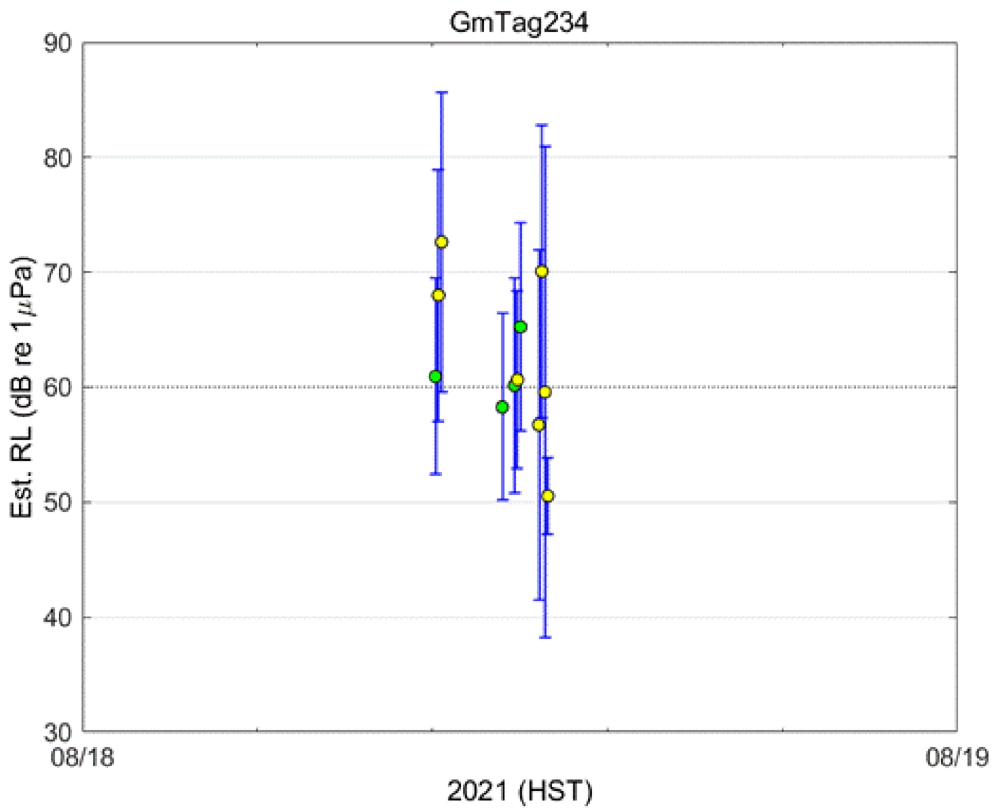
- Median RLs for GmTag233 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 µPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 8. Median RLs for GmTag233.

GmTag234 had similar low RLs and reduced probabilities of exposure (Table 10, Figure 9). Again, of the 11 track locations with exposures, eight of those had a less than 1 probability of actually getting exposed, and seven were at or below the 60 dB re 1 µPa ambient noise floor.

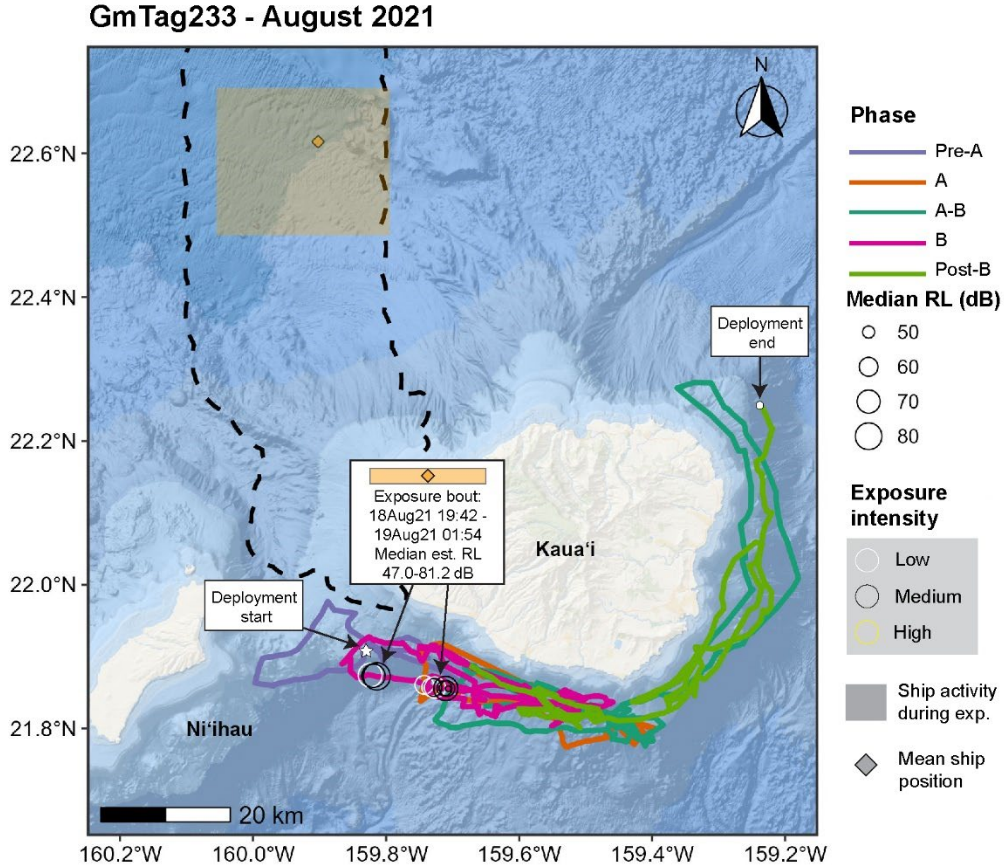
Table 10. Estimated received levels, cumulative sound exposure levels, and ship CPA for GmTag234.

Minimum median RL value (± 2 SD) dB re 1 μPa	NA
Maximum median RL value (± 2 SD) dB re 1 μPa	73 (60, 86)
CPA of ship (km)	72
Maximum overall cSEL dB re 1 μPa^2	80



- Median RLs for GmTag234 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 9. Median RLs for GmTag234.



- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level, and the time is given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygon represents the area of ship activity during each of the three MFAS bouts that GmTag233 was exposed to, and the corresponding diamond point represents the mean ship location during the bouts.
- Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

Figure 10. GmTag233 movements during the August 2021 SCC event (see text for description of phases).

3.2.1.1.1 Dive Behavior

GmTag232, GmTag233, and GmTag234 all transmitted dive behavior data for each phase (Table 6 and Table 7; and Figure 9, Figure 10, and Figure 11). However, when separated by time of day and phase, not every time of day and phase met the required coverage (relative to the phase duration) for inclusion in the analysis.

Dawn dive rates f(Table 6) or the three tags ranged from 0.56 dives/hr (GmTag233, Interphase) to 2.33 dives/hr (GmTag233, Phase B), with varied trends following exposure phases. Compared to Before, GmTag232 had a decreased dawn dive rate during Phase A but subsequently increased its dive rate across the next two phases. The dawn dive rate for GmTag233 also increased during Phase B.

In contrast, dawn dive rates for GmTag234 remained relatively consistent between Phase A and the Interphase and began to decrease during Phase B. Following Phase B dawn dives, rates decreased for both GmTag233 and GmTag234.

The percentage of surface time almost doubled during Phase A compared to Before (39.67% to 72.19%) for GmTag232 and decreased again during the interphase and Phase B. For GmTag233, the percentage of surface time was highest during the interphase period, after which it decreased to more consistent levels during Phase B and After. In contrast, GmTag234 maintained relatively consistent surface time percentages across phases, ranging from a minimum of 38.33% (Phase A) to a maximum of 53.42% (After). The variation in dawn dive depths between phases was not statistically significant for any tag, but there were significantly longer dives during After when compared to Phase B for GmTag233.

Day dive rates (Figures 11 - 13) for the three tags were generally lower than dawn dive rates and ranged from 0.35 dives/hr (GmTag233, After) to 1.89 dives/hr (GmTag234, Phase A), with varied trends following exposure phases. Compared to Before, GmTag232 had a sharply decreased day dive rate during Phase A, while GmTag233 remained relatively consistent between the two. Following Phase A, day dive rates remained fairly consistent for all tagged individuals but decreased following Phase B for GmTag233 and GmTag234. The percentage of surface time during the day remained fairly consistent across phases for all three tags, though it did increase moderately following Phase B for GmTag233 and GmTag234. Day dive depths had statistically significant variation between phases for all tags, though only GmTag233 and GmTag234 had statistically significant pairwise post-hoc comparisons between phases. For GmTag233, there were significantly shallower dives during After when compared to Before, while for GmTag234 there were significantly deeper dives during After compared to Phase A and the interphase, and significantly deeper dives during Phase B compared to the interphase. Day dive durations also had statistically significant variation between phases for GmTag232 and GmTag234, with GmTag232 having significantly shorter dives during Before compared to Phase A and interphase, while GmTag234 had significantly shorter dives during the interphase compared to Phase B and After.

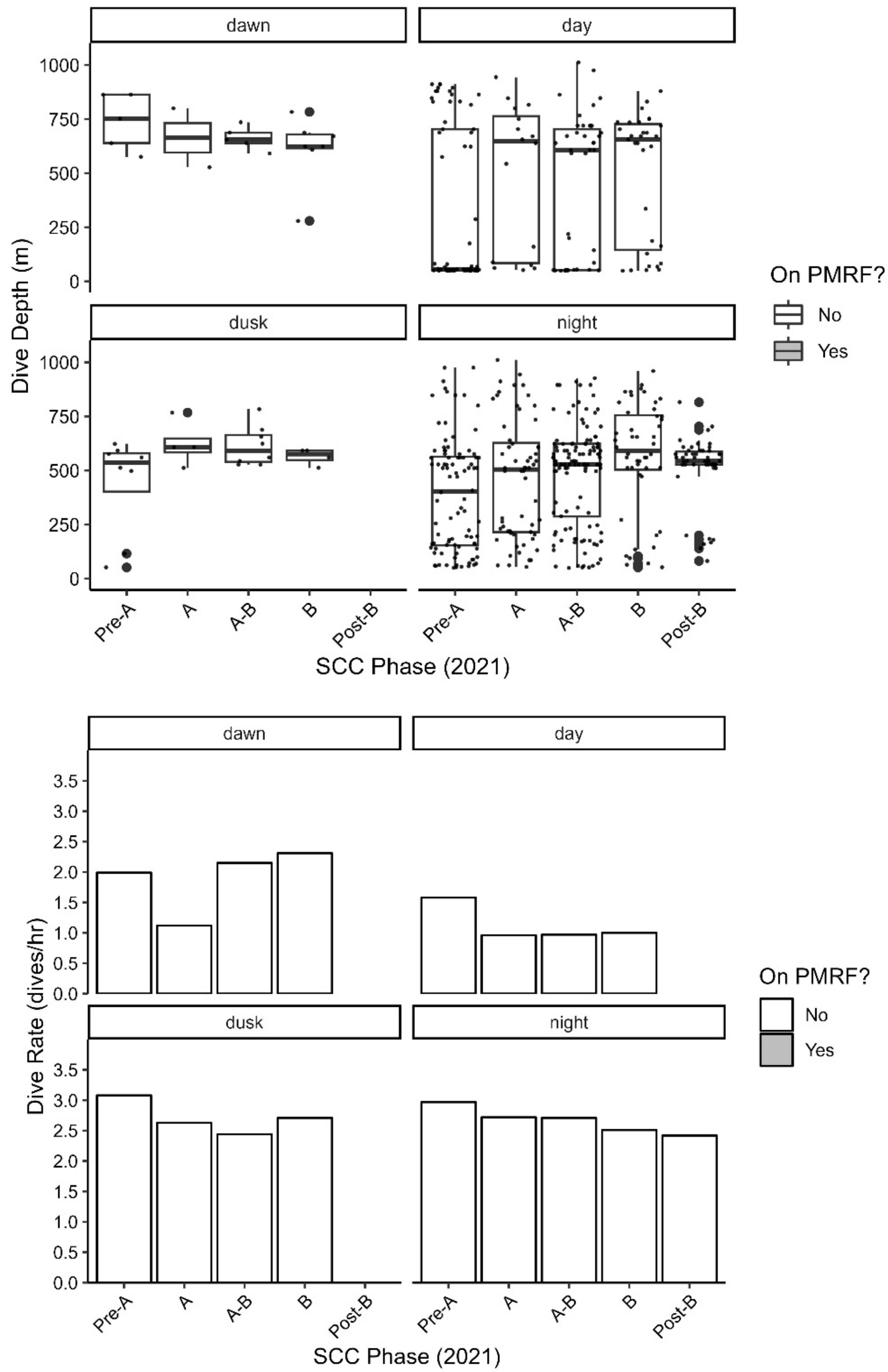
Dusk dive rates (Figures 11 - 13) were generally higher than dawn or daytime dive rates and ranged from 2.29 dives/hr (GmTag234, interphase) to 3.26 dives/hr (GmTag233, After), with varied trends following exposure phases. Compared to Before, GmTag232 had a decreased dusk dive rate during Phase A, and the dive rate for this tag continued to decrease during the interphase. During Phase B, dusk dive rates increased for GmTag232 and GmTag234, but fell for GmTag233. Following Phase B, GmTag233 had an increase in dusk dive rate, while GmTag234 had only a very slight decrease in dive rate. The percentage of surface time for all three tags remained comparatively low during the dusk hours and was generally consistent across most phases, with the exception of a moderate increase in surface time for GmTag233 during Phase B (43.46%) when compared to the interphase (31.72%) and After (25%). The variation in dusk dive depths and durations between phases was not statistically significant for any tag.

Night dive rates (Figures 11 - 13) were generally the highest of any time of day and ranged from 2.42 dives/hr (GmTag232, After) to 4.67 dives/hr (GmTag233, Phase A), with varied trends following exposure phases. Compared to Before, GmTag232 had only a slight decrease in night dive, and the dive rate for this individual did not vary substantially from Phase A to the interphase. Following Phase A, GmTag233 had a decrease in dive rate that continued throughout the remaining duration of the SCC, while GmTag234 had a slight increase in dive rate that continued into Phase B. Following Phase B, all individuals had decreases in night dive rates, though there was considerable variation in the extent of the decrease.

The percentage of surface time at night for all three tags remained largely consistent across phases, but there was significant variation in night dive depths. Night dive depths were significantly deeper during the interphase, Phase B, and After when compared to Before for GmTag232.

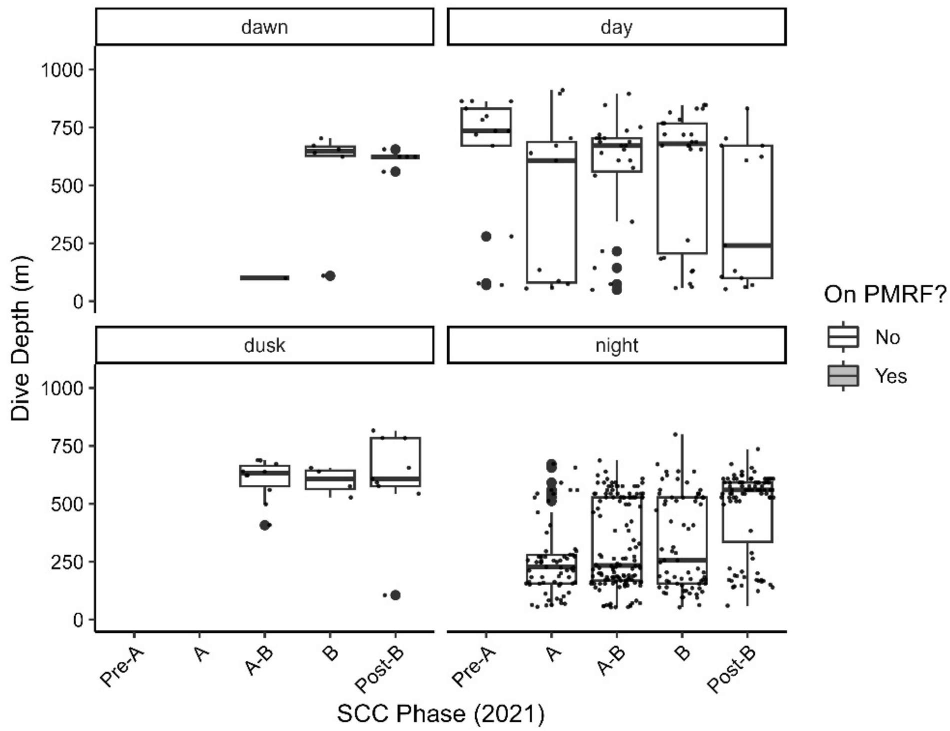
Dive depths were also significantly deeper during After when compared to Phase A, the interphase, and Phase B for GmTag233, and when compared to the interphase and Phase B for GmTag234.

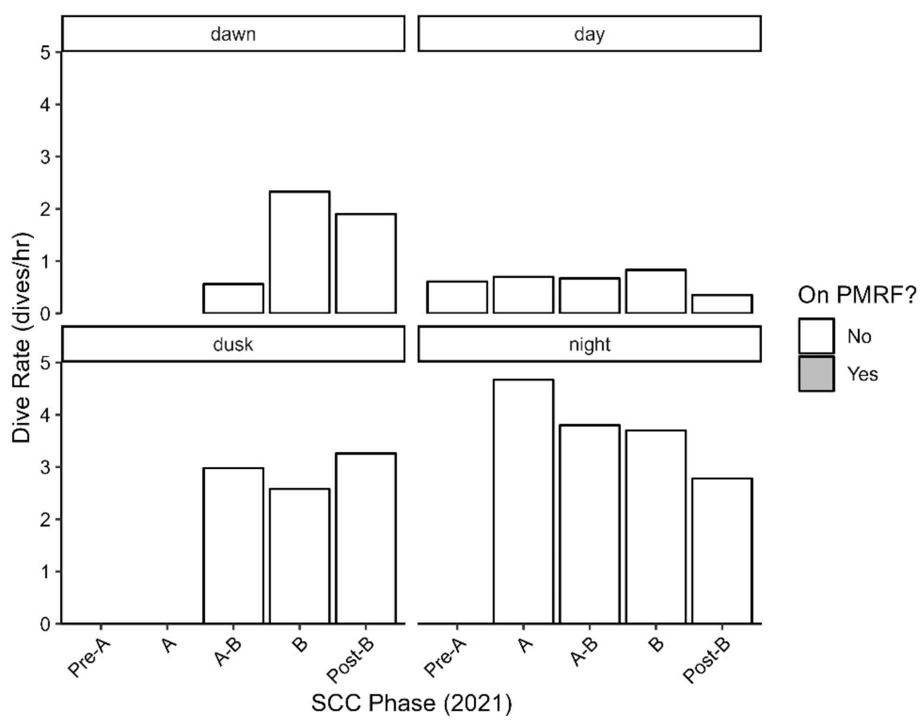
In contrast, night dive depths were significantly shallower during Phase B when compared to Phase A and the interphase for GmTag234. Night dive durations also varied significantly between phases for all tags, though only GmTag233 and GmTag234 had statistically significant post-hoc pairwise comparisons between phases. For GmTag233, Phase A had significantly shorter dive durations compared to all following phases, and After had significantly longer dive durations compared to all previous phases. For GmTag234, dive durations were significantly shorter during Phase B when compared to previous phases and significantly longer during After when compared to the interphase and Phase B.



- Top: Boxplot showing dive depths of GmTag232 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of GmTag232 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 80.4 dB re 1 μPa.

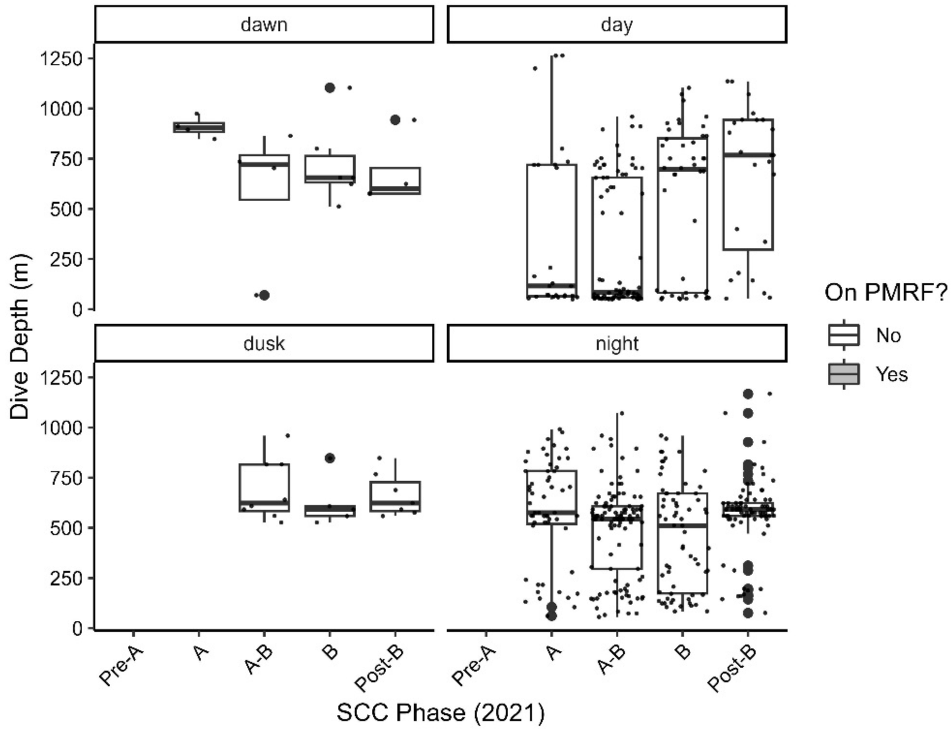
Figure 11. GmTag232 boxplot and barplot dive rates.

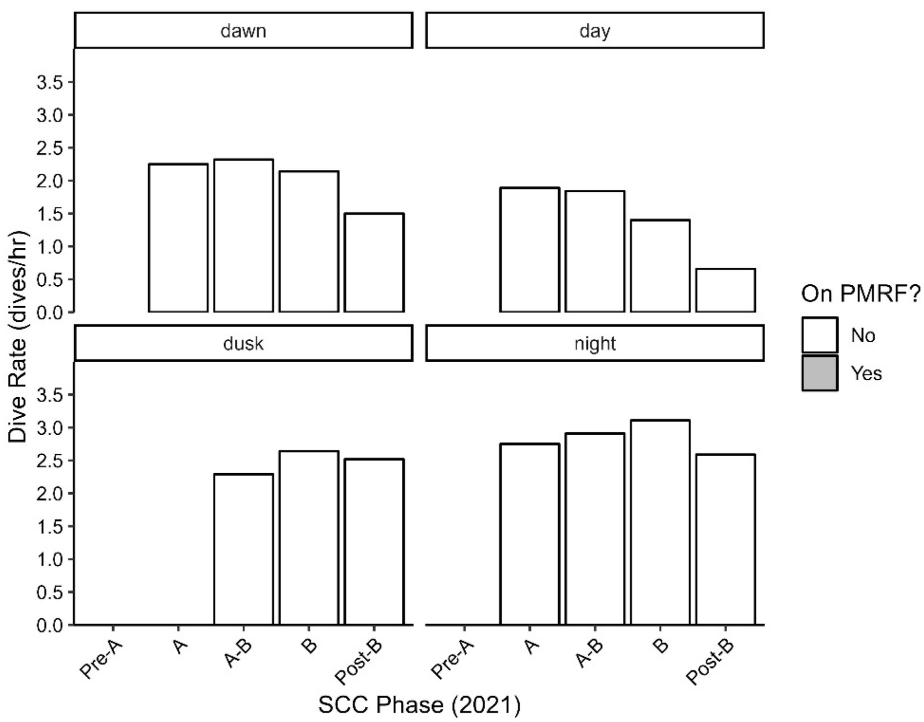




- Top: Boxplot showing dive depths of GmTag233 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of GmTag233 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 81.2 dB re 1 μPa.

Figure 12. GmTag233 boxplot and barplot dive rates.





- Top: Boxplot showing dive depths of GmTag234 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of GmTag234 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 72.6 dB re 1 μPa.

Figure 13. GmTag234 boxplot and barplot dive rates.

3.2.1.2 GmTag235, GmTag236, GmTag237

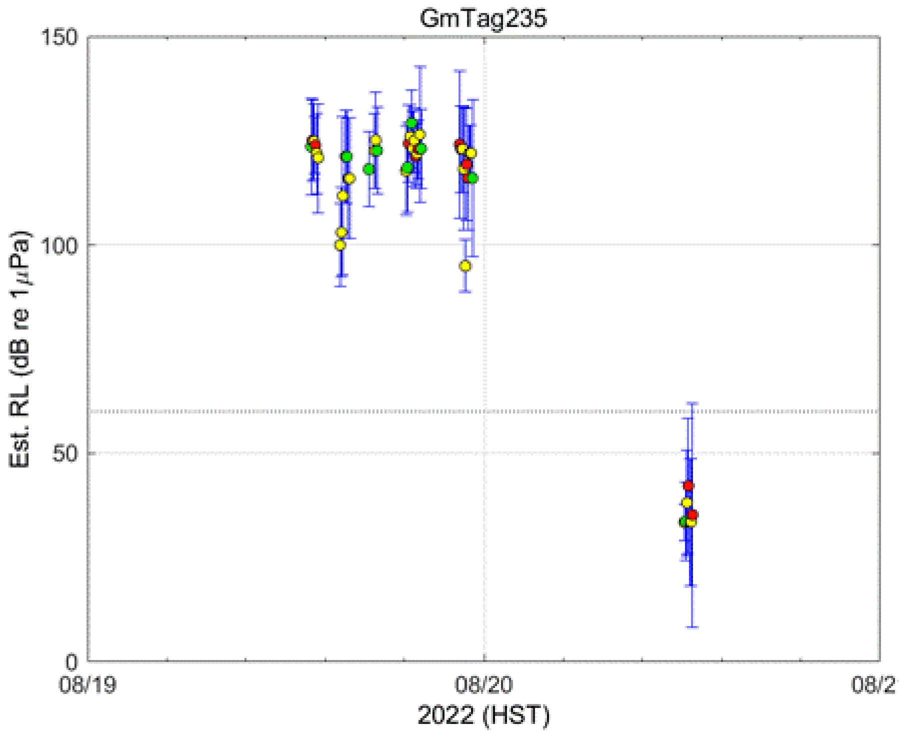
These three individuals were tagged within the same group in 2022 and generally remained associated over the overlapping period of tag attachment, with received levels during exposures varying only slightly between individuals. Information was available on movement patterns for GmTag235 and GmTag237 for the A/B mixed phase (3.5 and 3.7 days, respectively), the interphase period (3.5 days), the B/A mixed phase (0.2 days), and the after phase (9.8 and 38.3 days, respectively; Table 5). For GmTag236, movement data was available only for the A/B mixed phase (3.6 days) and the interphase period (0.5 days). All three tagged individuals were initially present on the range during the A/B mixed phase, then began to move southeast, with GmTag236 ceasing transmission halfway between Kaua‘i and O‘ahu and GmTag235 and GmTag237 continuing to transmit until they reached Maui Nui.

While all three tags were deployed on the range, prior to the start of exposures during the A/B mixed phase, the three individuals had begun moving towards the southern boundary of the range. Following the initial exposure, the animals continued to move southward and had left the range by the time the third exposure began, though received levels generally remained above 120 dB re 1 µPa during all three of these exposures. During the initial exposure, the three tags had median received levels over 10 dB re 1 µPa over a period of more than two hours, with the highest median received level reaching 125 dB re 1 µPa (for GmTag235). During the second exposure, the three tags had median received levels ranging from 116 to 128 dB re 1 µPa over a period of a half hour, and during the third (and longest) exposure, the three tags had median received levels ranging from 88 to 129 dB re 1 µPa over a period of four hours. By the time of the fourth exposure, they had moved far enough from the range that the highest median received levels decreased substantially and were below the ambient noise floor. Because all three individuals remained closely associated during the periods of interest and had highly similar exposure levels, only one individual was mapped here (Figure 17).

GmTag235 was exposed to six bouts of MFAS, with the first five being on or close to the range and the last once they had moved out of the area. Of the 47 track locations with exposures, the first 40 occurred in the initial 5 bouts of MFAS and had probabilities of exposure of 1, while the remaining 7 locations occurred in the last bout of MFAS and had much lower probabilities of exposures and very low received levels, well below the ambient noise floor (Table 11, Figure 14). The estimated received levels from the first 5 bouts of MFAS were at low to moderate levels (95 to 129 dB re 1 µPa), but some exposure locations also had a higher level of pings per 5-minute bin.

Table 11. Estimated received levels, cumulative sound exposure levels, and ship CPA for GmTag235.

Minimum median RL value (± 2 SD) dB re 1 µPa	NA
Maximum median RL value (± 2 SD) dB re 1 µPa	129 (124, 134)
CPA of ship (km)	48
Maximum overall cSEL dB re 1 µPa^2	135



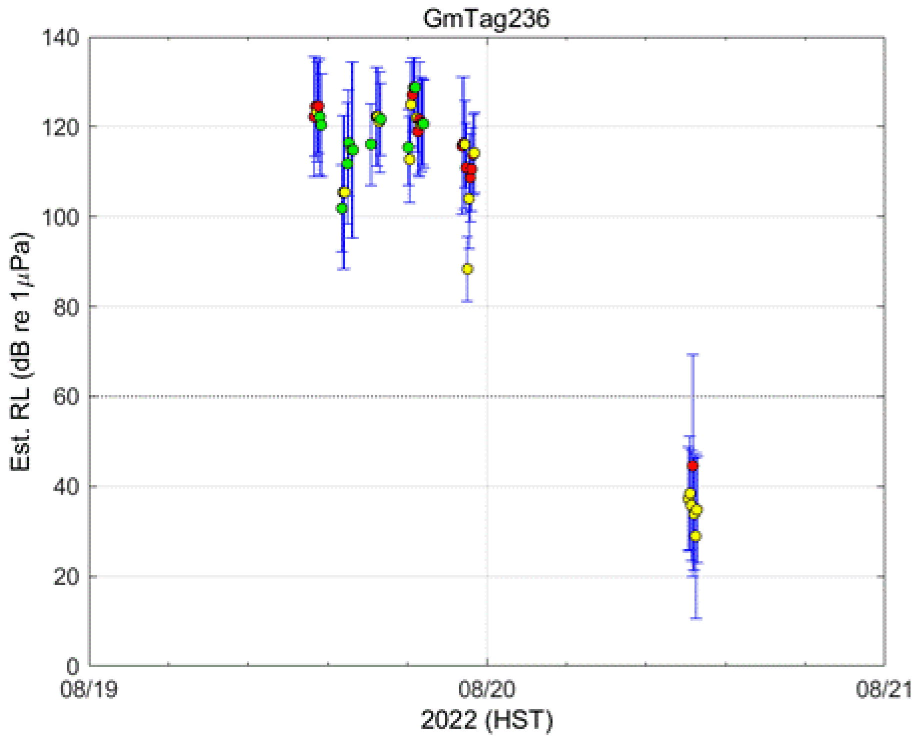
- Median RLs for GmTag235 in stoplight colors (green for few pings during 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 14. Median RLs for GmTag235.

GmTag236 similarly started on the range and then moved southwest around Kaua'i and out of the area. Once again this animal was exposed to six bouts of MFAS, with the first five occurring while the animal was still on or near the range and the last bout occurring after the animal was well out of the area (Table 12, Figure 15). Therefore, the probabilities of exposure were all 1 for the first 5 bouts and very low for the last bout, with some 5-minute bins having a high number of pings per bin, and again the last bout had RLs well under the ambient noise floor. RLs in the first five MFAS bouts ranged from 88 to 129 dB re 1 μPa.

Table 12. Estimated received levels, cumulative sound exposure levels, and ship CPA for GmTag236.

Minimum median RL value (± 2 SD) dB re 1 μPa	NA
Maximum median RL value (± 2 SD) dB re 1 μPa	129 (125, 133)
CPA of ship (km)	49
Maximum overall cSEL dB re 1 μPa^2	135



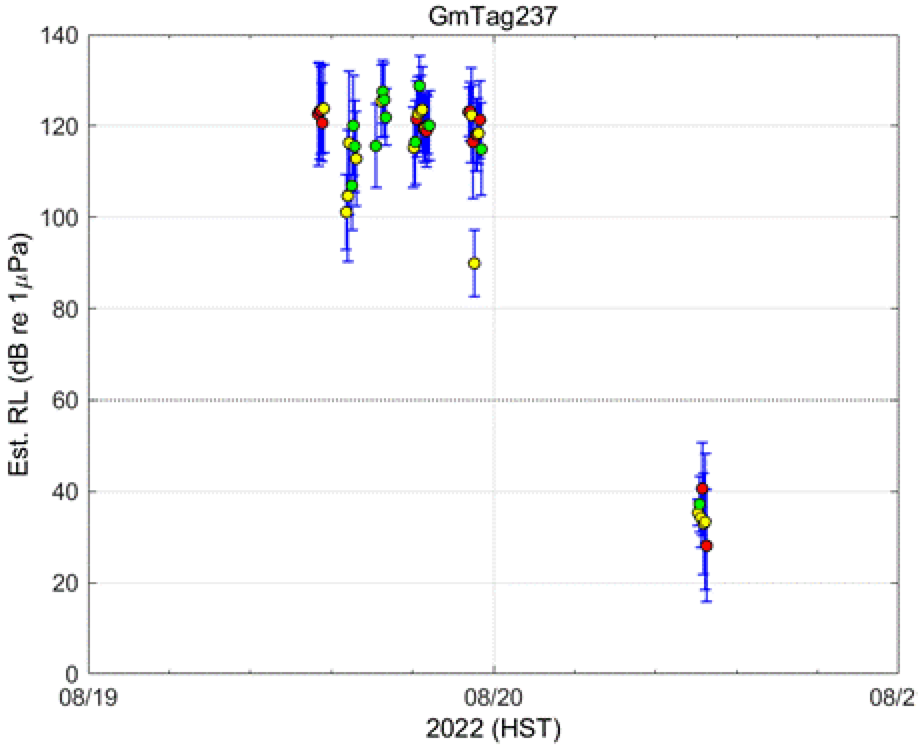
- Median RLs for GmTag236 in stoplight colors (green for few pings during 5-minute bin, yellow for moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 15. Median RLs for GmTag236.

GmTag237 also experienced six bouts of MFAS, with the last occurring after they had left the area, and so had low probabilities of exposures and low RLs. Their median RLs, while on the range, were comparable to the other members of their group, ranging from 89 to 129 dB re 1 μPa (Table 13, Figure 14).

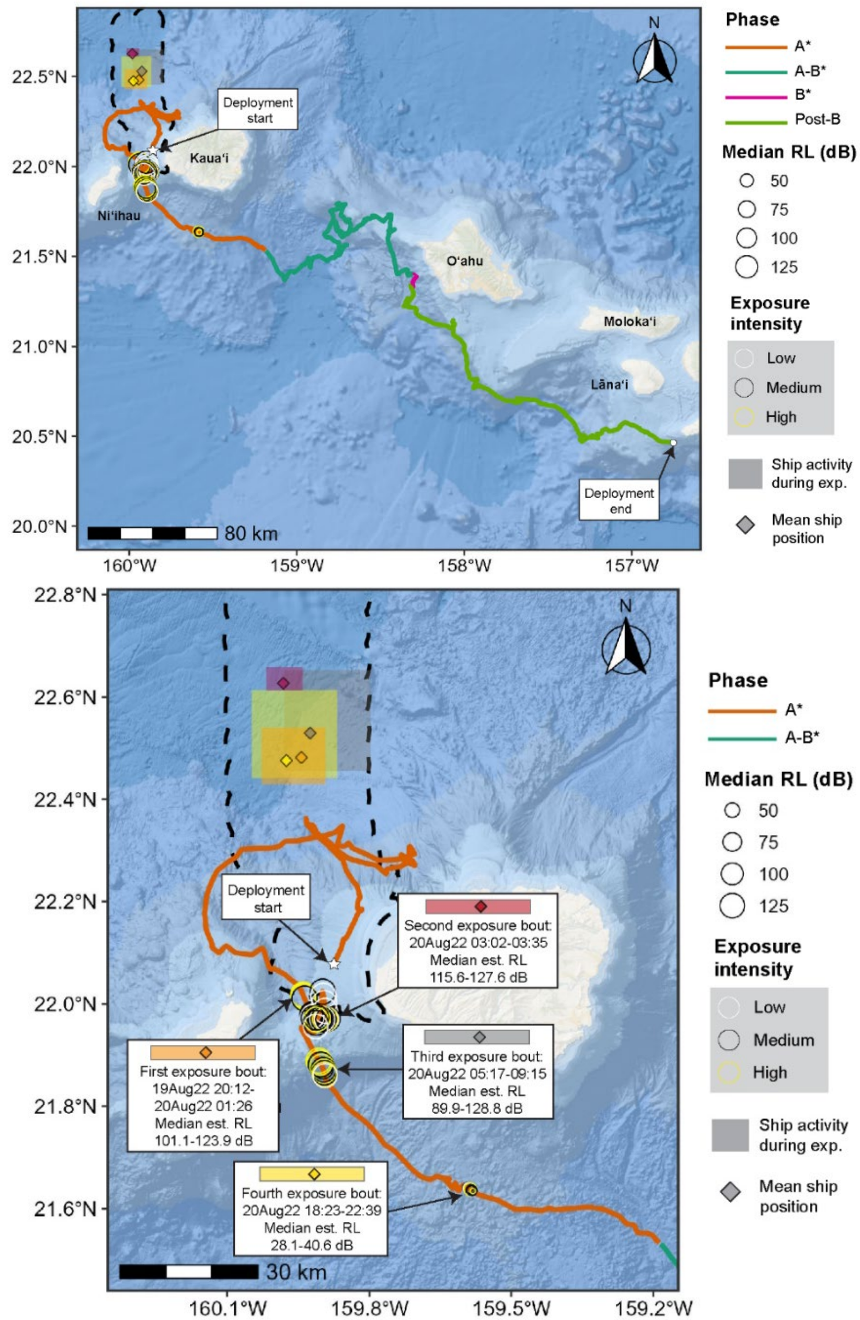
Table 13. Estimated received levels, cumulative sound exposure levels, and ship CPA for GmTag237.

Minimum median RL value (± 2 SD) dB re 1 μPa	NA
Maximum median RL value (± 2 SD) dB re 1 μPa	129 (125, 133)
CPA of ship (km)	48
Maximum overall cSEL dB re 1 μPa^2	134



- Median RLs for GmTag237 in stoplight colors (green for few pings during 5-minute bin, yellow for moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values.
- The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 16. Median RLs for GmTag237.



- Top: Movements of GmTag237 during the August 2022 SCC event, including extensive movements away from the range during Phase A/B.
- Bottom: zoomed-in panel of the track to highlight movements that occurred before, during, and after the exposure, prior to the animal's extensive movements away from the area.
- For this particular event, ship-based MFAS activity occurred during both A/B and B/A phases. The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT. Additionally, the RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the MFAS bouts that GmTag237 was exposed to, and the corresponding diamond points represent the mean ship location during each bout. Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

Figure 17. GmTag237 movement during the August 2022 SCC event.

3.2.1.2.1 Dive Behavior

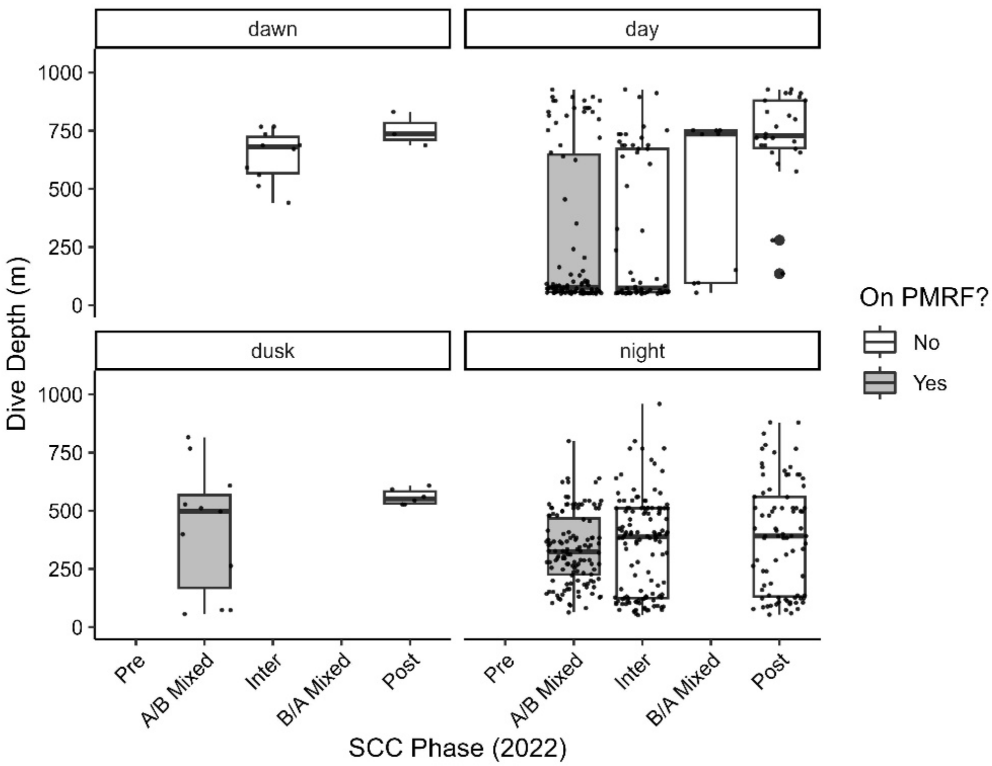
GmTag235 and GmTag237 both transmitted dive behavior for each phase, except the Before phase. GmTag236 only transmitted dive behavior for the A/B mixed phase and is given no further consideration (Figure 16, Figure 17). However, when separated by time of day and phase, not every time of day and phase met the required coverage (relative to the phase duration) for inclusion in the analysis.

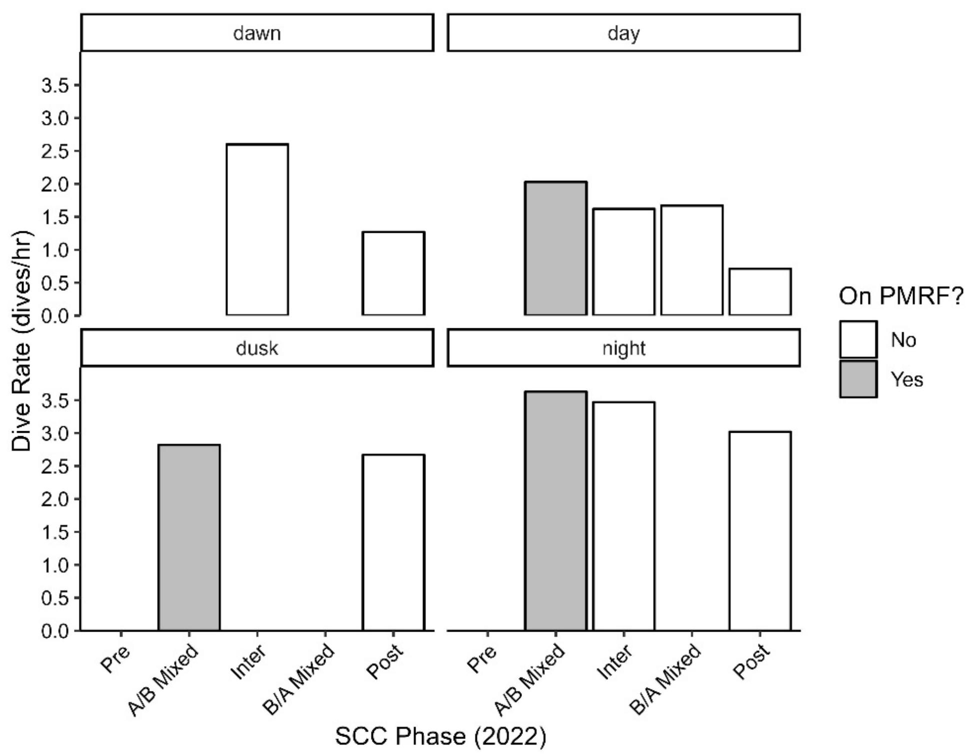
Dawn dive metrics could only be calculated for the interphase and B/A mixed phase for GmTag235 and GmTag237 due to limited coverage during other phases. Though these animals had already departed the area surrounding the range by the time the interphase period began, we include discussion of these metrics, as it is possible that there may have been ongoing effects on their behavior at this point caused by exposure during the A/B mixed phase. Dawn dive rates fell sharply between the interphase and after phase for both tags, while the percentage of surface time concurrently rose. Dawn dive depths did not vary significantly between interphase and after phase for either tag, but dive durations were significantly longer during the After phase for both tags.

Day dive rates for the three tags varied substantially between phases and ranged from 0.66 dives/hr (GmTag237, After phase) to 3.12 dives/hr (GmTag237, A/B mixed phase). Day dive rates were highest during the A/B mixed phase for both tags, GmTag235 and GmTag237, and generally decreased continuously in subsequent phases. Conversely, the percentage of surface time generally rose following the A/B mixed phase for both tags, although it did decrease slightly during the B/A mixed phase for GmTag235. Day dive depths and durations had statistically significant variation between phases for GmTag235 and GmTag237. For GmTag235, dives were significantly shallower during the A/B mixed phase and Interphase compared to the after phase, and for GmTag237, dives were significantly shallower during the A/B mixed phase compared to the B/A mixed phase and After phase, as well as shallower during the interphase compared to subsequent phases. In regard to dive durations, dives were significantly shorter during the A/B mixed phase and interphase compared to both the B/A mixed phase and the After phase for GmTag235 and GmTag237.

Dusk dive rates had minimal variation between phases and ranged from 2.27 (GmTag237, After phase) to 2.82 (GmTag235, A/B mixed phase). Similarly, the percentage of surface time had minimal variation for GmTag237, although GmTag235 had a slight decrease in the percentage of surface time between the A/B mixed phase and the After phase. There was no statistically significant variation in dusk dive depths or durations between phases.

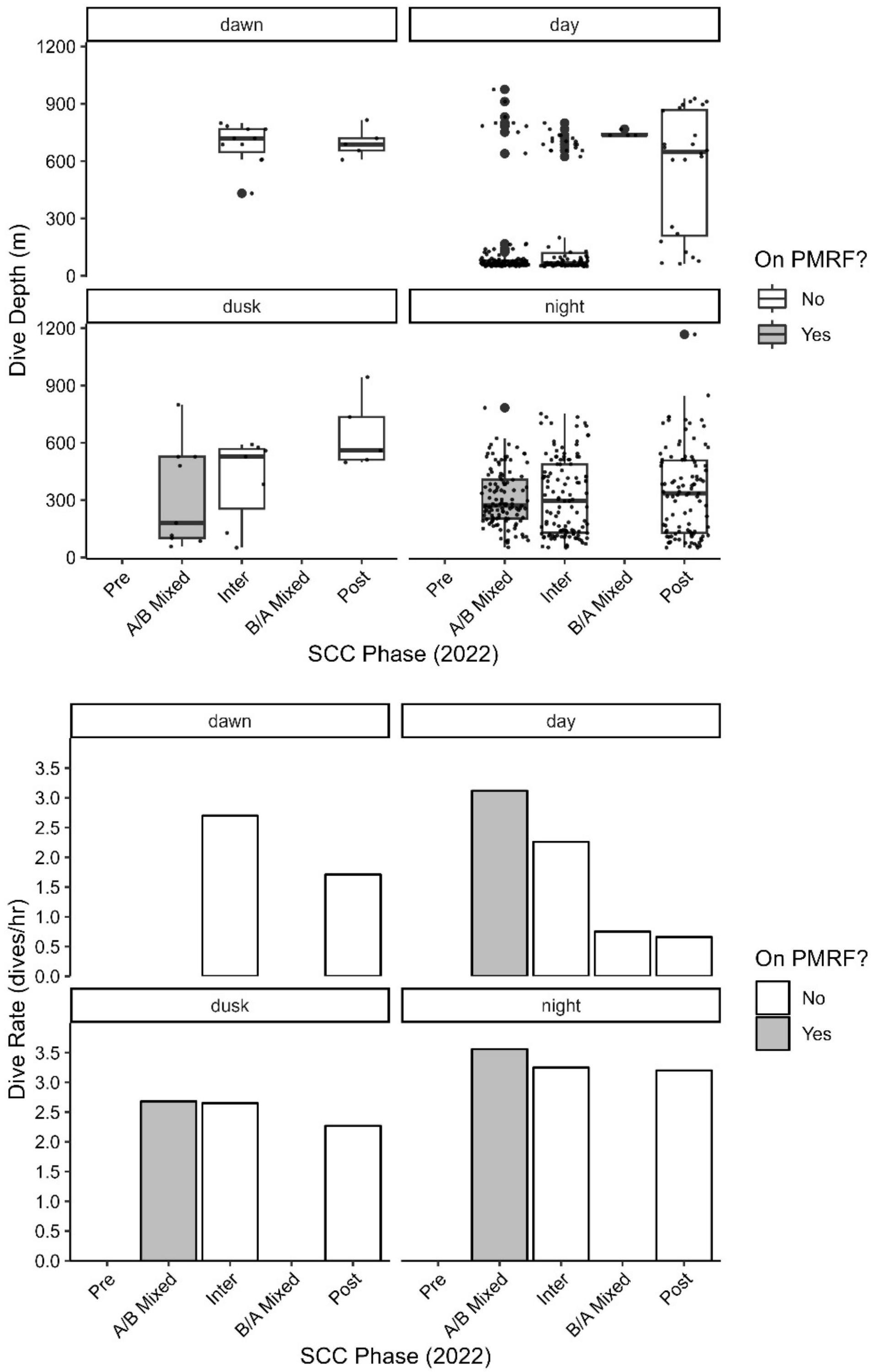
Night dive rates had moderate variation between phases and were higher than any other time of day. Night dive rates decreased in all phases following the A/B mixed phase for both GmTag235 and GmTag237. The percentage of surface time at night remained mostly consistent between phases for GmTag235 but rose slightly between the A/B mixed phase and Interphase for GmTag237. There was no statistically significant variation in night dive depths between phases for either tag, but dives were significantly longer during the after phase compared to the A/B mixed phase and interphase for GmTag235.





- Top: Boxplot showing dive depths of GmTag235 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of GmTag235 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 129.2 dB re 1 µPa.

Figure 18. GmTag235 boxplot and barplot dive rates.



- Top: Boxplot showing dive depths of GmTag237 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of GmTag237 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 128.8 dB re 1 μPa.

Figure 19. GmTag237 boxplot and barplot dive rates.

3.2.2 False killer whales

Only one false killer whale, from the main Hawaiian Islands insular population, was tagged off Kaua'i in 2021; summary statistics for the deployment are given in Table 14.

Table 14. Percentage of dive/surfacing data by phase for false killer whale PcTag074.

Individual	Percentage of dive/surfacing data				
	Before	Phase A	Interphase	Phase B	After
Duration overall (days)	3.5	1.7	3.8	2.4	0.7
Days surfacing/dive data	3.0	1.7	3.4	0.7	0.0
Percentage behavioral coverage	87.1	100.0	89.4	27.5	0.0

- 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.

3.2.2.1 PcTag074

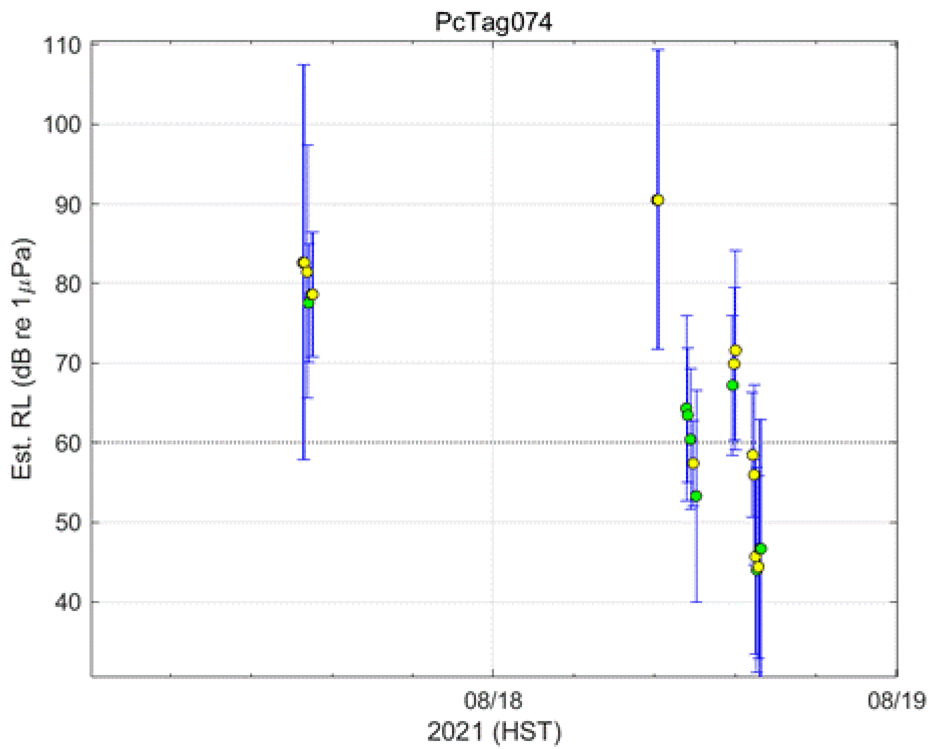
Information was available about PcTag074's movements in 2021 for all of Before (3.5 days), Phase A (1.7 days), the interphase period (3.8 days), Phase B (2.4 days), and the After period (0.7 days; Table 14). This individual ranged widely around both Kaua'i, Ni'ihau, and O'ahu but was only in proximity to the range during Phase B. As this animal was closest to O'ahu during Phase A, Phase B is the only period in which this animal would likely have been exposed to Navy activity.

After tagging (Before), this individual moved along the southern coast of Kaua'i and east to O'ahu, spending its time in waters around O'ahu for the entirety of Phase A and the beginning of the interphase (Figure 19). Approximately halfway through the interphase, PcTag074 moved offshore and northwest towards Ni'ihau and followed the northern coastline of Ni'ihau for the start of Phase B. Mirroring its movements post-deployment, PcTag074 gradually moved southeast along the southern edge of the range and continued to follow the southern coastline of Kaua'i during Phase B. While PcTag074 was at the southernmost part of the range, it was exposed to RLs ranging between 78 and 83 dB re 1 μPa. This individual continued its movements back towards O'ahu, where exposures occurred during a second MFAS bout (45–91 dB re 1 μPa). The tag stopped transmitting shortly after Phase B, on the northeast side of O'ahu.

PcTag074 was exposed to five bouts of MFAS over three days. The first bout had low probabilities of exposures (0.2–0.65), but the rest of the 5-minute bins had probabilities of 1, with the exception of one location in the 3rd bout with a low probability of 0.09. Their RLs were very low, with 10 of 23 5-minute bins having estimated median levels below the ambient noise floor and the remainder of the 5-minute bins having median RLs equal to or less than 91 dB re 1 μPa (Table 15, Figure 20). While the first bout of MFAS occurred while the animal was closer to the range, their position was largely blocked by the island and by the bathymetry of the area. In contrast, while they were much further away for the brief second bout, the estimated RLs were higher due to a direct path in that case.

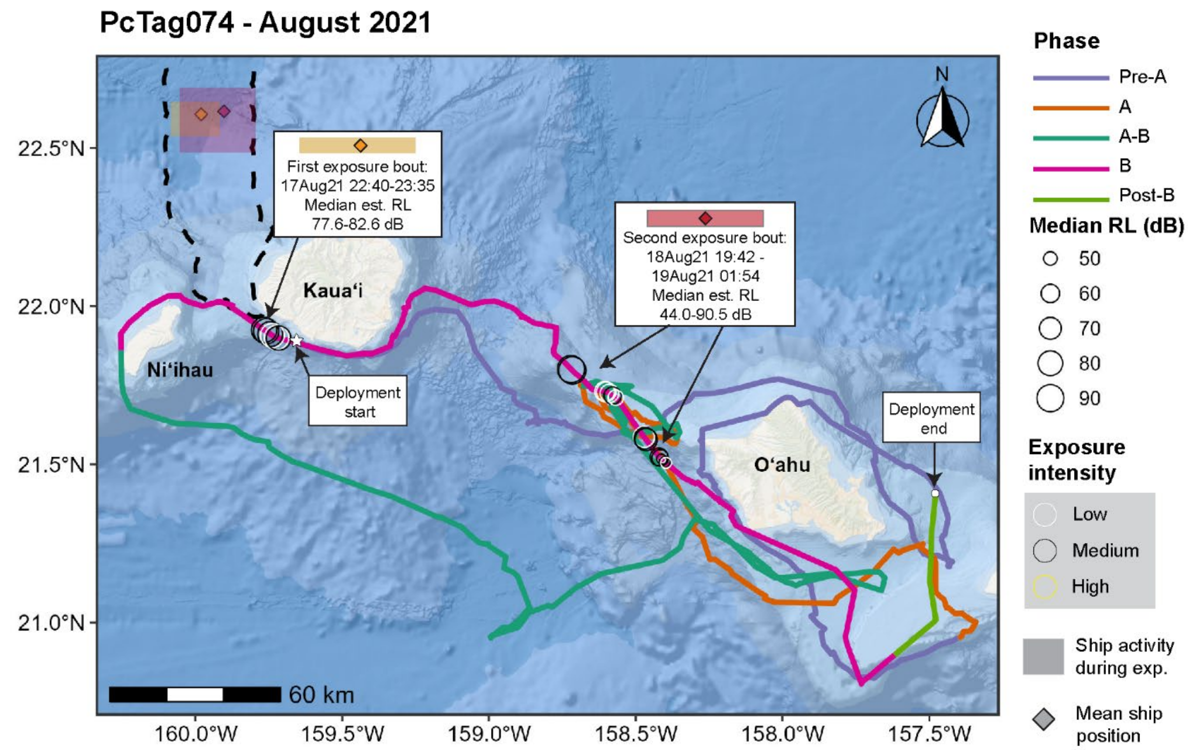
Table 15. Estimated received levels, cumulative sound exposure levels, and ship CPA for PcTag074.

Minimum median RL value (± 2 SD) dB re 1 µPa	NA
Maximum median RL value (± 2 SD) dB re 1 µPa	91 (72, 109)
CPA of ship (km)	29
Maximum overall cSEL dB re 1 µPa^2	98



- Median RLs for PcTag074 in stoplight colors (green for few pings during 5-minute bin, yellow for moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 µPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 20. Median RLs for PcTag074.



- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the three MFAS bouts that PcTag074 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC. The dashed black line represents the PMRF boundary.

Figure 21. Movements of PcTag074 during and after the August 2021 SCC event.

Dive behavior data were transmitted by the tag during all phases except for the After period. However, when broken down by time of day and phase, only the data from Before, Phase A, and the Interphase periods met the coverage requirements for inclusion in the analysis. Given that this animal was not exposed to Navy activities during any of these periods, this tag is given no further consideration for dive behavior analyses.

3.2.3 Melon-headed whales

Seven melon-headed whales had tag data during the SCCs (Table 16), three in 2021, and four in 2022. However, there was only enough dive data to analyze the night-time periods for three of the animals. (Table 17).

Table 16. Percentage of surfacing/dive data by phase for melon-headed whales.

Individual	Percentage of surfacing/dive data				
	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After
PeTag029					
Duration overall (days)	10.4	1.7	0.5	0.0	0.0
Days surfacing/dive data	1.2	0.1	0.0	0.0	0.0
Percentage behavioral coverage	11.1	4.8	0.0	0.0	0.0
PeTag031					
Duration overall (days)	0.4	1.7	3.8	2.4	12.4
Days surfacing/dive data	0.0	1.6	3.7	2.4	3.2
Percentage behavioral coverage	0.0	95.8	98.1	100.0	25.7
PeTag032					
Duration overall (days)	NA	NA	3.8	2.4	10.2
Days surfacing/dive data	NA	NA	3.1	0.2	0.7
Percentage behavioral coverage	NA	NA	82.8	6.3	6.9
PeTag033					
Duration overall (days)	NA	2.6	3.5	0.2	4.8
Days surfacing/dive data	NA	1.3	0.3	0.0	0.8
Percentage behavioral coverage	NA	51.0	9.5	0.0	16.2
PeTag034					
Duration overall (days)	NA	2.6	1.5	0.0	0.0
Days surfacing/dive data	NA	0.1	0.0	0.0	0.0
Percentage behavioral coverage	NA	3.1	0.0	0.0	0.0
PeTag035					
Duration overall (days)	NA	NA	0.1	0.2	18.1
Days surfacing/dive data	NA	NA	0.0	0.0	4.2
Percentage behavioral coverage	NA	NA	0.0	0.0	23.3

Table 16. Percentage of surfacing/dive data by phase for melon-headed whales. (Continued)

Individual	Percentage of surfacing/dive data				
	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After
PeTag036					
Duration overall (days)	NA	NA	NA	0.2	10.1
Days surfacing/dive data	NA	NA	NA	0.0	0.3
Percentage behavioral coverage	NA	NA	NA	0.0	2.6

- 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 days of surfacing/dive data is an indication of how much of the dive behavior data was received relative to the period that behavior data were meant to be collected.

Table 17. A comparison of nighttime diving parameters from melon-headed whales exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Night dive rate (dives/hour)							
PeTag031	NA	5.80	5.18	4.46	4.57	-	
PeTag032	NA	NA	5.49	NA	NA	-	
PeTag035	NA	NA	NA	NA	5.62	-	
% time in surface periods at night							
PeTag031	NA	29.79	33.27	45.94	39.11	-	
PeTag032	NA	NA	34.32	NA	NA	-	
PeTag035	NA	NA	NA	NA	35.70	-	
Median dive depth night (m)							
PeTag031	**NA**	**199.50**	**207.50**	**287.50**	**327.50**	**<0.0001**	**Inter-B; A-B; Inter-After; A-After; B-After**
PeTag032	NA	NA	247.50	NA	NA	NA	NA
PeTag035	NA	NA	NA	NA	195.50	NA	NA
Median dive duration night (min)							
PeTag031	**NA**	**7.27**	**8.00**	**7.40**	**8.07**	**<0.0001**	**Inter-A; Inter-B; A-After; B-After**
PeTag032	NA	NA	7.27	NA	NA	NA	NA
PeTag033	NA	NA	NA	NA	7.20	NA	NA

- The Kruskal-Wallis one-way ANOVA identified significant differences among phases, which are highlighted in bold. The post-hoc Dunn's test column lists pairs of phases with significant differences found at a significance level of 0.05. Each individual's dive rates and percentage time in surface periods were represented by single values; hence, no statistical testing was conducted.

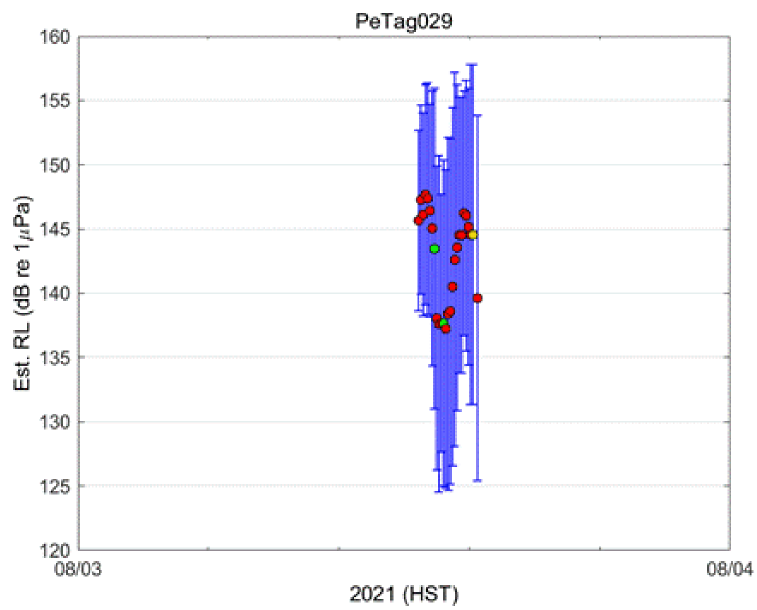
3.2.3.1 PeTag029

Information was available on movement patterns for PeTag029 in 2021 for Before (10.4 days), Phase A (1.7 days), and the interphase period (0.5 days; Table 16). During the Before period, PeTag029 ranged widely, entering and exiting the range multiple times, and was exposed to navy activities during a ULT period. While PeTag029 had been moving southeast prior to exposure during the ULT, following exposure, it quickly changed direction to move northeast, then changed direction soon again and began moving northwest until it exited the range. During the ULT, PeTag029 was exposed to median received levels exceeding 135 dB re 1 μPa and reaching 148 dB re 1 μPa for over two hours (Figure 23).

PeTag029 was exposed to a single long block of MFAS during the ULT prior to the SCC, but their tag stopped transmitting prior to the onset of Phase B of the SCC. They were on the range for the first few days of their tag deployment but were off the range to the east during the 2-hour period of exposure. About 5 hours after the end of the ULT, the whale crossed the range and then began traveling west and then south away from the range. All of their track locations during the exposure had probabilities of exposure of 1, and since they were just east of the training activity, their median RLs were similar throughout the exposure (137–148 dB re 1 μPa; Table 18, Figure 22), most of their 5-minute bins had high numbers of pings, and distances to ships were < 20 km. This animal had the highest median and +2 SD RL values of all the whales tagged in 2021 due to its proximity to the activity. They also had the highest maximum cSEL at 158 dB re 1 μPa^2.

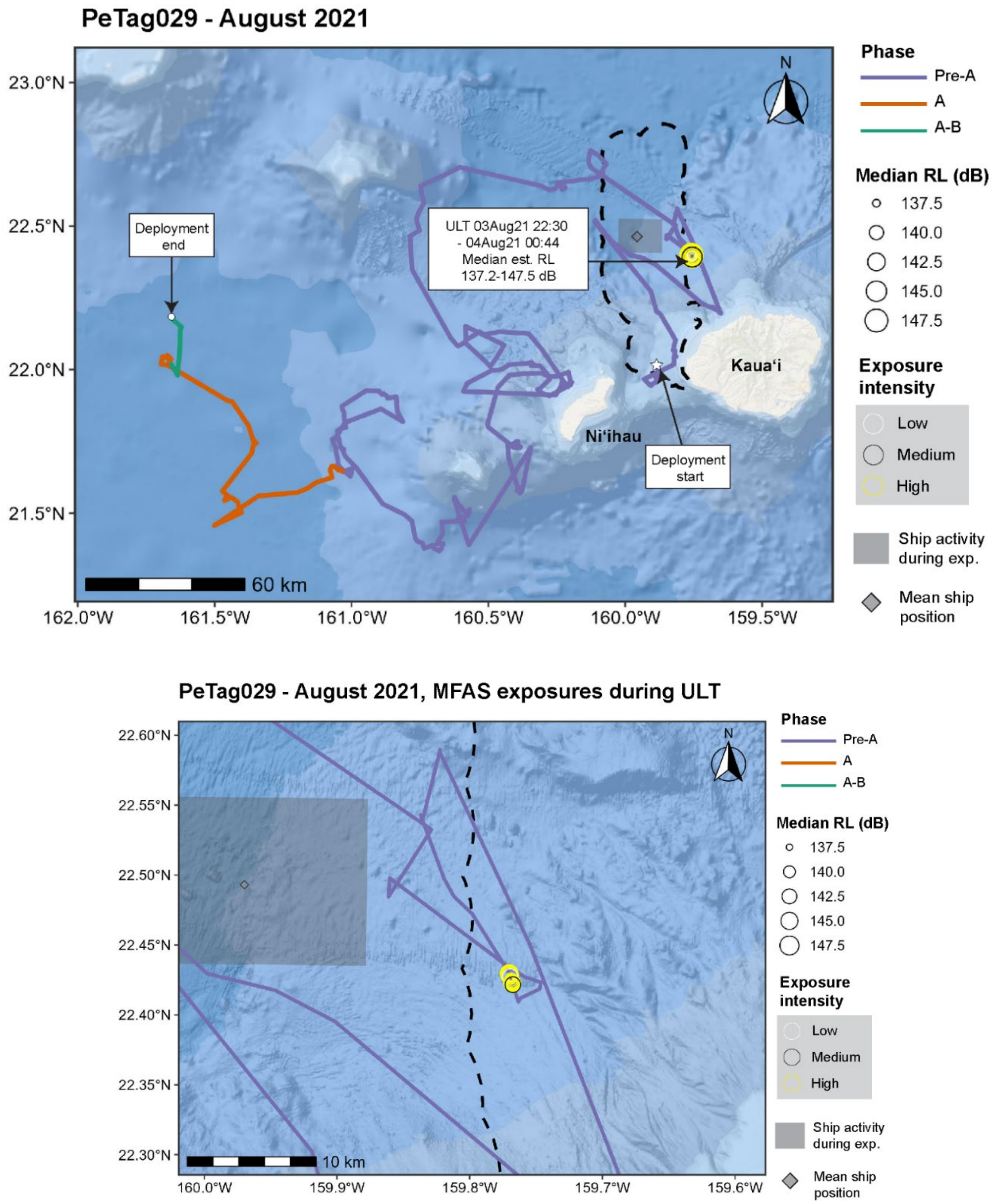
Table 18. Estimated received levels, cumulative sound exposure levels, and ship CPA for PeTag029.

Minimum median RL value (± 2 SD) dB re 1 μPa	137 (125, 150)
Maximum median RL value (± 2 SD) dB re 1 μPa	148 (139, 156)
CPA of ship (km)	25
Maximum overall cSEL dB re 1 μPa^2	158



- Median RLs for PeTag029 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values.

Figure 22. Median RLs for PeTag029.



- Top: Movements of PeTag029 prior to the August 2021 SCC event; this tag stopped transmitting before Phase B of the SCC event but was exposed to MFAS during a ULT period that occurred prior to Phase A of the SCC (see text for description of phases).
- Bottom: Movements of PeTag029 during the MFAS exposures that occurred during the ULT event.
- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level.
- RL circles are colored by “intensity,” which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin. The gray-shaded rectangular polygon represents the area of ship activity during the ULT, and the corresponding diamond point represents the mean ship location during the ULT. The dashed black line represents the PMRF boundary.

Figure 23. PeTag029 movements prior to the August 2021 SCC event.

PeTag029 transmitted dive behavior data for Before and Phase A, but when broken down by time of day and phase, the data coverage for both phases failed to meet the required coverage for inclusion in the dive behavior analysis.

3.2.3.2 PeTag031, PeTag032

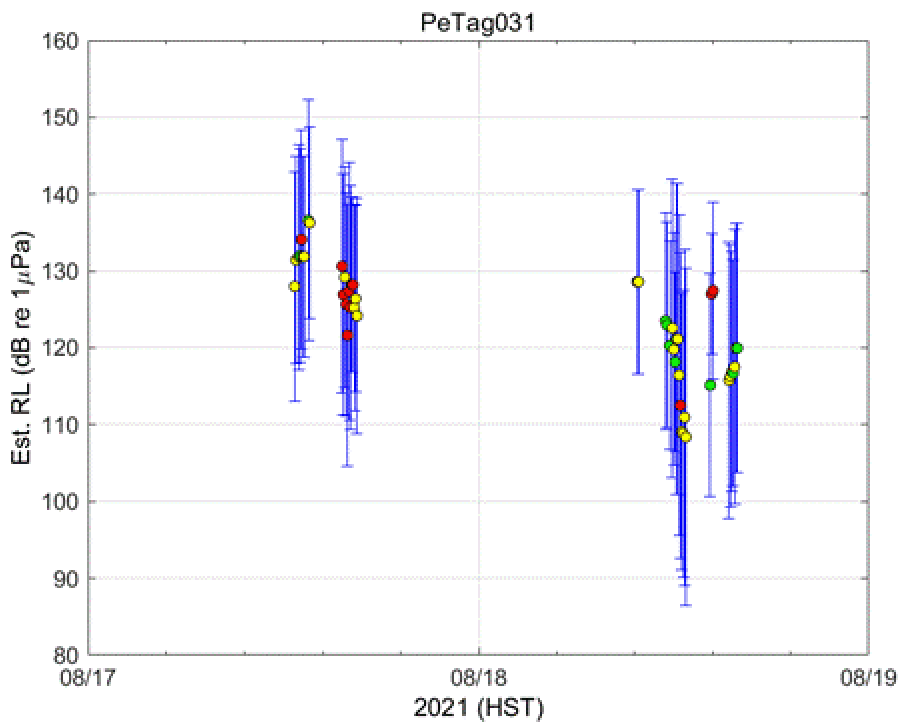
PeTag031 and PeTag032 were tagged in the same group in 2021 and generally remained associated over the overlapping period of tag attachment. Information was available on movement patterns for PeTag031 for Before (0.4 days) and for both tags for Phase A (1.7 and 0.04 days), the interphase period (3.8 days), Phase B (2.4 days), and the After period (12.4 and 10.2 days; Table 16). Both individuals moved on and off the range multiple times over the course of the SCC but consistently remained in close proximity to the range.

PeTag031 moved towards the east of the range after tag deployment (Figure 26). At the start of Phase A, this individual moved southwest through the southern portion of the range and into the canyon area between Kaua‘i and Ni‘ihau. During the interphase period (between Phases A and B), PeTag031 spent much of its time in this area between the two islands; PeTag032 was deployed in this area at this time (Figure 25). Both tagged individuals continued using this area, with some movements farther north of the channel, including use of the southwest portion of the range. Both whales were in the area just north of Ni‘ihau prior to the start of Phase B. Both individuals were exposed to their highest MFAS levels (maximum median RL of 137 dB re 1 μPa for PeTag031, 136 dB re 1 μPa for PeTag032) for approximately one hour at the start of Phase B when they entered the southwestern edge of the range. As they continued moving northwest into the range, they were exposed to another bout of MFAS (approximately one hour long, similar levels as the first bout). They both gradually moved northeast and exited the eastern portion of the range, where they were exposed to one last bout of MFAS that lasted just over six hours. Received levels were slightly lower than the first two bouts (between 105 and 128 dB re 1 μPa) and generally followed a decreasing trend over time. After this bout, they both moved west back inside the range and continued moving northwest outside of the range for the remainder of Phase B (no exposures during this period). In the three days following Phase B, both individuals moved north of the range, entering and exiting the northern portion of the range twice. At the end of the three days post-SCC, both individuals were just outside of the northwestern area of the range (Figure 26; Figure 27).

PeTag031 was on or relatively near the range for the full duration of their tag attachment period. They were exposed to six bouts of MFAS, and all 5-minute bins had a probability of exposure of 1. Median RLs ranged from 108 to 137 dB re 1 μPa (Table 19, Figure 24). They did move further away from the area of training activity between the 2nd and 3rd bouts, as median RLs were about 10–20 dB lower than they were for the 1st bout.

Table 19. Estimated received levels, cumulative sound exposure levels, and ship CPA for PeTag031.

Minimum median RL value (± 2 SD) dB re 1 μPa	108 (83, 134)
Maximum median RL value (± 2 SD) dB re 1 μPa	137 (121, 152)
CPA of ship (km)	0.8
Maximum overall cSEL dB re 1 μPa^2	142



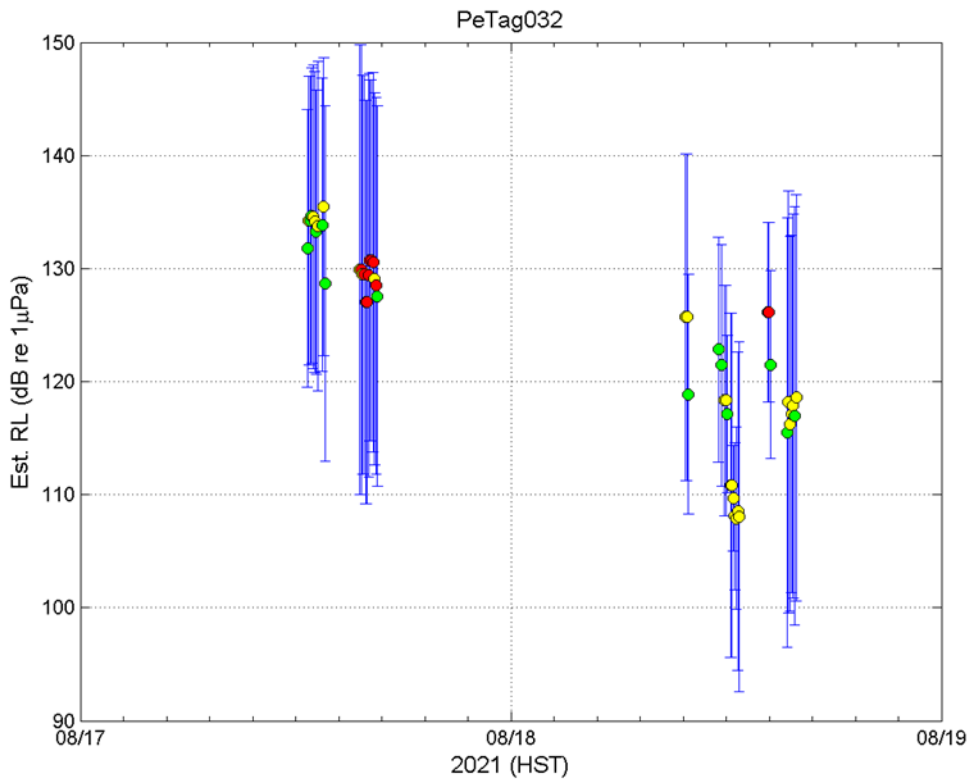
- Median RLs for Pe31 in stoplight colors (green for few pings during 5-minute bin, yellow for moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values.

Figure 24. Median RLs for Pe31.

PeTag032 had similar exposure patterns and estimated RLs, with all exposures having a probability of 1 and median RLs ranging between 108 and 135 dB re 1 µPa (Table 20, Figure 23). Again, their first two bouts of MFAS had higher median RLs values than the last three bouts, indicating the animals likely moved away from the main area of activity.

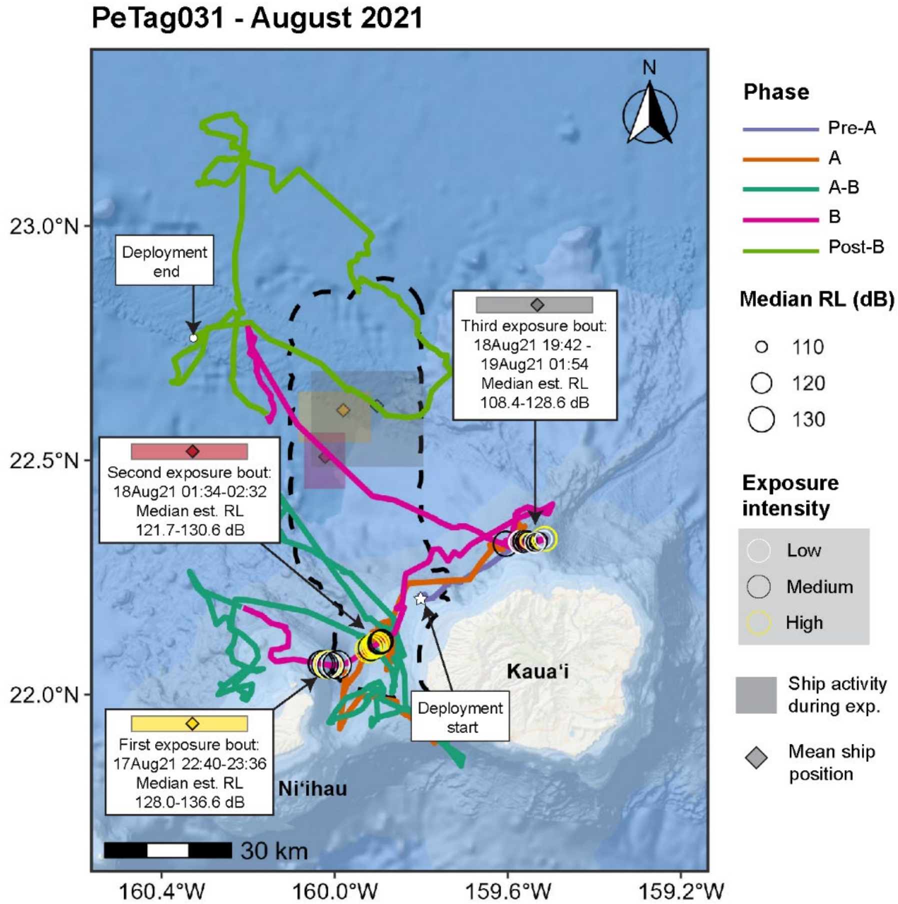
Table 20. Estimated received levels, cumulative sound exposure levels, and ship CPA for PeTag032.

Minimum median RL value (± 2 SD) dB re 1 µPa	108 (103, 113)
Maximum median RL value (± 2 SD) dB re 1 µPa	136 (122, 149)
CPA of ship (km)	5
Maximum overall cSEL dB re 1 µPa^2	142



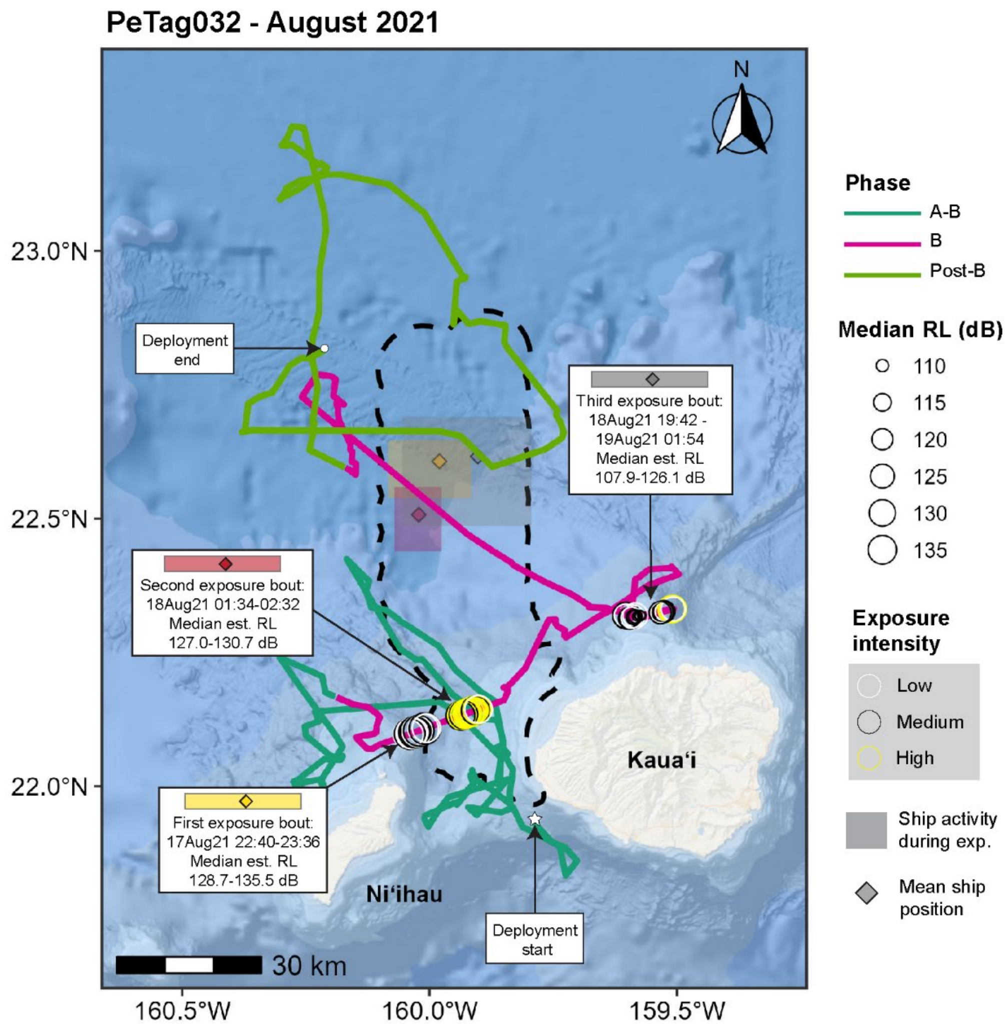
- Median RLs for PeTag032 in stoplight colors (green for few pings during 5-minute bin, yellow for moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values.

Figure 25. Median RLs for PeTag032.



- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the three MFAS bouts that PeTag031 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

Figure 26. Movements of PeTag031 during the August 2021 SCC event.



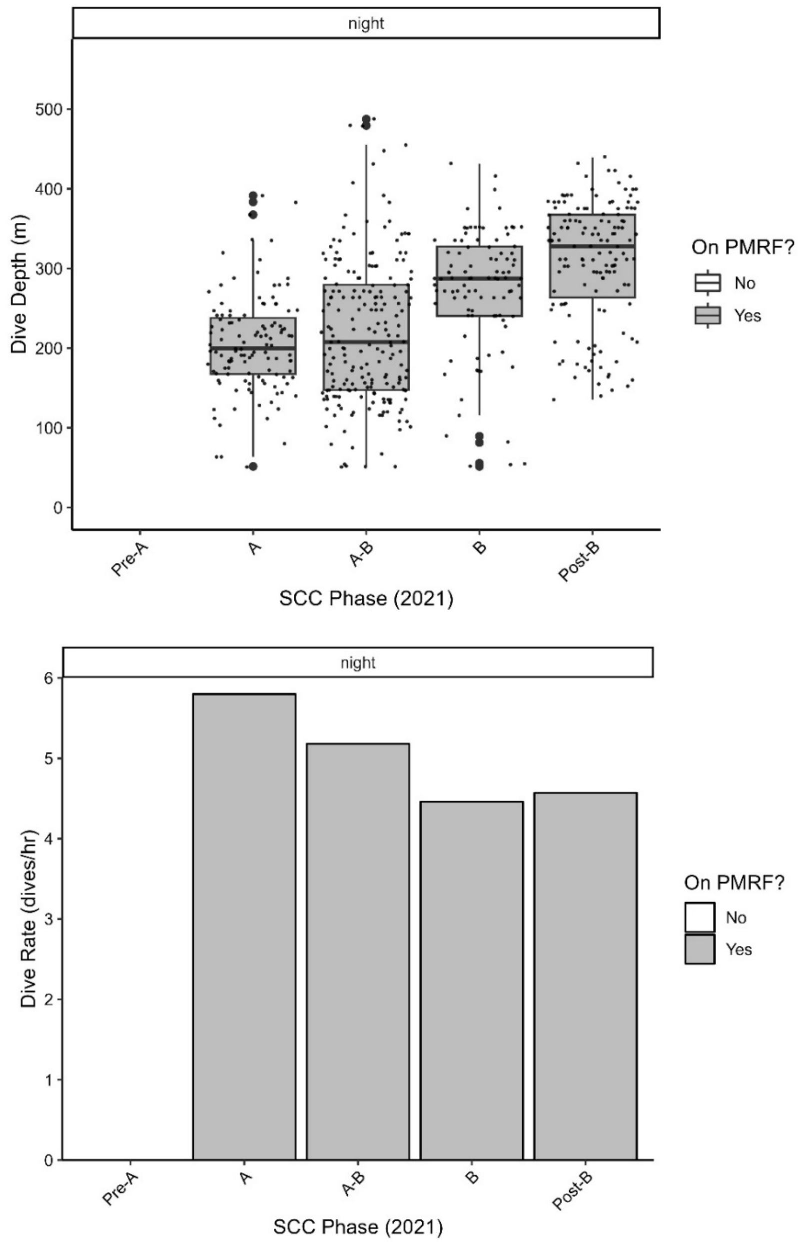
- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the three MFAS bouts that PeTag032 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC. The dashed black line represents the PMRF boundary.

Figure 27. Movements of PeTag032 during the August 2021 SCC event.

3.2.3.2.1 Dive behavior

Dive behavior data were transmitted by PeTag031 for Phase A and by both PeTag031 and PeTag032 for the Interphase, Phase B, and After. However, only the data from PeTag031 for all phases and PeTag032 for the Interphase period met the coverage requirements for inclusion in the analysis (Figure 28). Given that only PeTag031 offered multiple phases to compare, PeTag032 was given no further consideration in the dive analysis. As melon-headed whales dive almost exclusively at night, the dive behavior analysis is also restricted to this time of day.

Night dive rates for PeTag031 were highest during Phase A, decreased during the interphase and Phase B, and then rose slightly during After. Conversely, the percentage of surface time at night was lowest during Phase A and increased during the interphase and Phase B, then dropped slightly during After. Night dives increased in depth following Phase A and were significantly deeper during Phase B and After compared to all previous phases. Night dive durations, however, had a more mixed trend. Night dives were shorted during Phase A, slightly longer during the interphase, slightly shorter during Phase B, and longest during After. Durations were significantly longer during the interphase and After compared to Phase A and Phase B.



- Top: Boxplot showing dive depths of PeTag031 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of PeTag031 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 136.6 dB.

Figure 28. PeTag031 boxplot and barplot dive rate.

3.2.3.3 PeTag033, PeTag034

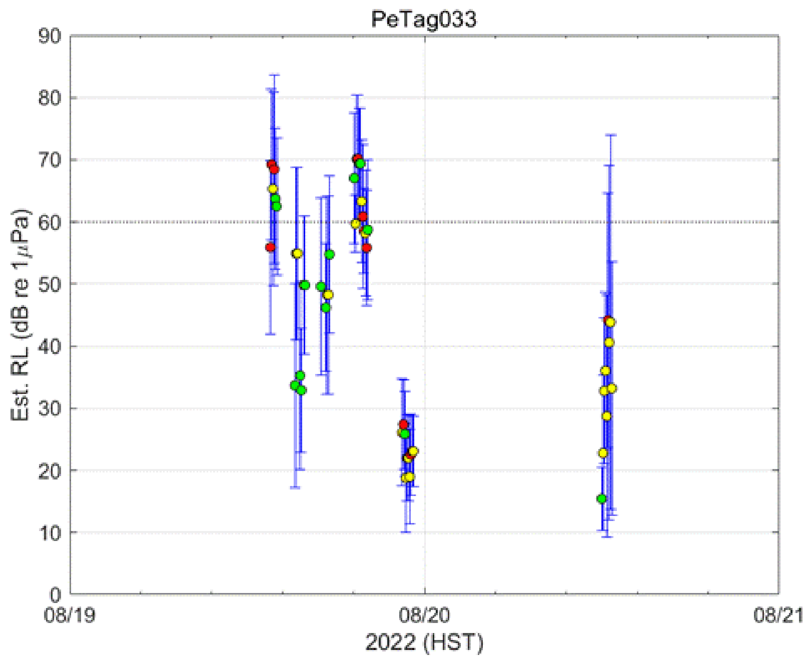
PeTag033 and PeTag034 were both tagged in the same group in 2022 and remained in close proximity for at least the initial part of their deployments. Information was available on movements of both tags for the A/B mixed phase (2.6 days), the interphase period (3.5 days for PeTag033, and 1.5 days for PeTag034), and for PeTag033 for the B/A mixed phase (0.2 days) and After phase (4.8 days; Table 16).

Both PeTag033 and PeTag034 moved south and to offshore waters shortly after tag deployment (Figure 31, Figure 32). As they continued south, they were exposed during several MFAS bouts, although received levels were very low given the large distance from the range (all under 70 dB re 1 μPa). PeTag034's deployment ended shortly after Phase A in offshore waters south of Niʻihau. PeTag033 turned north after the exposures and moved northeast through the waters between Kauaʻi and Niʻihau for the interphase period. For the second mixed phase A/B period, this individual started heading east towards Oʻahu (no exposures) and continued this movement through the end of the study period (3 days post-SCC). Insufficient data was available to include either tag in the dive behavior analysis.

Because PeTag033 immediately left the range area after being tagged, all estimated RLs were at or below 70 dB re 1 μPa, and most were below the ambient noise floor (Table 21, Figure 27).

Table 21. Estimated received levels, cumulative sound exposure levels, and ship CPA for PeTag033.

Minimum median RL value (± 2 SD) dB re 1 μPa	NA
Maximum median RL value (± 2 SD) dB re 1 μPa	70 (64, 77)
CPA of ship (km)	124
Maximum overall cSEL dB re 1 μPa^2	80



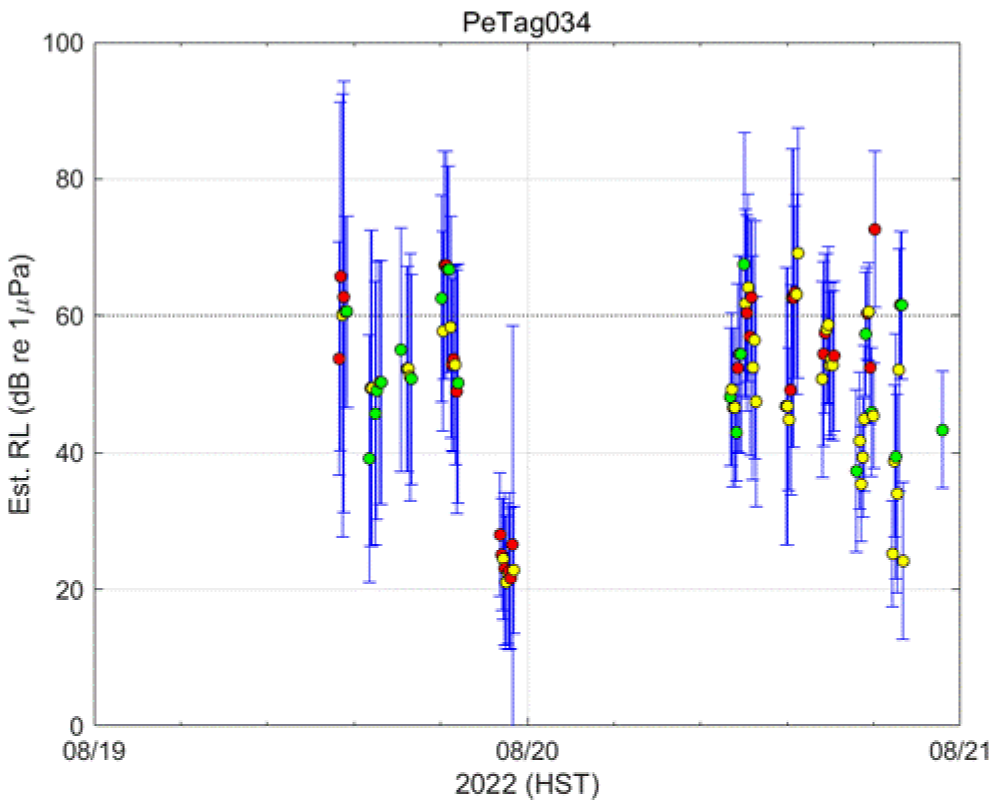
- Median RLs for PeTag033 in stoplight colors (green for few pings during 5-minute bin, yellow for moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 29. Median RLs for PeTag033.

PeTag034's estimated RLs were also quite low, with a max of 73 dB re 1 μPa and most below the ambient noise floor (Table 22, Figure 30). They also had several 5-minute bins with probabilities less than 1 of exposure.

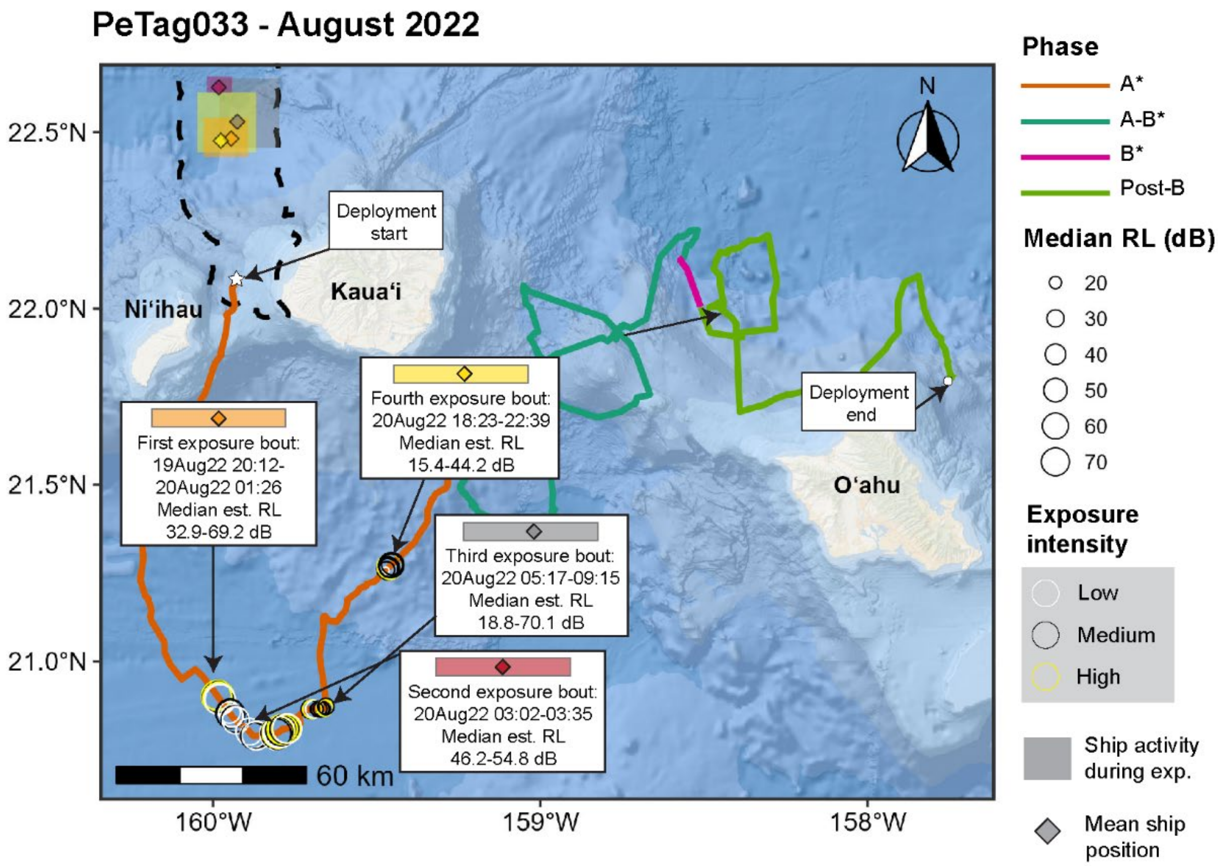
Table 22. Estimated received levels, cumulative sound exposure levels, and ship CPA for PeTag034.

Minimum median RL value (± 2 SD) dB re 1 μPa	NA
Maximum median RL value (± 2 SD) dB re 1 μPa	73 (61,84)
CPA of ship (km)	164
Maximum overall cSEL dB re 1 μPa^2	77



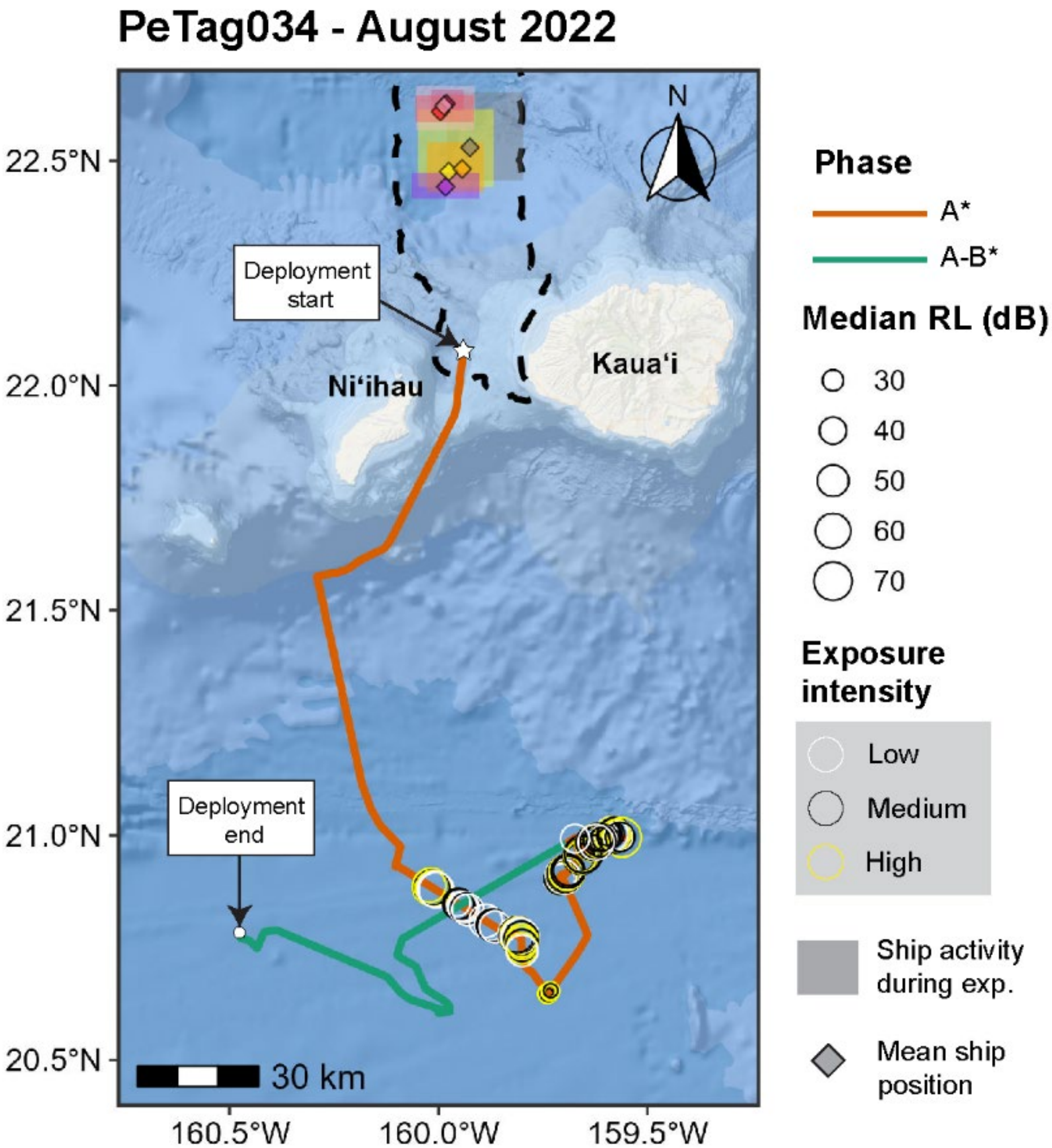
- Median RLs for PeTag034 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 30. Median RLs for PeTag034.



- For this particular event, ship-based MFAS activity occurred during both A/B and B/A phases.
- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT.
- RL circles are colored by “intensity,” which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the MFAS bouts that PeTag033 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

Figure 31. Movements of PeTag033 during the August 2022 SCC event, including extensive movements away from the range at the start of Phase A/B.



- For this particular event, ship-based MFAS activity occurred during both A/B and B/A phases.
- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the MFAS bouts that PeTag034 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

Figure 32. PeTag034 movements during the August 2022 SCC event, including extensive movements away from the range at the start of Phase A/B.

3.2.4 Rough-toothed dolphins

While three rough-toothed dolphins were tagged (Table 23), only one animal had any exposure to MFAS. SbTag025 did have some overlap with Phase B/A mixed, but did not receive any MFAS exposures. Diel dive data were assessed for two of the animals (Table 24 and Table 25).

Table 23. Percentage of surfacing/dive data by phase for rough-toothed dolphins.

Individual	Percentage of surfacing/dive data				
	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After
SbTag023					
Duration overall (days)	2.3	1.7	3.8	2.4	2.8
Days surfacing/dive data	1.9	1.7	3.8	2.4	0.7
Percentage behavioral coverage	83.2	100.0	100.0	100.0	24.5
SbTag024					
Duration overall (days)	2.3	1.7	0.5	0.0	0.0
Days surfacing/dive data	NA	NA	NA	NA	NA
Percentage behavioral coverage	NA	NA	NA	NA	NA
SbTag025					
Duration overall (days)	NA	NA	NA	0.2	7.3
Days surfacing/dive data	NA	NA	NA	0.2	5.8
Percentage behavioral coverage	NA	NA	NA	100.0	80.2

- 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 days of surfacing/dive data is an indication of how much of the dive behavior data was received relative to the period that behavior data were meant to be collected.

Table 24. A comparison of daytime diving parameters from rough-toothed dolphins exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Day dive rate (dives/hour)							
SbTag023	0.00	0.24	0.18	0.32	NA	-	
SbTag025	NA	NA	NA	NA	0.11	-	
% time in surface periods at day							
SbTag023	100.00	99.06	98.81	98.85	NA	-	
SbTag025	NA	NA	NA	NA	99.67	-	
Median dive depth day (m)							
SbTag023	NA	76.50	159.50	82.50	NA	0.1363	NA
SbTag025	NA	NA	NA	NA	76.50	NA	NA
Median dive duration day (min)							
SbTag023	**NA**	**2.18**	**3.95**	**2.20**	**NA**	**0.0019**	**Inter-A; Inter-B**
SbTag025	NA	NA	NA	NA	1.95	NA	NA

- The Kruskal-Wallis one-way ANOVA results indicate significant differences among phases, shown in bold. The associated post-hoc Dunn's test column lists pairs of phases where significant differences were detected at a level of significance of 0.05. Each individual has single values for dive rates and percentage time in surface periods, so no statistical testing was conducted.

Table 25. A comparison of nighttime diving parameters from rough-toothed dolphins exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Night dive rate (dives/hour)							
SbTag023	4.16	3.22	2.20	3.30	NA	-	
SbTag025	NA	NA	NA	NA	2.19	-	
% time in surface periods at night							
SbTag023	73.72	80.79	87.76	81.63	NA	-	
SbTag025	NA	NA	NA	NA	91.71	-	
Median dive depth night (m)							
SbTag023	**81.50**	**73.50**	**91.50**	**92.50**	**NA**	**0.0005**	**Inter-A; A-B; Inter-Before**
SbTag025	NA	NA	NA	NA	71.50	NA	NA
Median dive duration night (min)							
SbTag023	**3.83**	**3.65**	**3.40**	**3.32**	**NA**	**0.0154**	**Inter-Before; B-Before**
SbTag025	NA	NA	NA	NA	2.23	NA	NA

- Significant differences among phases were detected in the Kruskal-Wallis one-way ANOVA findings, which are highlighted in bold. The post-hoc Dunn's test column lists pairs of phases where significant differences were identified at a significance level of 0.05. Individuals were represented by single numbers for dive rates and percentage time in surface periods; hence, no statistical analysis was conducted.

3.2.4.1 SbTag023

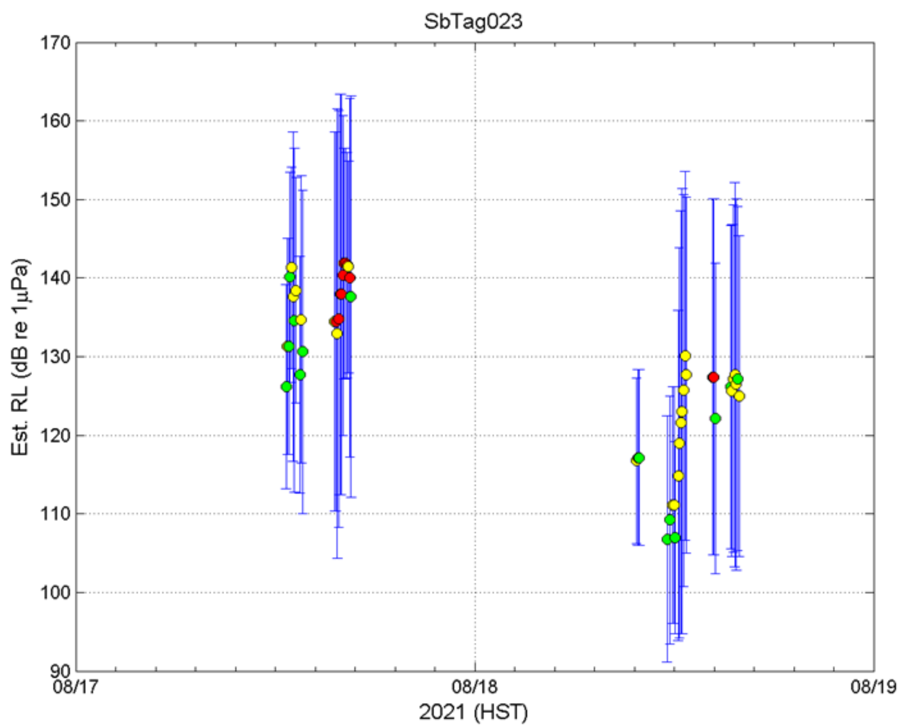
Information was available about SbTag023's movements in 2021 for Before (2.3 days), Phase A (1.7 days), the interphase period (3.8 days), Phase B (2.4 days), and After (2.8 days; Table 24). During this time, SbTag023 remained on or in close proximity to the range throughout the course of the SCC.

SbTag023 was tagged prior to the start of Phase A; this individual largely remained on the southern end of the range prior to and during Phase A (Figure 34). At the end of Phase A, SbTag023 had exited the southernmost end of the range and remained in this area (the slope between Ni‘ihau and Kaua‘i) for most of the Interphase period before moving north back into the range and then just outside the southwestern portion of the range prior to the start of Phase B. SbTag023 re-entered the range after the start of Phase B and moved northeast along the southeastern area of the range, where it was exposed to its highest received levels during two MFAS bouts (maximums of 141 and 142 dB re 1 µPa for each, with an approximately one-hour break in between). This individual continued to move northeast and was on the edge and just outside of the southeastern portion of the range during the last MFAS bout that it was exposed to (levels between 105 and 130 dB re 1 µPa). After this bout, SbTag023 re-entered the range and moved southwest across the range through the end of Phase B. During the three days post-SCC, SbTag023 largely remained on the southwestern edge of the range.

Because SbTag023 remained on or close to the range for their entire tag attachment period, all of their 5-minute bins had probabilities of 1 for exposure, and their estimated median RLs ranged from 107–142 dB re 1 μPa (Table 26, Figure 33). They were exposed to six bouts of MFAS, and the first two bouts had higher median RLs than the last four bouts by 10–20 dB. This animal had the highest estimated median and + 2 SD RL values for the animals tagged in 2022.

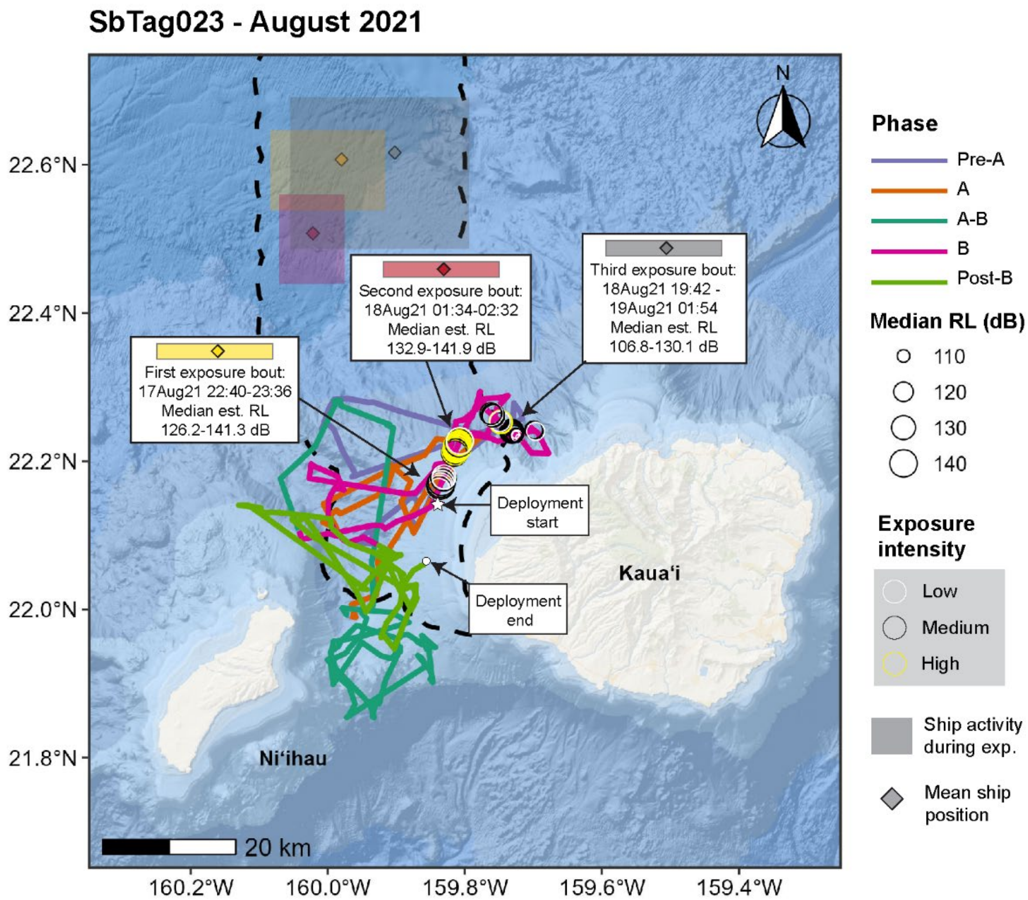
Table 26. Estimated received levels, cumulative sound exposure levels, and ship CPA for SbTag023.

Minimum median RL value (± 2 SD) dB re 1 μPa	107 (95, 119)
Maximum median RL value (± 2 SD) dB re 1 μPa	142 (121, 157)
CPA of ship (km)	14
Maximum overall cSEL dB re 1 μPa^2	151



- Median RLs for SbTag023 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values.

Figure 33. Median RLs for SbTag023.



- Movements of SbTag023 during the August 2021 SCC event (see text for description of phases).
- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times are given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the three MFAS bouts that SbTag023 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

Figure 34. SbTag023 movements during the August 2021 SCC event.

3.2.4.1.1 Dive Behavior

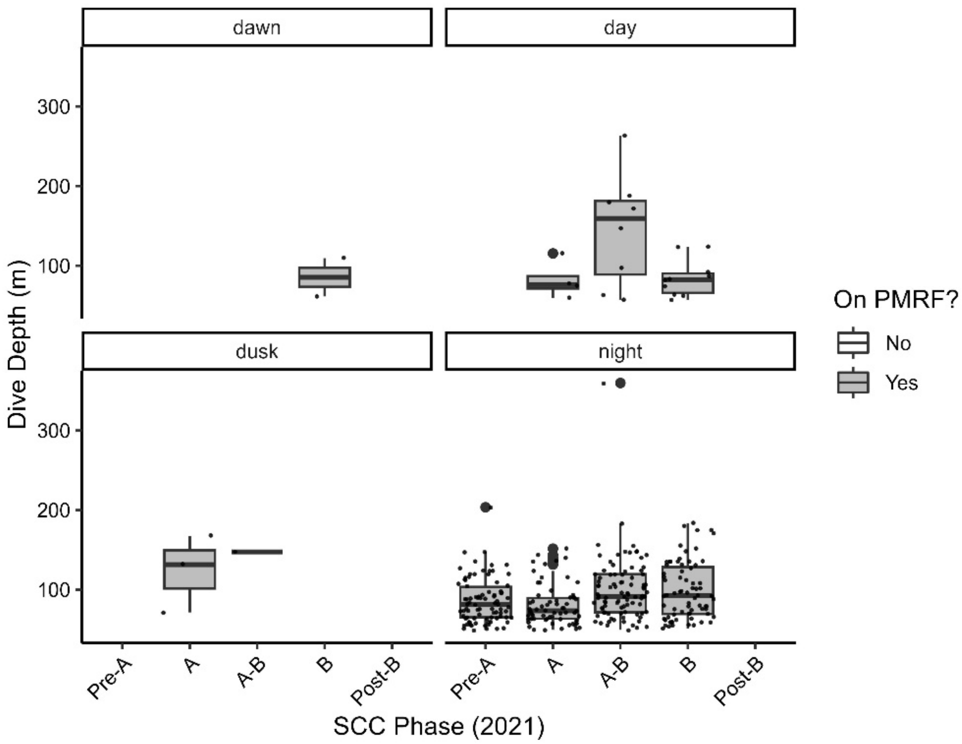
Dive behavior data were available for SbTag023 for all phases (Table 24, Table 25, Figure 35). However, when separated by time of day and phase, not every time of day and phase met the required coverage (relative to the phase duration) for inclusion in the analysis.

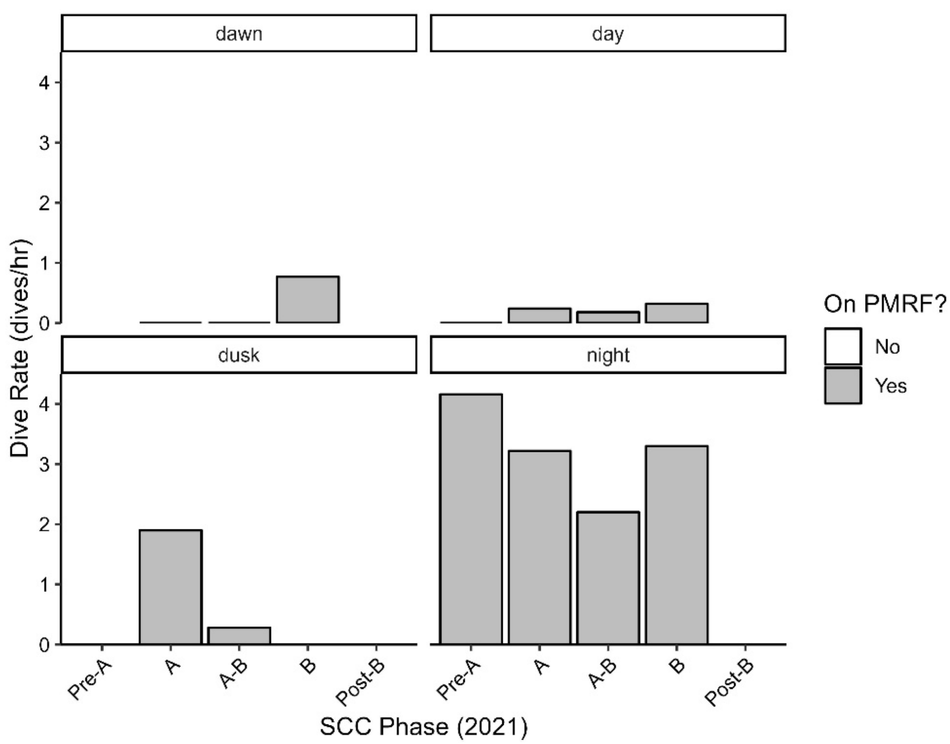
Behavior data for the dawn hours were available for Phase A, the interphase period, and Phase B, but the tagged individual remained exclusively at the surface during Phase A and the interphase. Day dive metrics were available for all phases except After. No day dives were recorded Before, and day dive rates for the remaining phases had only slight variation. The day dive rate fell slightly between Phase A and the interphase and rose to its highest during Phase B. The percentage of surface time during day hours remained high across all phases, never dipping below 98%.

There was no statistically significant variation in day dive depths, but dives were significantly longer during the interphase compared to Phase A and Phase B.

Dusk dive metrics were available for Phase A, the interphase period, and Phase B, but no dusk dives were recorded during Phase B. The dusk dive rate was highest during Phase A and dropped sharply during the interphase. The percentage of surface time during dusk hours was lowest during Phase A and rose during the interphase. Dusk dive depths and durations did not vary significantly between phases.

Night dive metrics were available for all phases except After. Night dive rates were highest Before, dropped during Phase A, continued to drop during the interphase, and rose during Phase B. The percentage of surface time during night hours was lowest during Before, rose during Phase A and the interphase, and dropped again during Phase B. Night dives were significantly deeper during the interphase compared to Before and significantly deeper during the interphase and Phase B compared to Phase A. Night dives were also significantly longer during Before compared to the interphase, or Phase B.





- Top: Boxplot showing dive depths of SbTag023 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of SbTag023 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 141.9 dB.

Figure 35. SbTag023 boxplot and barplot dive depths.

3.2.5 Common bottlenose dolphins

Three bottlenose dolphins had tag data during the SCCs, two in 2021 and one in 2022 (Table 27). Diel dive analyses could be conducted for one animal from each year (Table 28 and Table 29).

Table 27. Percentage of surfacing/dive data by phase for common bottlenose dolphins.

Individual	Percentage of surfacing/dive data				
	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After
TtTag039					
Duration overall (days)	NA	1.0	3.8	2.4	5.7
Days surfacing/dive data	NA	0.7	3.0	2.0	1.4
Percentage behavioral coverage	NA	75.3	80.4	83.8	25.5
TtTag040					
Duration overall (days)	NA	NA	2.8	2.4	10.7
Days surfacing/dive data	NA	NA	NA	NA	NA
Percentage behavioral coverage	NA	NA	NA	NA	NA
TtTag041					
Duration overall (days)	NA	NA	3.0	0.2	13.8
Days surfacing/dive data	NA	NA	3.0	0.2	5.0
Percentage behavioral coverage	NA	NA	100.0	100.0	36.1

- 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 days of surfacing/dive data is an indication of how much of the dive behavior data was received relative to the period that behavior data were meant to be collected.

Table 28. A comparison of daytime diving parameters from common bottlenose dolphins exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Day dive rate (dives/hour)							
TtTag039	NA	NA	0.85	0.69	NA	-	
TtTag041	NA	NA	0.82	1.11	0.75	-	
% time in surface periods at day							
TtTag039	NA	NA	90.06	94.15	NA	-	
TtTag041	NA	NA	87.59	89.87	88.32	-	
Median dive depth day (m)							
TtTag039	**NA**	**NA**	**123.50**	**71.50**	**NA**	**0.0218**	**Inter-B**
TtTag041	**NA**	**NA**	**607.50**	**116.50**	**591.50**	**0.0102**	**Inter-B/A; B/A-After**
Median dive duration day (min)							
TtTag039	**NA**	**NA**	**7.50**	**5.17**	**NA**	**0.0068**	**Inter-B**
TtTag041	**NA**	**NA**	**9.67**	**5.57**	**10.20**	**0.0183**	**Inter-B/A; B/A-After**

- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

Table 29. A comparison of nighttime diving parameters from common bottlenose dolphins exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Night dive rate (dives/hour)							
TtTag039	NA	NA	4.01	5.08	3.83	-	
TtTag041	NA	NA	2.95	NA	2.65	-	
% time in surface periods at night							
TtTag039	NA	NA	65.40	54.64	70.07	-	
TtTag041	NA	NA	67.84	NA	75.15	-	
Median dive depth night (m)							
TtTag039	NA	NA	115.50	97.50	109.50	0.0884	NA
TtTag041	NA	NA	199.50	NA	137.50	0.1106	NA
Median dive duration night (min)							
TtTag039	**NA**	**NA**	**4.67**	**5.23**	**4.78**	**0.0472**	**B-After**
TtTag041	**NA**	**NA**	**6.60**	**NA**	**4.70**	**0.0142**	**Inter-After**

- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period, thus no statistical testing was undertaken.

3.2.5.1 TtTag039

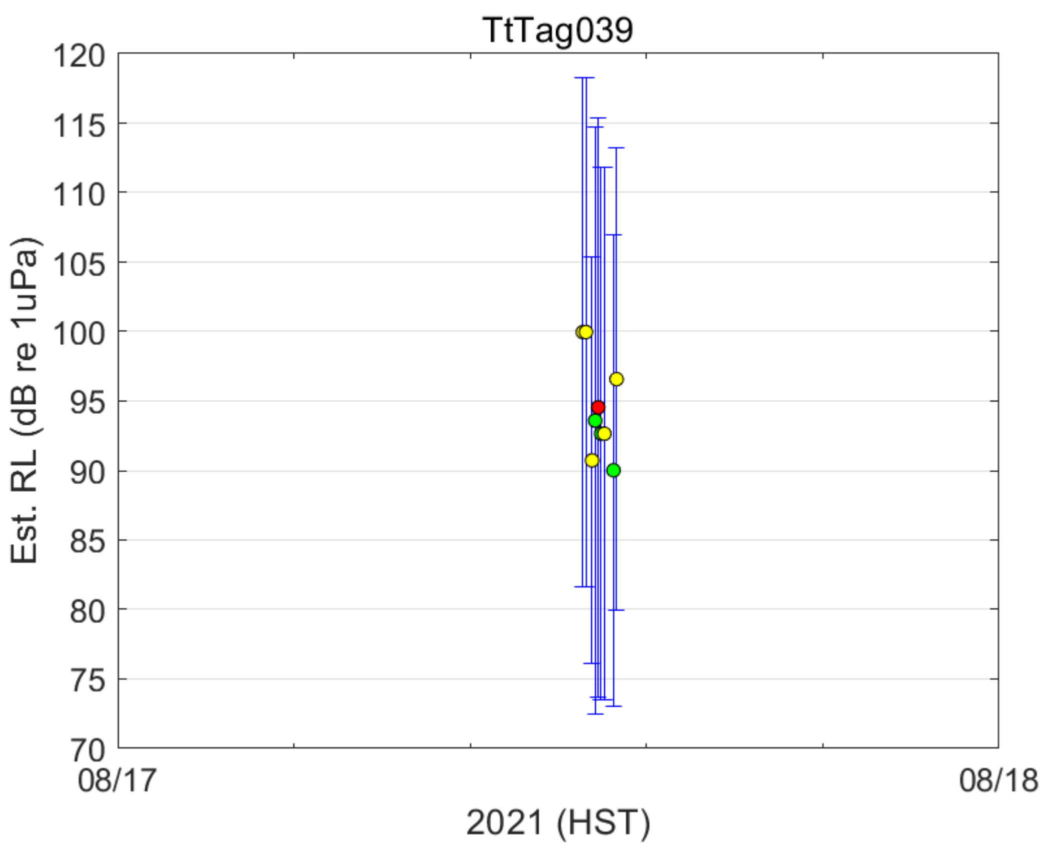
Information was available about TtTag039's movements in 2021 for Phase A (1.0 days), the interphase period (3.8 days), Phase B (2.4 days), and After (5.7 days; Table 27). TtTag039 spent time during each phase on the range but also moved extensively around the island of Kaua‘i.

Movements of TtTag039 relative to SCC phases are shown in Figure 37. After tag deployment, TtTag039 spent its time during Phase A in the nearshore waters along the northern Kaua‘i coast. During the interphase, TtTag039 began moving southwest along the easternmost edge of the south end of the range, continued following the coast (counter-clockwise), and remained on the northeastern coast of Kaua‘i through the end of the interphase. At the start of Phase B, this individual began moving south along the east coast of the island, where it was exposed to one bout of MFAS for approximately one hour (received levels remained under 100 dB re 1 μPa). TtTag039 continued south and followed the coastline back around to the range and near its deployment location through the end of Phase B. In the three days after Phase B, this individual moved along the north-northwest coastline of Kaua‘i.

TtTag039 only had one short bout of exposure, with only nine 5-minute bins with estimated RLs equal to or less than 100 dB re 1 μPa, and all had probabilities of exposures less than 0.29 (Table 30, Figure 34).

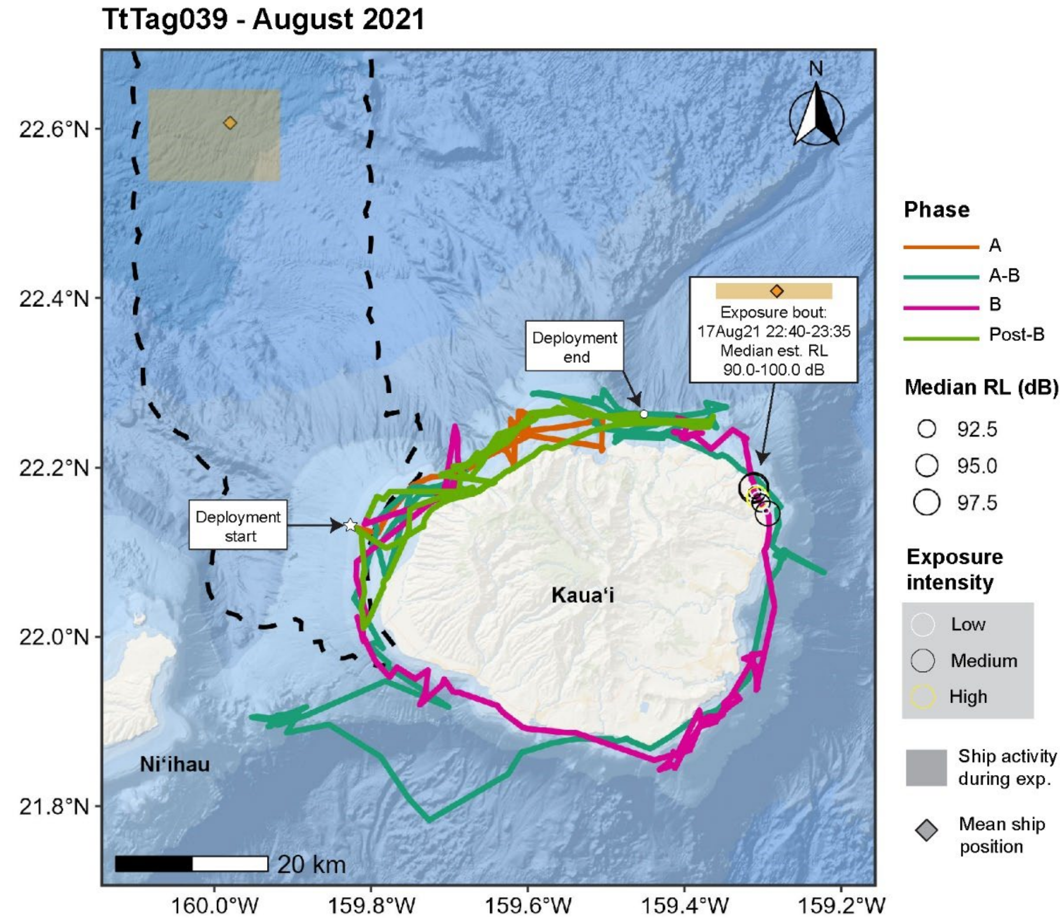
Table 30. Estimated received levels, cumulative sound exposure levels, and ship CPA for TtTag039.

Minimum median RL value (± 2 SD) dB re 1 μPa	90 (73, 107)
Maximum median RL value (± 2 SD) dB re 1 μPa	100 (84, 116)
CPA of ship (km)	35
Maximum overall cSEL dB re 1 μPa^2	106



- Median RLs for TtTag039 in stoplight colors (green for few pings during the 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values.

Figure 36. Median RLs for TtTag039.



- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the three MFAS bouts that TtTag039 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that After is restricted to three days after the end of the SCC.
- The dashed black line represents the PMRF boundary.

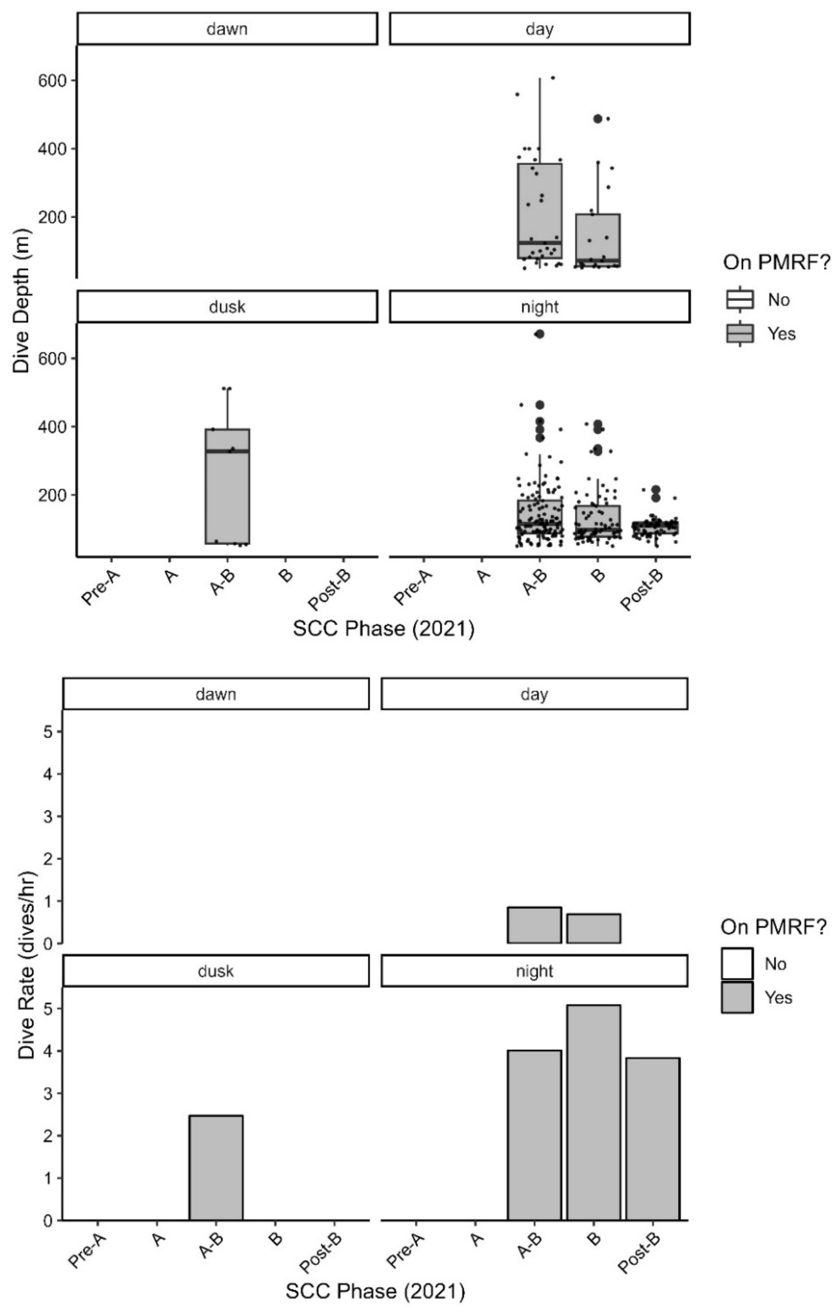
Figure 37. TtTag039 movements during the August 2021 SCC event.

3.2.5.1.1 Dive Behavior

Dive behavior data were available for TtTag039 for all phases except Before (Table 28, Table 29, Figure 36). However, when separated by time of day and phase, not every time of day and phase met the required coverage (relative to the phase duration) for inclusion in the analysis. Coverage was insufficient during dawn to calculate any metrics, and only metrics for the interphase period during dusk hours could be calculated. As a result, analysis was restricted to the day and night hours.

Day dive metrics were available for the interphase and Phase B. The day dive rate was highest during the interphase and dropped slightly during Phase B, while the percentage of surface time during day hours was lowest during the interphase and rose slightly during Phase B. Day dives were significantly deeper and longer during the interphase than Phase B.

Night dive metrics were available for the interphase, Phase B, and After. The night dive rate was highest during Phase B and dropped sharply during After, while the percentage of surface time was lowest during Phase B and rose sharply during After. Night dive depths did not show statistically significant variation between phases, but night dives were significantly shorter during After compared to Phase B.



- Top: Boxplot showing dive depths of TtTag039 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of TtTag039 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 100.0 dB.

Figure 38. TtTag039 boxplot and barplot dive depths.

3.2.5.2 *TtTag040*

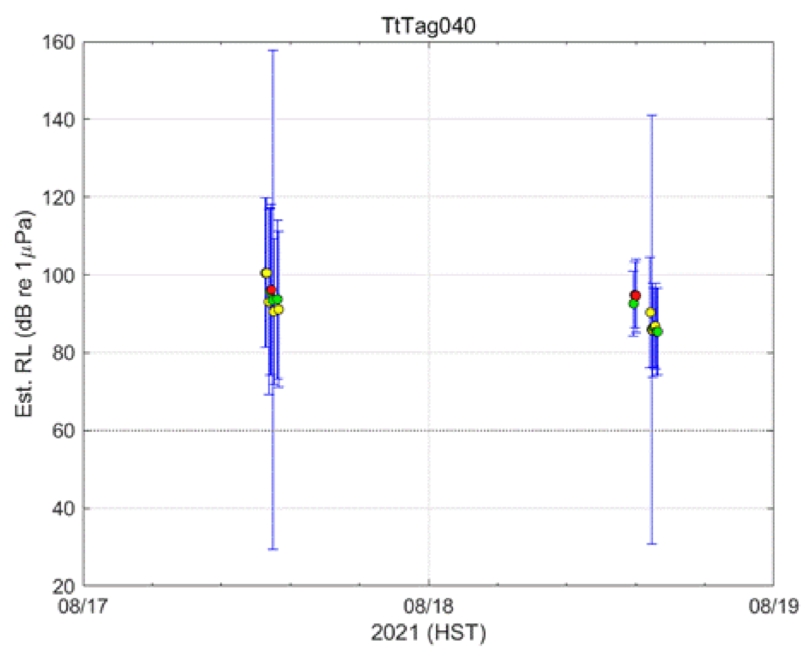
Information was available about TtTag040’s movements in 2021 for the interphase period (3 days), Phase B (0.2 days), and After (13.8 days; Table 27). TtTag040 was not closely associated with TtTag039 for the entirety of its deployment period, although they exhibited similar movement patterns and generally remained along the nearshore coasts of Kaua‘i.

TtTag040 was tagged during the interphase period; during this time, this individual moved along the western coast of Kaua‘i (the southeastern edge of the range) and then eventually along the northern coast (Figure 40). At the start of Phase B, this individual was on the eastern side of Kaua‘i and was exposed to two bouts of MFAS, with exposure periods (when received levels were computed) lasting about an hour each; received levels were under 100 dB re 1 μPa during both bouts. TtTag040 continued to use the nearshore waters on the east coast of Kaua‘i throughout the rest of Phase B. In the After period, this individual moved west along the southern coast of the island, then back along the east coast, and eventually the north coast of Kaua‘i.

TtTag040 was exposed to three separate bouts of MFAS over two different days; they also had less than 0.77 probability of exposure for any of their 5-minute bins, and had estimated median RLs of 100 dB re 1 μPa or less (Table 31, Figure 39).

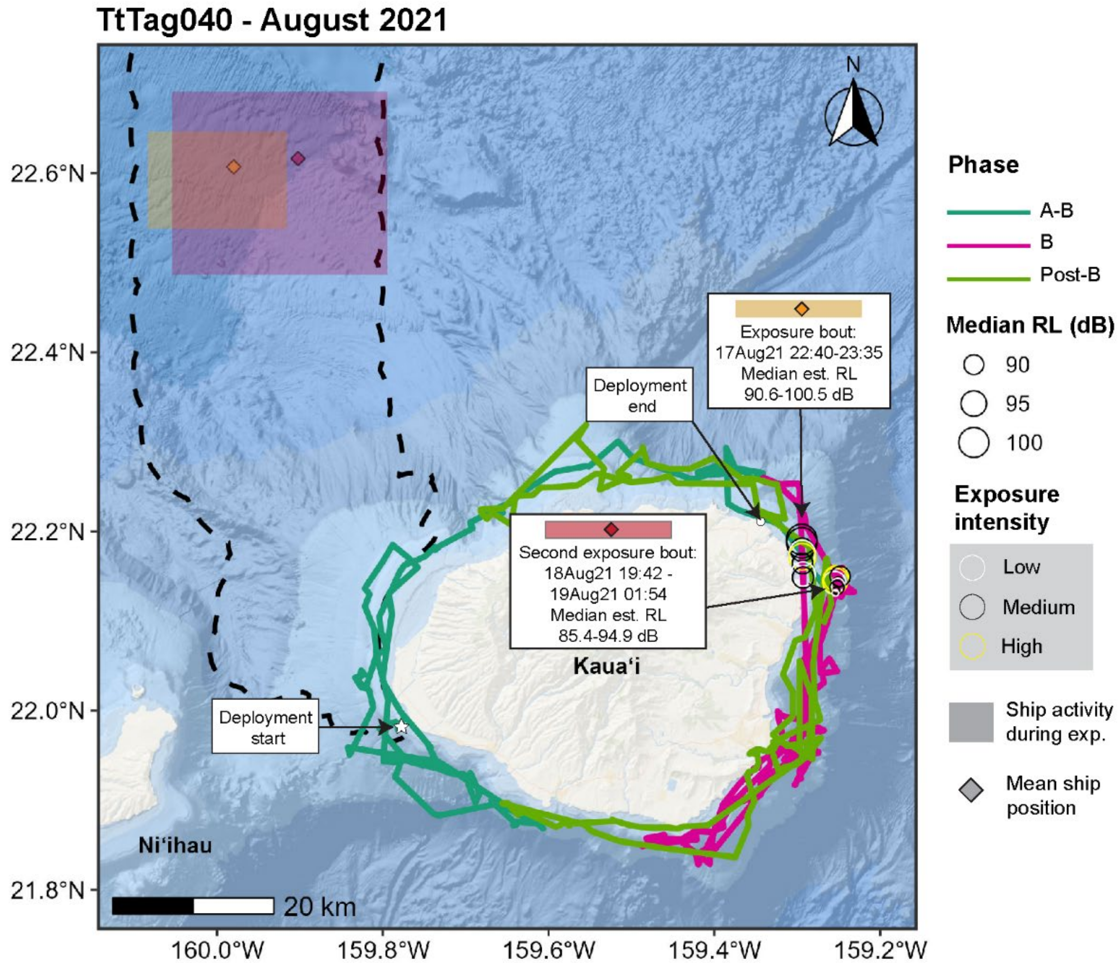
Table 31. Estimated received levels, cumulative sound exposure levels, and ship CPA for TtTag040.

Minimum median RL value (± 2 SD) dB re 1 μPa	85 (78, 93)
Maximum median RL value (± 2 SD) dB re 1 μPa	101 (82, 119)
CPA of ship (km)	55
Maximum overall cSEL dB re 1 μPa^2	108



- Median RLs for Tt040 in stoplight colors (green for few pings during a 5-minute bin, yellow for a moderate number of pings, red for a high number of pings) with error bars giving the ± 2 SD values. The dotted line at 60 dB re 1 μPa represents the ambient noise floor below which animals are unlikely to detect a sound.

Figure 39. Median RLs for Tt040.



- The maximum and median estimated received levels (RLs) that occurred during each 5-minute exposure bin are plotted as open circles, with the size of the circle scaled to the RL level and times given in GMT.
- RL circles are colored by "intensity," which is characterized by the frequency of MFAS exposures that occurred during that given 5-minute exposure bin.
- The shaded rectangular polygons represent the area of ship activity during each of the three MFAS bouts that TtTag040 was exposed to, and the corresponding diamond points represent the mean ship location during each bout.
- Note that after is restricted to three days after the end of the SCC. The dashed black line represents the PMRF boundary.

Figure 40. TtTag040 movements during the August 2021 SCC.

4. DISCUSSION

This report describes the movement patterns, diel dive behavior, and estimated RLs for 15 of 21 satellite-tagged odontocetes on and near PMRF during the two-week SCC training events in August 2021 and 2022. These data add to the growing catalog of odontocetes that have been tagged concurrently with these training events since 2011. While received levels for these tagged animals have been reported since 2014, in 2021 a major re-analysis was conducted of 9 of 12 short-finned pilot whales, 4 of 7 rough-toothed dolphins, and 2 bottlenose dolphins using updated methods to estimate received levels more accurately (Henderson et al., 2021). These methods, including estimating RLs for the full error ellipse of each *crawl*-interpolated track position every 5-minute and utilizing modeled dive depth information, allow for more rigorous estimations of RL in three dimensions (four, including time along the track). These methods were replicated in this report and support better assessments of behavioral responses. New statistical methods of behavioral response analyses for both horizontal movement and dive behavior are being developed for satellite tags (e.g., Hewitt et al., 2022); by building up an extensive catalog of individuals and species, these aggregated methods may be applicable in the future for the species at PMRF as well.

The 15 tagged animals with MFAS exposures in 2021 and 2022 had relatively low RLs. PeTag029 had the highest levels, with a maximum medium SPL of 148 dB re 1 μPa (up to 156 dB re 1 μPa with 2 SD) and a maximum cSEL of 158 dB re 1 μPa^2. Two other melon-headed whales received maximum median RL values of 136–137 dB re 1 μPa two short-finned pilot whales had RLs of 129 dB re 1 μPa, and one rough-toothed dolphin had maximum medium RLs up to 142 dB re 1 μPa. The remainder of the animals' RLs were less than 100 dB re 1 μPa, and many of the median 5-minute bin values were below the ambient noise floor of 60 dB re 1 μPa (at and above 1 kHz, Širović et al. 2013). These levels were lower than those for most of the animals re-analyzed in 2021, where median RLs ranged from 101 dB to as high as 177 dB re 1 μPa (Henderson et al. 2021), with the + 2 SD extending as high as 195 dB re 1 μPa, although these high values were at the tail end of the RL histograms and were very unlikely.

In fact, in 2022, only three of the short-finned pilot whales were on the range during the SCC and only during the A/B mixed phase, after which they left the range, and they only received exposures once off the range. Similarly, the false killer whale tagged in 2021 was also off the range during their periods of exposure, as were the two bottlenose dolphins tagged in 2021 and the two melon-headed whales tagged in 2022. The rough-toothed dolphin tagged in 2021 remained on the range for almost the whole SCC, and two of the melon-headed whales from 2021 moved on and off the range throughout the SCC, while the animal with the highest exposure (PeTag029) was on and off the range during the ULT prior to the SCC but then moved far out of the area before the SCC began. While the latter four tags could be candidates for a statistical analysis of their movement behavior, the rest of the animals had low enough received levels and were far enough away from the range that behavioral responses, if they occurred, were likely to be too subtle to be detected by coarse analyses of satellite tag data.

However, dive behavior was analyzed with a statistical approach for the animals who had enough data in each temporal period (dawn, day, dusk, night) and SCC period (Before, Phase A or A/B, Interphase, Phase B or B/A, and After). Differences in dive rates, time in surface periods, dive depth, and dive duration were compared across phases and diel periods, and dives were also identified as occurring on or off the range. However, the resulting changes in dive behavior across years, species, and individuals, even among those in the same groups, were variable and contrasting, making it difficult to identify consistent patterns of response to Navy training activity, or MFAS.

Of the pilot whales, only GmTag233, GmTag235, and GmTag237 had significant differences in their median dive durations in the dawn diel period; for GmTag233, significant differences occurred between Phase B and the After period, while for GmTag235 and GmTag237, differences occurred between the Interphase and the After period. During the daytime period, several of the short-finned pilot whales had significant differences in both their median dive depth and dive duration across SCC phases. While there were individual differences, the two most common phases with differences were the Interphase to After period and the Phase A to After period. However, the differences in dive behavior also varied between individuals, even within the same phases. For example, GmTag233 had deeper daytime dives (median depths > 500 m) in all phases except After, when their median dive depths were around 250 m. In contrast, GmTag234, GmTag235, and GmTag237 had very shallow median dive depths during Phase A and the Interphase, but then deep median depths during Phase B and After. Similarly, several of the short-finned pilot whales had significant differences in their median dive depths and durations for their nighttime dives across SCC phases. The 2021 pilot whales had variability in their dive depths across almost all phases, but again patterns diverged among individuals, with GmTag232 having all deep night-time dives that got progressively deeper across phases, while GmTag234 had moderately deep (> 500 m) median depths that got progressively shallower during the SCC then deeper again After, and GmTag233 had shallow nighttime median dive depths (< 250 m) during the SCC but median dive depths jumped to > 500 m in the After period.

The short-finned pilot whales tagged in 2021 were off the range during the SCC, and many of their exposures were partially blocked, so changes in dive behavior were more likely due to their location around the island and relative prey patterns in those areas rather than training activity. However, the short-finned pilot whales tagged in 2022 were on the range at the start of the A/B mixed phase; their exposures occurred at the southern end of the range when the animals were already moving south and away from the area. Exposure levels were highest during the first period of MFAS, up to a median RL of 125 dB re 1 μPa, and remained at similar levels while the animals were in the same general area during the second MFAS period. However, by the third MFAS period, the animals had begun moving further south, and so exposure levels were reduced. While dive rates were not significantly different across SCC phases, it may be worth noting that dive rates were highest during this A/B mixed Phase, when the animals were on the range near training activity and MFAS, and then rates decreased across subsequent phases. In addition, both GmTag235 and GmTag237 had significantly shallower dives during the A/B mixed Phase than the B/A mixed phase (and After phase for GmTag237) when the animals had moved well away from the area on the far side of Kaua‘i.

Similar changes and variability in dive behavior were found for short-finned pilot whales tagged prior to 2021 (Henderson et al., 2021). There were no significant differences in dive rates or time at the surface for any of the individuals, but a few animals had significant differences in daytime and nighttime median dive depths and durations. The patterns again varied among individuals, with some animals having variability in both daytime and nighttime dive depths across SCC phases (GmTag081, GmTag214), and others showing distinct changes across phases. For example, GmTag153 had very shallow median daytime and shallower (around 250 m) nighttime dive depths, with deeper dives in both diel periods in the After phase.

In contrast, GmTag152’s median dive depths were already deep (> 250 m at night and > 500 m during the day) and got deeper across SCC phases during both the daytime and nighttime periods, while GmTag214’s median dive depths were deeper than 250 m both day and night during the SCC and then became shallower than 250 m After. Therefore, across a decade of effort and with 15 individuals tagged, no clear and consistent patterns have emerged in changes to short-finned pilot whale dive behavior during exposure to Navy training activity and MFAS.

In fact, in Henderson et al. (2021), a few of the short-finned pilot whales had potentially high levels of MFAS exposure because they approached active sources on the range, perhaps demonstrating either habituation to MFAS by resident animals or indicating that the area is particularly important for foraging, and thus the animals may be more willing to tolerate MFAS or other training activities. Based on 24 satellite tag deployments on individuals from the western community of island-associated short-finned pilot whales in Hawaiʻi between 2008 and 2021, a Biologically Important Area was designated around Kauaʻi, encompassing much of the southern part of the PMRF (Kratofil et al., 2023; see page 144, Supplemental File A).

For melon-headed whales, only nighttime dives could be assessed statistically, and only PeTag031 had significant differences in their median dive depths and durations across SCC phases. This animal remained on or near the range during all phases and so had multiple bouts of MFAS exposure, although none exceeded median RLs of 137 dB re 1 μPa. Their median dive depths increased significantly across all phases, from around 200 m during Phase A to over 300 m during the After period. Their dive rates also decreased across phases. In the same year, PcTag029 had the highest exposure levels as they were directly east of the ULT training activity and remained there for the duration of the ULT. As dive behavior was only compared across SCC phases, it is unknown if there were any short-term changes in their dive behavior during this period. They did cross the range and then travel to the west and then south once the ULT was finished, which could have been a subsequent avoidance response of the area, although they did not move away during the actual period of exposure. The two melon-headed whales tagged in 2022 left the area right after tagging, so all exposures were at low RLs and were partially blocked by land.

Of the three rough-toothed dolphins tagged in 2021, only two had enough dive data to conduct statistical analyses, and only one, SbTag023, had significant differences in their daytime median dive duration and nighttime median dive depth and dive durations. Median daytime dive depths were shallow (< 100 m) during both Phase A and B and then deepened to almost 200 m during the Interphase period. The pattern was less clear at night, although dives were slightly shallower in Phase A than in any other period and were slightly deeper in the Interphase and Phase B than during Phase A. This animal's dive rates were highest in the Before period and lowest during the Interphase. This was also the only rough-toothed dolphin with MFAS exposures and had the second-highest median RLs in this study, up to 142 dB re 1 μPa, although they generally remained in the southern portion of the range for the exposure periods. They were tagged on the range and then continued to move on and off the range and into the channel between Niʻihau and Kauaʻi for the duration of the SCC. Similar results were found for rough-toothed dolphins in Henderson et al., (2021); only two of those four animals had sufficient dive data for a statistical analysis, and significant differences were found for both animals for their nighttime median dive depths and durations.

These animals were tagged in the Interphase in 2016. SbTag017 had shallower (< 100 m) nighttime median dive depths during the Interphase and Phase B and then deeper (> 100 m) nighttime dives in the After period. SbTag018 had slightly shallower nighttime median dive depths in the Interphase and then slightly deeper median dive depths in Phase B and After, although in all three phases median dive depths were < 100 m. These animals again occupied the southern portion of the range or the area off the range in the channel between Niʻihau and Kauaʻi, and they had maximum median RLs of 148 dB re 1 μPa and 157 dB re 1 μPa (Henderson et al. 2021). Rough-toothed dolphins generally occupy the same habitat at the southern end of the range (see Figure 5 in Kratofil et al., 2023) and are therefore not likely to experience much higher RLs than these as most training activity at PMRF takes place in the northern portion of the range, as can be seen in Figure 34.

Three common bottlenose dolphins were tagged in 2021 and 2022, but only two had sufficient dive data for analysis. Both the median dive depths and durations were statistically different across SCC phases for TtTag039 and TtTag041 during the day, while only durations were different for both at night. Both variables differed for TtTag039 between the Interphase and Phase B during the day, with deeper median and overall depths during the Interphase than during Phase B and shorter dives at night After than during Phase B. However, this animal and TtTag040 circled Kaua‘i throughout the whole SCC, and the few exposures that occurred were partially blocked by land and had low RLs. Therefore, like the pilot whales tagged in 2021, the changes in dive behavior for these animals were more likely due to variability in prey than any response to Navy training. For TtTag041, both dive depth and duration differed between the Interphase and Phase B and between Phase B and After during the day, and duration differed between the Interphase and After at night. They had much deeper median dive depths (> 500 m) during the Interphase and After than during Phase B, when median dive depths were < 250 m. This animal also circumnavigated Kaua‘i throughout the SCC and had no MFAS exposures; therefore, differences in their dive behavior were more likely due to foraging patterns than to Navy training.

The two bottlenose dolphins analyzed in Henderson et al. (2021) also had significant differences in their median dive depths and durations both day and night across SCC phases. Both animals had deeper daytime than nighttime dives throughout the SCC, although TtTag034 had slightly deeper median daytime dives during Phase B than the Interphase or After period, while TtTag035 had slightly shallower daytime median dive depths during Phase B than the Interphase or After. Both animals had median nighttime dive depths that decreased from the Interphase (> 300 m) through Phase B and further into the After period, although not significantly for TtTag034. These animals actually remained on the range side of Kaua‘i during Phase B and therefore had median RLs up to 146 dB re 1 μPa. Much like the rough-toothed dolphins, bottlenose dolphins generally remain in the southern portion of the range (Kratofil et al. 2023, see page 36 in Supplemental File A) and even closer to shore than rough-toothed dolphins, and so again will not likely have exposure levels much higher than those.

The false killer whale, all six short-finned pilot whales, two bottlenose dolphins, and one rough-toothed dolphin were all resights of previously identified animals, and all but the three pilot whales from 2022 are known to be part of island-associated resident populations. The resident pilot whales, bottlenose dolphins, and rough-toothed dolphins have also been observed off the island of Kaua‘i, and in fact, the latter two species are specifically Kaua‘i-island-associated populations. Similarly, of the tagged delphinids assessed in Henderson et al. (2021), all but two of the short-finned pilot whales were from the Western Hawaiian population, and all of the rough-toothed and bottlenose dolphins were from the Kaua‘i/Ni‘ihau population.

The two short-finned pilot whales that were from the pelagic population had also been previously photo-identified. Therefore, these data can begin to shed light on behavioral responses by animals that have likely been exposed more than once to Navy training activity and to MFAS. As there were no obvious changes in movement behavior, and as none of the changes in dive behavior were consistent enough to point to being responses to MFAS, none of these animals at least appear to be sensitized to MFAS. Likewise, in Henderson et al. (2021) there were no overt behavioral responses, and some animals approached active MFAS sources. While in Henderson et al. (2021), there were instances where the direction of travel abruptly changed to move away from MFAS, the direction of travel often seems to change abruptly, as can be seen in multiple individuals in both that study and in this one.

As these data are aggregated and as more statistical tools are developed, these nuances in behavior may be able to be teased out further. While we must consider the argument by Forney et al. (2017) that populations such as these that are relegated to finite areas may have no choice other than to co-exist with anthropogenic stressors, and therefore no obvious response does not mean there isn't a stress response or other long-term, population-level effect, at this time it does not appear as though resident odontocetes are responding to Navy training activity with MFAS at PMRF. However, future studies of stress hormones in these populations during these SCC-associated tagging efforts are recommended, as are drone studies comparing the body composition of Kaua'i-associated populations compared to those associated with other Hawaiian Islands. These types of studies may be able to detect responses that satellite-tagging studies cannot. That said, these kinds of long-term tagging studies that build up databases of multiple species are also invaluable, as behavior could change over time and new methods are continually being developed that may be more sensitive to changes in satellite tag behavior than currently can be detected.

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APPENDIX A
ADDITIONAL DIVE BEHAVIOR RESULTS AND MOVEMENT NARRATIVES

This section contains all diving behavior tables and figures for tags/TODs where there is no statistically significant difference between phases, as well as all narratives/figures for tags where there was no exposure. Sections are broken down by species and organized with tables first, then dive behavior figures, then narratives, then maps.

Short-finned pilot whales

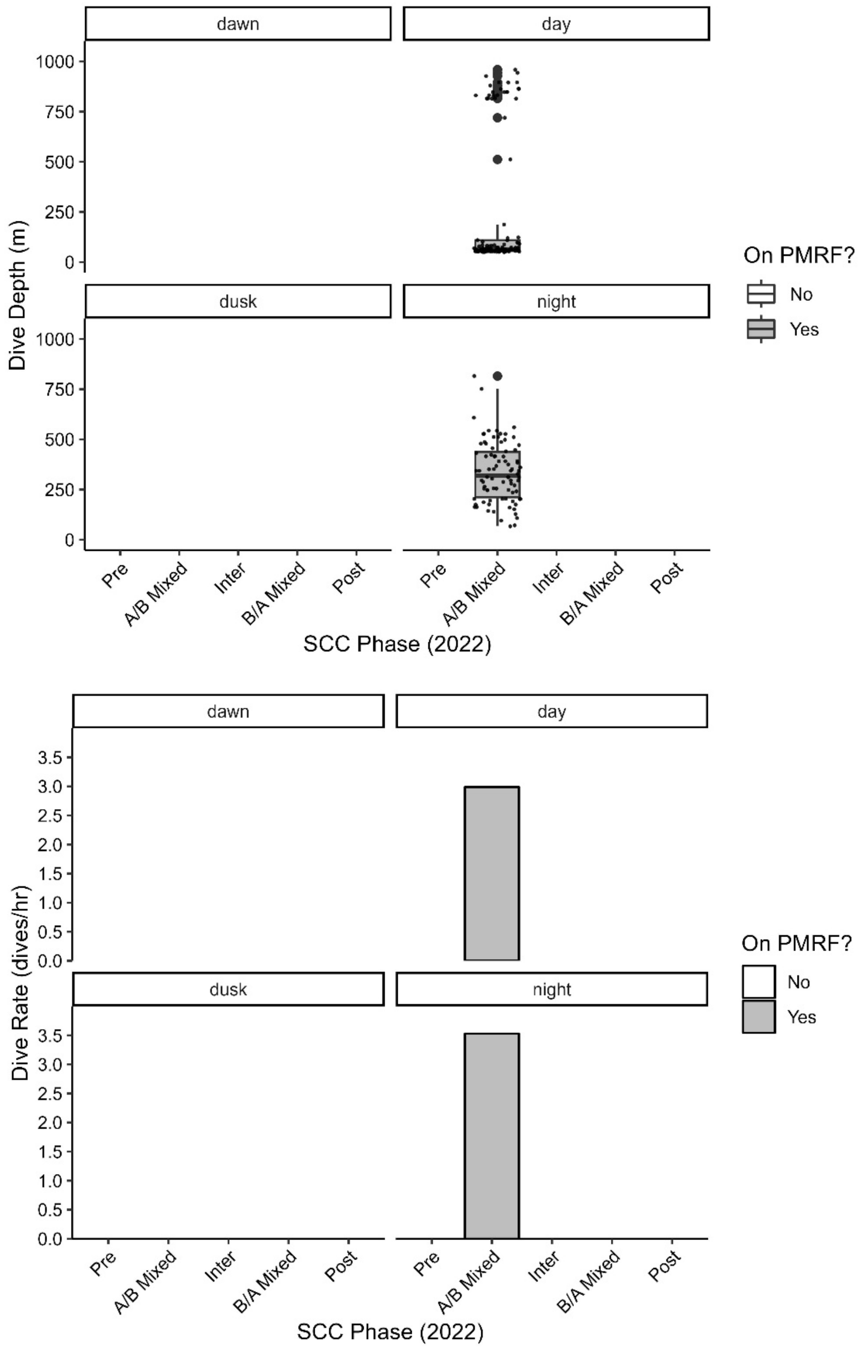
Table A-1. A comparison of dusk diving parameters from short-finned pilot whales exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dusk dive rate (dives/hour)							
GmTag232	3.08	2.63	2.44	2.71	NA	-	
GmTag233	NA	NA	2.98	2.58	3.26	-	
GmTag234	NA	NA	2.29	2.64	2.52	-	
GmTag235	NA	2.82	NA	NA	2.67	-	
GmTag237	NA	2.68	2.65	NA	2.27	-	
% time in surface periods at dusk							
GmTag232	27.16	23.69	25.80	23.82	NA	-	
GmTag233	NA	NA	31.72	43.46	25.00	-	
GmTag234	NA	NA	31.27	29.26	29.55	-	
GmTag235	NA	40.47	NA	NA	26.52	-	
GmTag237	NA	39.89	44.47	NA	35.33	-	
Median dive depth dusk (m)							
GmTag232	535.50	607.50	591.50	575.50	NA	0.2181	NA
GmTag233	NA	NA	631.50	607.50	607.50	0.8532	NA
GmTag234	NA	NA	623.50	591.50	623.50	0.6797	NA
GmTag235	NA	497.50	NA	NA	551.50	0.1436	NA
GmTag237	NA	179.50	527.50	NA	559.50	0.1388	NA

Table A-1. A comparison of dusk diving parameters from short-finned pilot whales exposed to MFAS for phases that meet the required coverage cutoff. (Continued)

Dive parameter per individual	Before	Phase A/ A/B Mixed	Interphase	Phase B/ B/A Mixed	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Median dive duration dusk (min)							
GmTag232	14.92	17.28	18.50	16.53	NA	0.1235	NA
GmTag233	NA	NA	13.87	13.27	14.67	0.9682	NA
GmTag234	NA	NA	17.52	15.63	16.57	0.0669	NA
GmTag235	NA	13.97	NA	NA	16.63	0.0875	NA
GmTag237	NA	14.17	13.80	NA	19.10	0.2874	NA

- Kruskal-Wallis one-way ANOVA: significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.



- Top: Boxplot showing dive depths of GmTag236 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of GmTag236 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 128.8 dB.

Figure A-1.GmTag236 boxplot and barplot dive depths.

False killer whale

Table A-2. A comparison of dawn diving parameters for false killer whale PcTag074 exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dawn dive rate (dives/hour)	1.49	0.56	0.00	NA	NA	-	
% time in surface periods at dawn	91.03	92.31	100.0	NA	NA	-	
Median dive depth dawn (m)	143.50	751.50	NA	NA	NA	0.1573	NA
Median dive duration dawn (min)	3.25	8.30	NA	NA	NA	0.1573	NA

- Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

Table A-3. A comparison of daytime diving parameters for false killer whale PcTag074 exposed to MFAS for phases that meet the required coverage cutoff.

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)	0.68	0.37	0.34	NA	NA	-	
% time in surface periods at day	96.04	97.26	97.43	NA	NA	-	
Median dive depth day (m)	151.50	137.50	159.50	NA	NA	0.5492	NA
Median dive duration day (min)	3.10	4.08	3.77	NA	NA	0.1740	NA

- Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

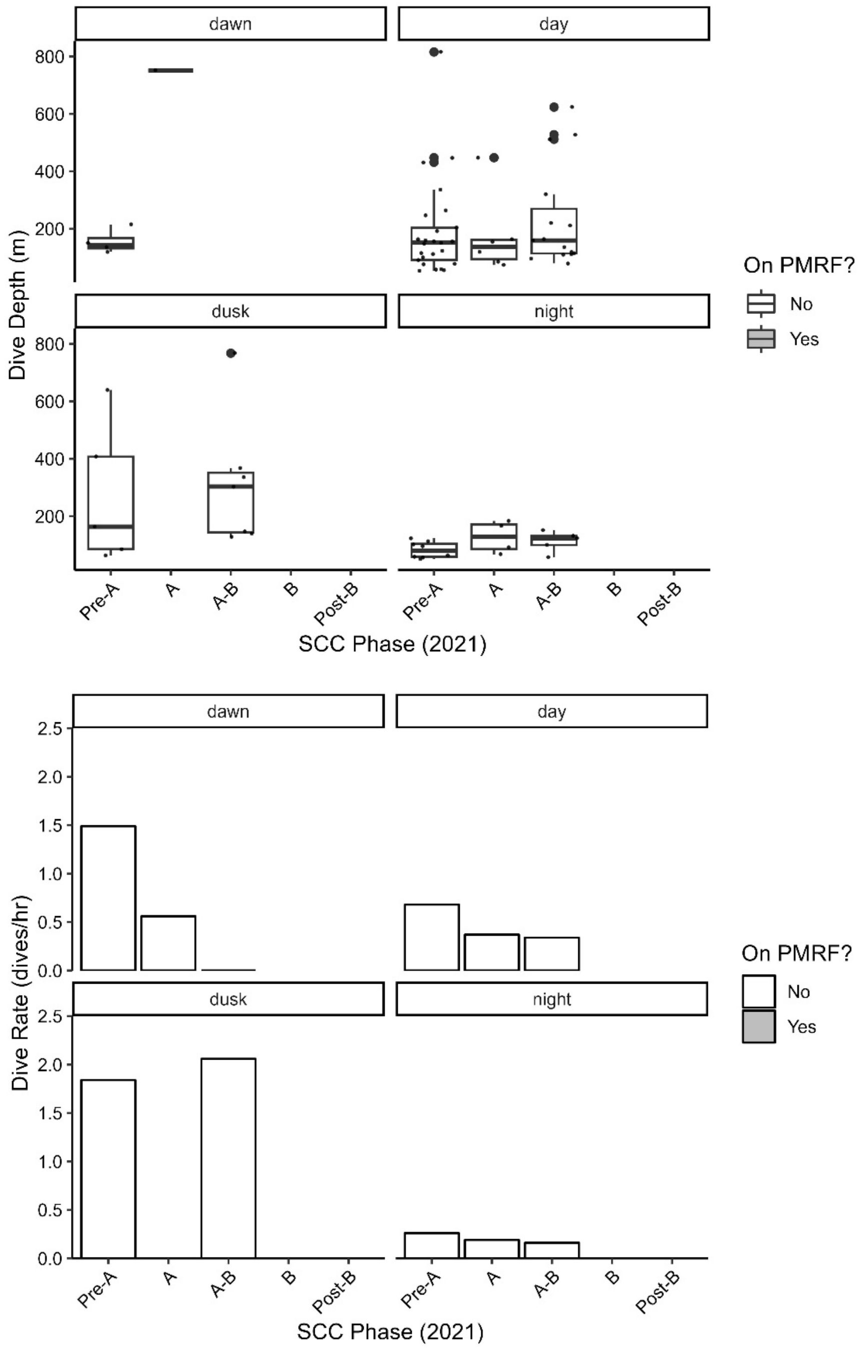
Table A-4. A comparison of dusk diving parameters for false killer whale PcTag074 exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dusk dive rate (dives/hour)	1.84	0.00	2.06	NA	NA	-	
% time in surface periods at dusk	85.47	100.00	84.89	NA	NA	-	
Median dive depth dusk (m)	163.50	NA	303.50	NA	NA	0.6847	NA
Median dive duration dusk (min)	4.10	NA	3.90	NA	NA	0.8075	NA

Table A-5. A comparison of nighttime diving parameters for false killer whale PcTag074 exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Night dive rate (dives/hour)	0.26	0.19	0.16	NA	NA	-	
% time in surface periods at night	98.46	98.20	98.63	NA	NA	-	
Median dive depth night (m)	79.50	129.50	123.50	NA	NA	0.199	NA
Median dive duration night (min)	3.00	5.33	3.80	NA	NA	0.0773	NA

- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.



- Top: Boxplot showing dive depths of PcTag074 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of PcTag074 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 90.5 dB.

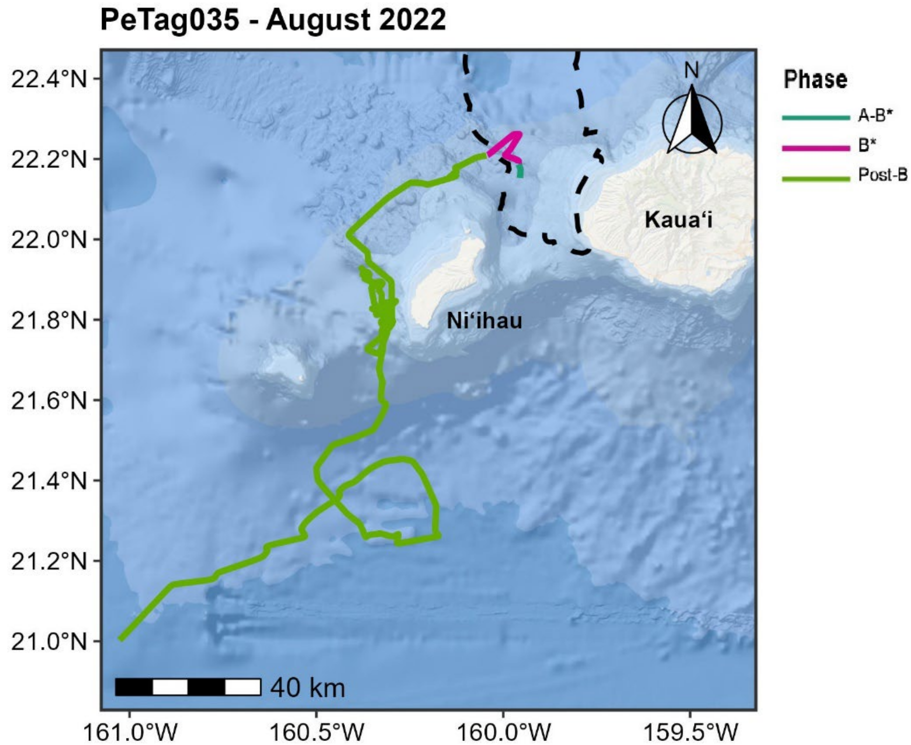
Figure A-2. PcTag074 boxplot and barplot dive depths.

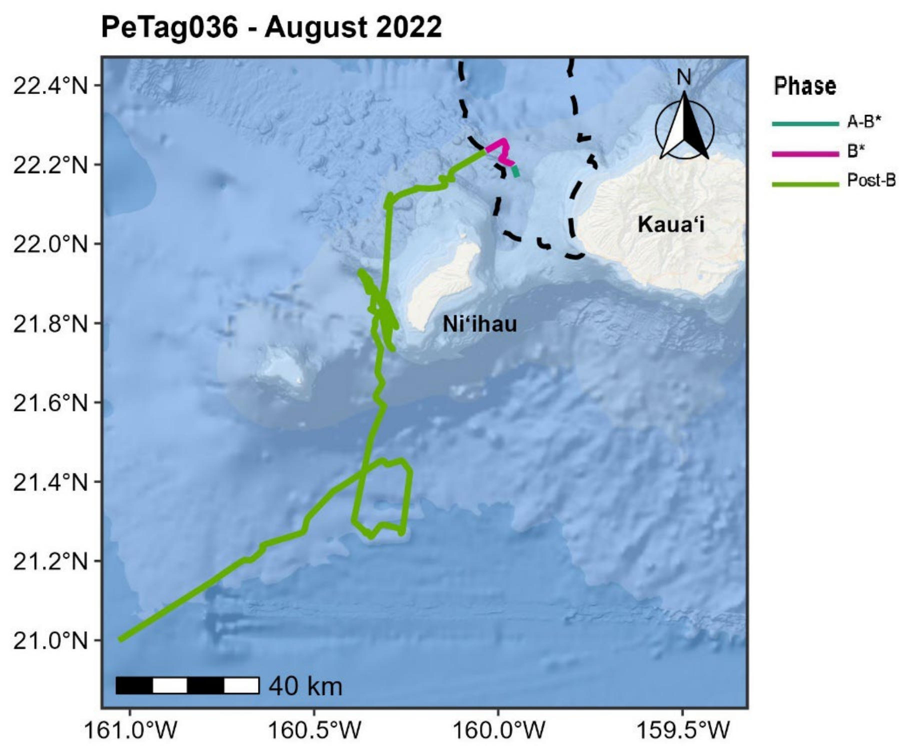
Melon-headed whales

PeTag035, PeTag036

These individuals were tagged in the same group in 2022. For PeTag035, information is available on movement patterns for the interphase period (0.1 days), the B/A mixed phase (0.2 days), and the after phase (18.1 days). While PeTag035 was tagged on the range, it moved off the range during Phase B and continued to move southwest away from the range over the remainder of its deployment. Information is available on movement patterns for PeTag036 for the B/A mixed phase (0.2 days) and the after phase (10.1 days).

Dive behavior data for both tags were only transmitted during the after phase, after any potential exposure had occurred, and these tags are hence given no further consideration in the dive behavior analysis.





- Top: Map showing crawl model trackline of PeTag035 during the 2022 August SCC.
- Bottom: Map showing crawl model trackline of PeTag036 during the 2022 August SCC.

Figure A-3. Crawl model trackline of PeTag035 and PeTag036 during the 2022 August SCC.

Rough-toothed dolphins

Table A-6. A comparison of dawn diving parameters from rough-toothed dolphins exposed to MFAS for phases that meet the required coverage cutoff.

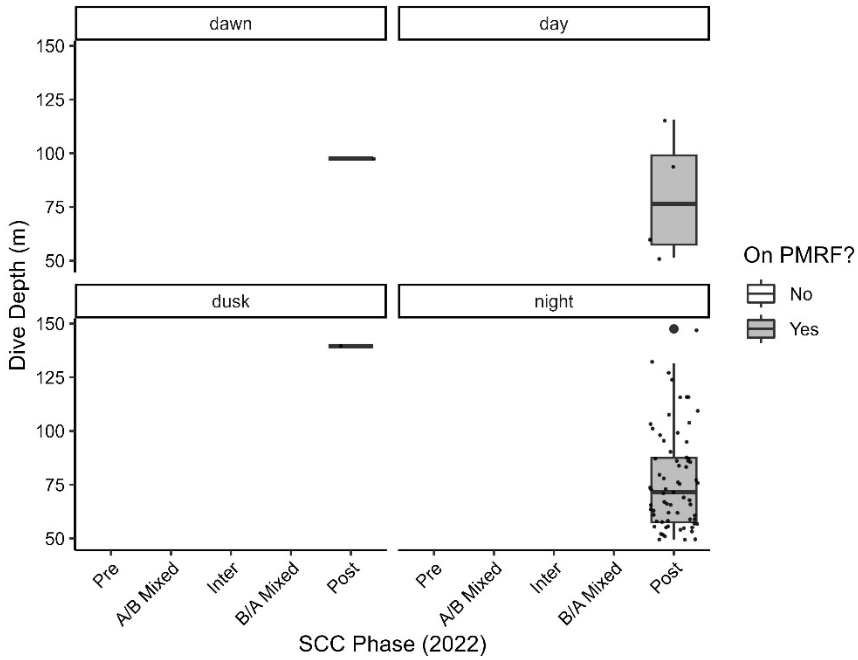
Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dawn dive rate (dives/hour)							
SbTag023	NA	0.00	0.00	0.77	NA	-	
SbTag025	NA	NA	NA	NA	0.38	-	
% time in surface periods at dawn							
SbTag023	NA	100.00	100.00	97.89	NA	-	
SbTag025	NA	NA	NA	NA	98.65	-	
Median dive depth dawn (m)							
SbTag023	NA	NA	NA	85.50	NA	NA	NA
SbTag025	NA	NA	NA	NA	97.50	NA	NA
Median dive duration dawn (min)							
SbTag023	NA	NA	NA	1.65	NA	NA	NA
SbTag025	NA	NA	NA	NA	2.13	NA	NA

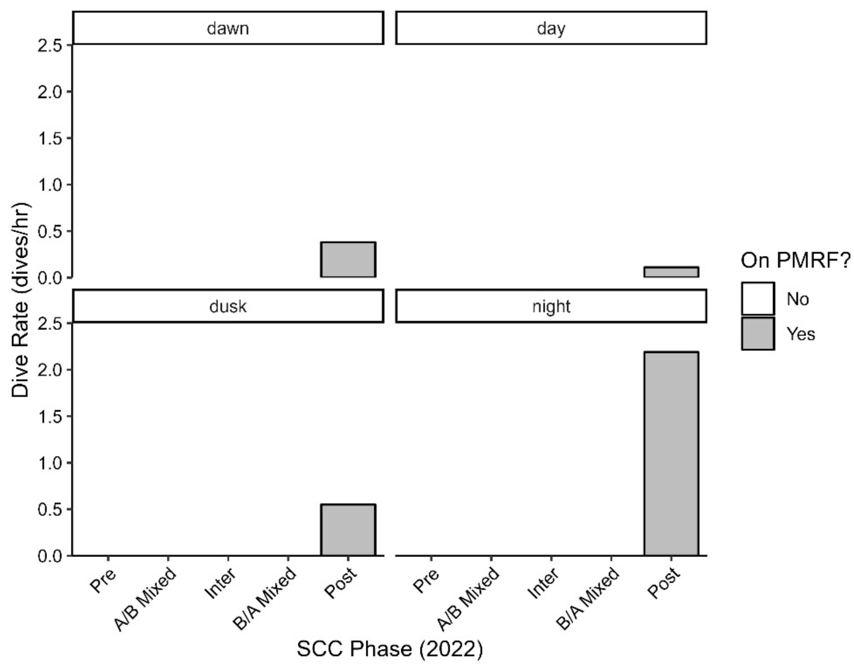
- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

Table A-7. A comparison of dusk diving parameters from rough-toothed dolphins exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dusk dive rate (dives/hour)							
SbTag023	NA	1.90	0.28	0.00	NA	-	
SbTag025	NA	NA	NA	NA	0.55	-	
% time in surface periods at dusk							
SbTag023	NA	85.66	98.32	100.00	NA	-	
SbTag025	NA	NA	NA	NA	95.65	-	
Median dive depth dusk (m)							
SbTag023	NA	131.50	147.50	NA	NA	0.6547	NA
SbTag025	NA	NA	NA	NA	139.50	NA	NA
Median dive duration dusk (min)							
SbTag023	NA	5.17	3.67	NA	NA	0.6547	NA
SbTag025	NA	NA	NA	NA	4.77	NA	NA

- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.





- Top: Boxplot showing dive depths of SbTag025 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of SbTag025 by SCC Phase and time of day.

Figure A-4. SbTag025 boxplot and barplot dive depths.

SbTag024

Information was available about SbTag024's movements in 2021 for Before (2.3 days), Phase A (1.7 days), and the Interphase period (0.5 days). During this time, SbTag024 spent most of its time on the range, though the deployment duration did not overlap with any potential MFAS exposures.

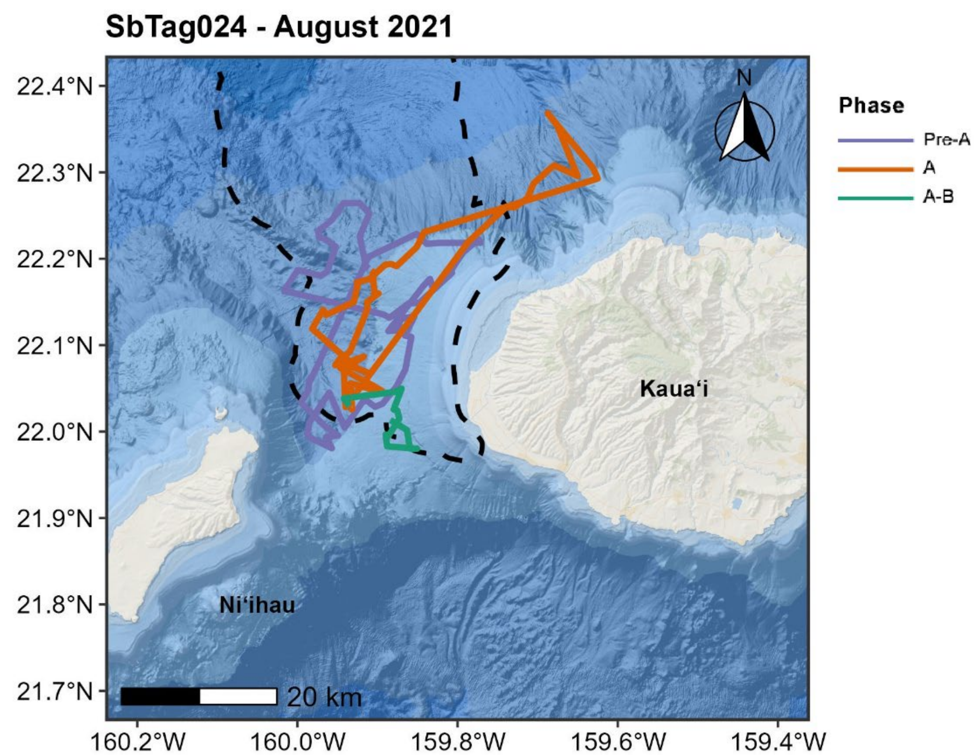


Figure A-5. Map showing crawl model trackline of SbTag024 during the 2021 August SCC.

SbTag025

Information was available about SbTag025's movements in 2022 for a very short part of the interphase (0.01 days), the B/A mixed phase (0.2 days), and the After phase (7.3 days). During this time, SbTag025 remained on or near the range. This individual was not exposed to MFAS.

Dive behavior data were available for SbTag025 for only the B/A mixed phase and the after phase. However, when broken down by time of day and phase, only the After phase data met the required coverage (relative to the phase duration) for inclusion in the dive analysis, and hence this tag was given no further consideration in the dive behavior analysis.

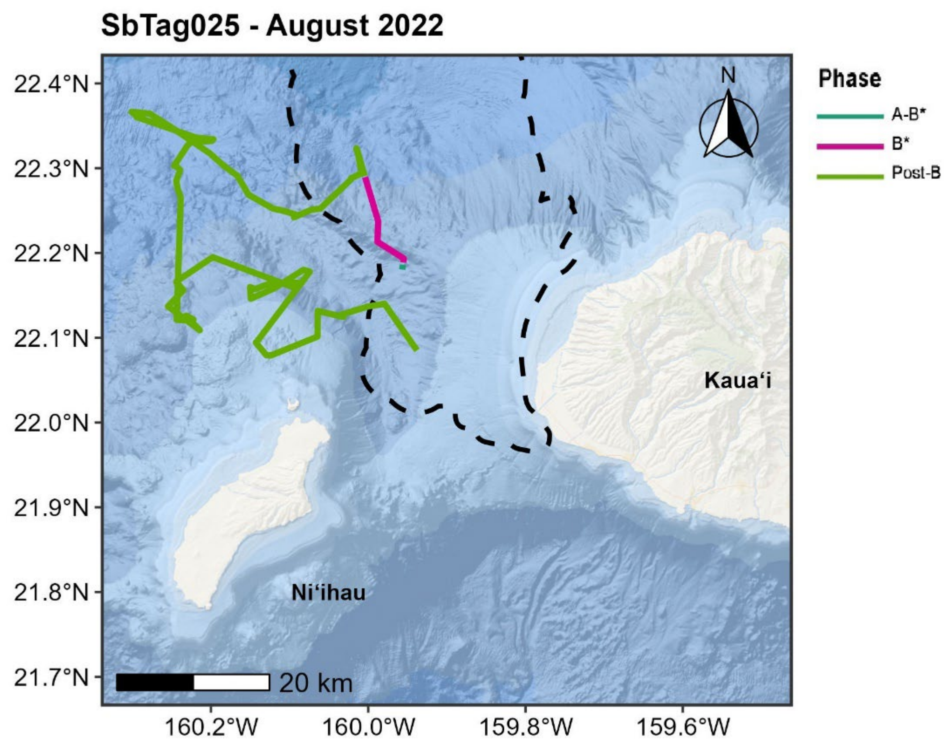


Figure A-6. Map showing crawl model trackline of SbTag025 during the 2022 August SCC. This individual was not exposed to Navy activities.

Common bottlenose dolphins

Table A-8. A comparison of dawn diving parameters from common bottlenose dolphins exposed to MFAS for phases that meet the required coverage cutoff.

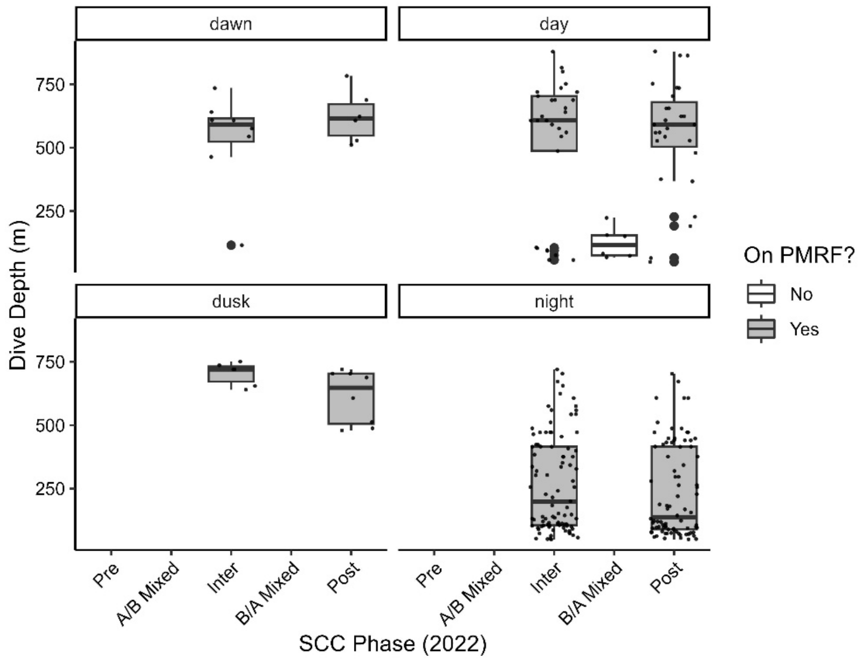
Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dawn dive rate (dives/hour)							
TtTag041	NA	NA	2.92	NA	2.35	-	
% time in surface periods at dawn							
TtTag041	NA	NA	54.69	NA	55.94	-	
Median dive depth dawn (m)							
TtTag041	NA	NA	591.50	NA	615.50	0.4366	NA
Median dive duration dawn (min)							
TtTag041	NA	NA	10.30	NA	11.10	0.0933	NA

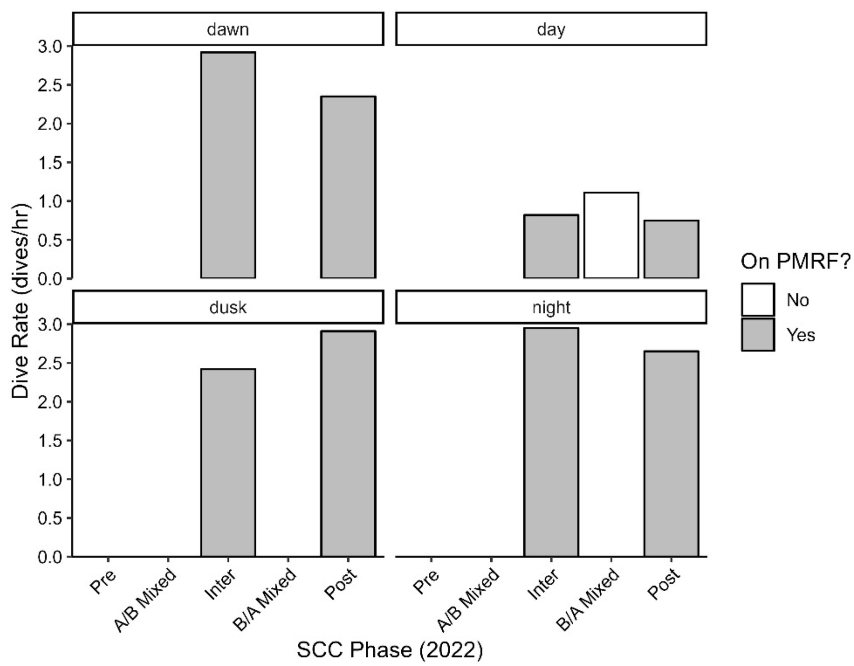
- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.

Table A-9. A comparison of dusk diving parameters from common bottlenose dolphins exposed to MFAS for phases that meet the required coverage cutoff.

Dive parameter per individual	Before	Phase A	Interphase	Phase B	After	Kruskal-Wallis Test p-value*	Post-hoc Dunn's test significant pairs
Dusk dive rate (dives/hour)							
TtTag039	NA	NA	2.47	NA	NA	-	
TtTag041	NA	NA	2.42	NA	2.91	-	
% time in surface periods at dusk							
TtTag039	NA	NA	74.61	NA	NA	-	
TtTag041	NA	NA	53.35	NA	51.89	-	
Median dive depth dusk (m)							
TtTag039	NA	NA	327.50	NA	NA	NA	NA
TtTag041	NA	NA	719.50	NA	647.50	0.0515	NA
Median dive duration dusk (min)							
TtTag039	NA	NA	6.50	NA	NA	NA	NA
TtTag041	NA	NA	11.55	NA	10.53	0.0707	NA

- Kruskal-Wallis one-way ANOVA significant results (i.e., significant differences among phases were detected) are shown in bold. Pairs of phases where significant differences were detected are listed in the associated post-hoc Dunn's test column (level of significance: 0.05). Values for dive rates and percentage time in surface periods represent single values for each individual for each period; thus, no statistical testing was undertaken.





- Top: Boxplot showing dive depths of TtTag041 by SCC Phase and time of day.
- Bottom: Barplot showing dive rates of TtTag041 by SCC Phase and time of day.
- Maximum estimated RL from MFAS for this individual was 100.5 dB.

Figure A-7. TtTag041 boxplot and barplot dive depths.

TtTag041

Information was available about TtTag041’s movements in 2022 for the interphase period (3.0 days), the B/A mixed phase (0.2 days), and the after phase (13.8 days). TtTag041 was deployed on the range during the interphase period, then moved to the east side of Kaua‘i, where it spent the duration of the B/A mixed phase, then continued to circumnavigate the island by moving southwest and back onto the range.

Dive behavior data were available for TtTag041 for the interphase period, the B/A mixed phase, and the After phase. However, when broken down by time of day and phase, not every time of day and phase met the required coverage (relative to the phase duration) for inclusion in the analysis. Coverage was sufficient for the Interphase and After phase for each time of day, as well as for daytime during the B/A mixed phase.

The dawn dive rate was highest during the Interphase and dropped slightly in the After phase, while the percentage of surface time during dawn hours remained fairly consistent between the two phases. There was no statistically significant variation between phases for dawn dive depths or durations.

The day dive rate was highest during the B/A mixed phase and lowest during the After phase, while the percentage of surface time during day hours remained fairly consistent between phases. Day dives were significantly shallower and shorter during the B/A mixed phase than during either the interphase or after phase.

The dusk dive rate was highest during the after phase, and the percentage of surface time during dusk hours remained fairly consistent between the two phases. There was no statistically significant variation between phases for dusk dive depths or durations.

The night dive rate was highest during the interphase, and the percentage of surface time during night hours rose slightly during the After phase. There was no statistically significant variation in night dive depth between phases, but night dives were significantly shorter during the After phase than during the Interphase.

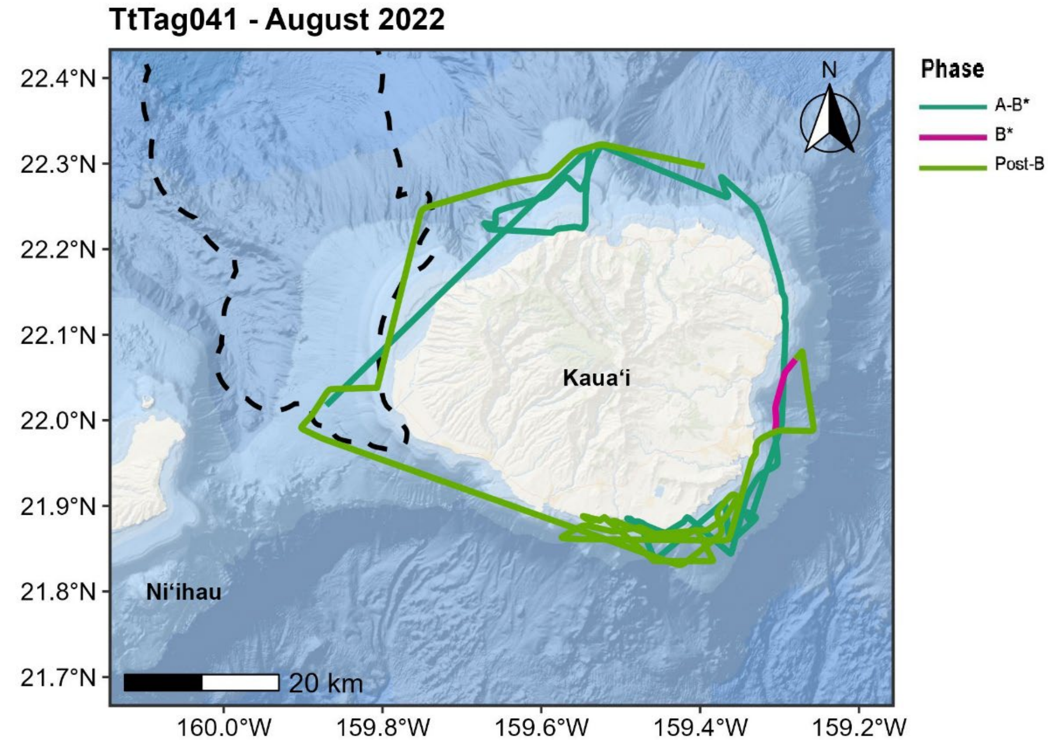


Figure A-8. Map showing crawl model trackline of TtTag041 during the 2022 August SCC. This individual was not exposed to Navy activities.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-01-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
August 2024	Final	

4. TITLE AND SUBTITLE

Received Level Estimation, Behavioral Response, and Diel Behavior Analyses for Delphinids Tagged at the Pacific Missile Range Facility in 2021-2022

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHORS

E. Elizabeth Henderson, Ph.D.
Cameron Martin
NIWC Pacific

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

Steve W. Martin
National Marine Mammal

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NIWC Pacific
53560 Hull Street
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-3353

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Commander, U.S. Pacific Fleet
250 Makalapa Drive
JBPHH, HI 96860-3131

10. SPONSOR/MONITOR'S ACRONYM(S)

COMPACFLT

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report summarizes the results of satellite-tagging efforts conducted before Submarine Command Course (SCC) training events at the Pacific Missile Range Facility (PMRF) near Kaua'i. Researchers tagged 21 delphinids to observe their behavior before, during, and after the SCCs to estimate received levels of mid-frequency active sonar (MFAS). Fifteen animals remained in the area or traveled between their locations and the sources of MFAS from surface ships. These animals included six short-finned pilot whales, one false killer whale, five melon-headed whales, one rough-toothed dolphin, and two common bottlenose dolphins. Analysis of the data involved smoothing animal tracks, calculating the 95% confidence error ellipse, and modeling transmission loss in three dimensions to estimate the received level at the whales' positions. Researchers examined dive behavior variables during different times of day and SCC phases to determine if there were any changes related to training activity or MFAS. The combined data, along with information from previously tagged or photo-identified animals from Kaua'i and other Hawaiian Islands, provides a basis for understanding the long-term consequences of exposure at the population level and for identifying the impact of repeated exposures.

15. SUBJECT TERMS

satellite tagging, odontocetes, Pacific Missile Range Facility, MFAS, behavioral response, received levels

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	SAR	126	E. Elizabeth Henderson, Ph.D.
					19b. TELEPHONE NUMBER *(Include area code)* (619) 553-5067

Standard Form 298 (Rev. 10/17)
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