Integrating remote sensing methods to measure baseline behavior and responses of social delphinids to Navy sonar

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Award Number: N00014-17-1-3132 (to SEA; see note below)
http://sea-inc.net/2017/10/06/tagless-brs-from-the-field-update/

NOTE: This project involves a close collaboration among researchers from SEA, NOAA Fisheries Southwest Fisheries Science Center (SWFSC), Cascadia Research Collective (CRC), and Kelp Marine Research (KMR). The ONR grant referenced was issued to SEA and includes subcontracts to CRC and Kelp. Additional support through smaller parallel awards for the project was provided under three separate ONR awards issued to SWFSC (PI: Dr. John Durban - N00014-18-IP-00021), CRC (PI: John Calambokidis – N00014-17-1-2887), and the Naval Undersea Warfare Center (NUWC; PI: David Moretti (Stephanie Watwood now POC) - N0001418WX01327. This annual report for the overall project is intended to serve as the annual report for each of these awards.

A separate ONR award to SWFSC (PI: Dr. Nick Kellar) to investigate potential physiological stress responses to noise was coordinated with this project following discussions with the ONR Marine Mammal Program Manager. This coordination is described here, but a separate annual report for this project is being submitted.

LONG-TERM GOALS

I. Develop *integrated* methods to simultaneously track group movement/behavior using shore- or vessel-based *visual observers*, *aerial photogrammetry*, and remote-deployed *acoustic recorders*.

II. Apply group-sampling methods using integrated technologies to better characterize typical (undisturbed) behavioral parameters.

III. Obtain direct measurements of group behavioral changes and stress hormone responses in these delphinids, if any, resulting from experimentally controlled, simulated Navy mid-frequency active sonar.

OBJECTIVES

This report summarizes the second field season and reviews accomplishments of this proof-of-concept project to test and evaluate the integration of various remote sampling methods to study the baseline behavior and behavioral response of small delphinid cetaceans without the use of tag sensors placed on individuals. Our overall objective is to quantify fine-scale aspects of behavior in fast, ephemeral, large group, social species that have proven difficult to study with tag-based methods. Given the completely novel nature of this approach for studying group behavioral dynamics using an integration of some established and some new and evolving methods, the broad objectives for this pilot project were relatively straightforward. Essentially, we aimed to: 1) determine whether and under what conditions we could realistically apply these methods to address these questions for the focal species in quest and, if so; 2) adapt and apply methods in conducting controlled exposure experiments (CEEs) with and without Navy mid-frequency active sonar (MFAS) to begin to evaluate the nature of potential responses, none of which have ever been directly tested in these species. Building on the very successful first field season (two field periods – Spring and Fall 2017) in which we proved the concept of obtaining behavioral and physiological data from three delphinid species within the southern California research area, we sought to continue to move forward on both priorities (but most notably the second) during field effort in the second field season (one field period – Spring 2018). Specifically, our objective for this field effort was to (1) continue to learn from and adapt our approaches based on lessons-learned and (2) to strategically add to our sample size of CEEs with simulated MFAS for which behavioral and physoilogical data were collected.

APPROACH

The approach taken in the 2018 field effort was essentially the same as what we pioneered during the first phases of this pilot effort and described in our 2017 annual report. We describe the basic approach here with additional details on progress largely related to our analytical approaches. Our derivation of field methods for this effort built upon related field work with delphinid species that our team has been involved in with previous ONR and other Navy supported behavioral response studies in southern California (see: Southall *et al*., 2013; 2019b) and successful related studies in the Azores. With these experiences and other field efforts using unmanned aerial systems (UAS) described below, during the 2017 field season we developed, evaluated, modified, and successfully implemented a novel integration of sampling methods to quantify behavior in several smaller delphinid species (common dolphin (*Delphinus delphis* and *Delphinus capensis*), bottlenose dolphin (*Tursiops truncatus*), and Risso's dolphins (*Grampus griseus*), which are given in specified priority order. This integration was designed to enable the measurement of both baseline behavior as well as the evaluation of potential responses to simulated MFAS using controlled exposure experiments CEEs. For the 2018 season, we essentially applied the integrated approaches to increase sample size, but continued to improve upon and increase the processing efficiency of some analytical methods.

These oceanic delphinids are generally not endangered, nor have they been observed in mass-stranding events associated with Navy sonar, but these taxa include some of the most common protected marine mammal species exposed to sonar in high numbers in some Navy operational areas. Consequently, they represent a large proportion of predicted negative effects of sonar operations (*e.g*., behavioral harassment) for many Navy environmental compliance assessments. Their response probabilities have been inferred from laboratory measurements and/or from anecdotal field observations in uncontrolled contexts, each of which have significant limitations. Within this pilot project, we developed innovative methods to measure both broad and fine-scale group and individual observations and conduct the first-ever experimental behavioral response studies.

The nature of the resulting data are categorically different from previous response studies involving tagging of single individuals. Beyond the fact that maintaining attached tags on individuals of these species for hours to days has proven infeasible to date, these social species typically occur in groups and group members likely interact in their response to external stimuli (Visser *et al*., 2014; 2016). As such, the group, or part of the group, is likely a particularly relevant unit of behavioral analysis, in addition to individual behavior of one or a few group members. We are explicitly identifying group behavioral state in evaluating potential responses to disturbance, although it is acknowledged that our methods are likely most effective for documenting near-surface social interaction and group behavior rather than studying sub-surface feeding behavior. The identification of behavioral state as a relevant contextual covariate in marine mammal behavioral response probabilities is clearly important (*e.g.*, Southall et al., 2016; 2017; 2019a) and is being explicitly considered within response analyses.

The field methods applied in measuring behavior involve a completely novel combination of shore- and vessel-based visual sampling, unmanned aerial systems (UAS) for aerial photogrammetry, and remote-deployed passive acoustic sensors to document specific aspects of baseline (undisturbed) behavior and potential responses during CEEs involving either no sound transmissions (control sequences) or MFAS exposure from a simulated 53C sonar source used in previous CEEs for the SOCAL-BRS project (Southall *et al*., 2012; 2019). Physiological samples are obtained using standard field sampling methods, but at strategic times during control periods or following known noise exposure during CEEs.

Overall Field Configuration

Field operations occured from three different vessel platforms, as well as a shore-based visual observer team. Vessel platforms include:

- *M/V Magician* (20 m recreational dive boat with home port in San Pedro, CA; http://magicianscuba.com/): serves as centralized/base vessel for at-sea team; UAS base of operations; visual observation platform

- *RHIB Musculus* (Cascadia Research 7.33 m Hurricane): serves as sound source vessel for MFAS CEEs; primary photo ID/biopsy sampling option; visual observation platform

- *RHIB Ziphid* (Cascadia Research 5.9 m Hurricane): PAM base of operations; visual observation platform; secondary photo ID/biopsy sampling option.

- *Shore-based visual team*: The shore-team was based at the Wrigley Institute (UCS) on Catalina Island and was mobile in operations to allow two observation locations (see map below: east-facing Wrigley Station; west-facing Indian Head harbor observer station). On several occassions when animals were further from either observation station, members of the shore-based visual team were pulled onto the Magician to conduct behavioral observers from a boat-based observer platform. This was done strategically on multiple occassions in 2018 off the south side of Catalina in areas that were more acoustically isolated from the two shore-based field sites in order to provide additional operating areas with less habituation of animals in those areas as well as to operate in areas closer to sonar use areas for a possible follow-on phase of this experiment with operational Navy sonars.

Behavioral Data Collection Methods and Protocols

Group-level behavioral observations were obtained using visual observeration, photogrammetric and passive acoustic methods. The behavior of small delphinids can be challenging to study, because of large group sizes, dynamic aggregations and fast and fluent movement patterns. Given these characteristics, even moderate duration (>10 min) tracking of a specific individual or even a clearly defined group, within a larger aggregation is practically impossible using conventional tagging, visual observations or acoustic tracking alone. Therefore we developed in the 2017 season and applied in 2018 a cross-disciplinary, integrated approach to study larger (up to several hundred individuals) aggregations and group dynamics. Our novel behavioral approach consisted of three complementary data collection systems to measure aspects of baseline behavior and quantify responses to MFAS signals projected during controlled exposure experiments using a vertical line array sound source. These data collection systems include:

1. Shore- and vessel-based visual sampling;
2. Unmanned aerial systems (UAS) for photogrammetry;
3. Remote-deployed passive acoustic sensors;
4. Biopsy sampling to obtain samples at strategic times following noise exposure as part of the companion physiological/stress response study.

Some of the methods and remote sampling technologies described in this proposal are well established (*e.g.*, visual sampling; PAM), while others (*e.g.*, aerial photogrammetry of group characteristics from UASs) have been more recently developed and are continuing to evolve. However, their integration to study baseline behavior and potential behavioral responses of groups of any free-ranging cetaceans within CEEs is completely novel. Many of the initial steps relating to Objectives I and II relate to the development of the integrated data collection and analysis required to evaluate the feasibility and potential limitations of reliably measuring group responses for species in which behavior may commonly change quickly and regularly. Again, these were largely developed, tested, and adapted in the first year of this pilot effort and were largely applied within the field period reported here to increase sample size.

Shore-based visual team

Our shore team conducted broad-scale visual monitoring with theodolite/binoculars to track both entire groups and sub-groups for periods of up to several hours. Observations were conducted from elevated cliffs on Catalina Island, specifically near Two Harbors, Catalina harbor, and at the Indian Head station in areas where all three focal species regularly occur close to shore. The shore-based team consisted of 4 observers to conduct visual observations with high-power binoculars, spotting scopes, and record locations using theodolites. A data recorder archived information of both types in custom tracking software. Target groups were located using survey effort, scanning the research area until a suitable group had been located. In some cases, shore-based tracking observations during CEEs were infeasible, (*e.g.*, due to lack of target species in the research area) and a portion of the shore team moved offshore to conduct comparable visual focal follow observations from one of the research vessels.

Visual observations were made at two different spatial resolution scales: coarse scale (recording behaviora metrics at level of the whole group), and fine-scale, recording detailed movement metrics of a part of the group. Visual observers recorded both types of observations from the observation platform, with sampling methods designed to complement the spatial resolution of photographic measurements from the UAS. Shore-based focal follows consisted of relatively brief (30-60 minute) visual tracking of a target groups, in comparable time windows either completely without exposure (baseline behavior), or during CEEs. Two observer-modes were used to collect data on two different scales: 1) traditional focal follow observations and 2) novel group-movement tracking. Focal follow observations were conducted with an experienced observer tracking the behaviour of the entire group, where possible. During focal follows, the following parameters were recorded each minute: group size, spread, clustering, synchrony of movement (within-group directionality) and presence/absence of behavioral events (*e.g.*, breaches). Focal follow tracking provides data at relatively coarse scales, identifying the degree of aggregation, synchrony and cohesion at the level of the group. Conversely, fine-scale observations of movement and behaviour were recorded with theodolite tracking, providing a comparable level of spatial resolution to UAS photogrammetry at higher elevations.

Tracking the movement of commonly fast-moving, gregarious and diving animals is challenging and precludes the use of several traditional movement tracking techniques (*e.g.,* longer-term tracking of one individual or smaller group). We therefore developed novel methods relying on many consecutive but short tracks of nearby small groups within the larger target group. Observers tracked one individual or a small clustered group of individuals for at least three consecutive location records, then shifted to a nearby individual or small group. This procedure was repeated until the end of the observation. For each short track, the following parameters were calculated: group direction, speed (mean ± SD) and directionality. Together, the individual short tracks show the overall movement pattern of the group over the course of the follow. Location records within one short track were sampled at regular, short intervals (<1 minute). The aim and purpose of this method was to test the potential to record small delphinid movements quantitatively and reliably for longer periods, which was evaluated within the context of the higher resolution UAS data obtained for a portion of the group.

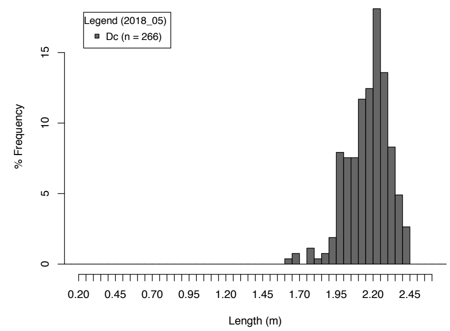
Aerial UAS photogrammetry

Recent advances in the use of small unmanned aerial systems (UAS) offer new opportunities to augment traditional visual observations. Some of these earlier applications have involved relatively larger fixed-wing vehicles, but new technologies with smaller aircraft are now facilitating a wider range of practical applications. Durban et al. (2015, 2016) described the successful use of a small (22 inch across), unmanned hexacopter (APH-22; Aerial Imaging Solutions) to obtain high-resolution photographs to measure whales at sea, including blue whales (Durban et al. 2016). The utility of this UAS system has recently been extended by the use of larger 28” hexacopter (APH-28) and 42” octocopter (APO-42) that have similar flight, telemetry and photographic systems but enable more stable flight in higher wind conditions, provide greater visibility for longer range flight missions and can carry multiple lithium polymer batteries to enable flights >30 minute duration. These multi-copter platforms can be safely hand-deployed and recovered on boats. A Micro Four-Thirds system camera captures images with a ground-resolved distance of <1.4 cm to 2cm (from an altitude range of 30 to 60m, respectively) across the entire flat and undistorted field of view. An onboard laser altimeter enables measurements in pixels to be scaled to true size with an average accuracy of ~2cm from 60-30m, respectively. Images are consequently sharp enough to differentiate individual animals and resolve differences in individual morphometrics.

We successfully used this UAS system to complement shore- and vessel-based visual survey teams and to provide high-resolution measurement of individual and group movement behavior in studying the normal behavior and potential responses to sound of all three focal delphinid cetaceans. Such integration with conventional visual sampling and PAM methods (discussed below) in measuring the dynamic behavior of small, potentially fast-moving groups of cetaceans in the field has not been previously conducted. A significant component of this project, particularly in the spring field effort simply lied in the testing, evaluation, and application of these new methods as tools to empirically document aspects of behavior in unique ways. Initial deployments evaluated the appropriate elevation for different types of spatial resolution on focal groups in complementing visual survey data.

UAS operations from the M/V Magician, showing hand-deloyments and catches of the APO-42 Octocopter.

Higher-altitude photogrammetry (45-60m) provided images for the quantification of spatial distribution, cohesion, movement speed, and movement synchrony of at least one defined subgroup within the larger group that was being tracked by shore-based focal follows. Lower-altitude photogrammetry (30-45m) enabled higher-resolution photogrammetry measurements of the length of the target animals (see Durban *et al*., 2015, 2016). Individual morphometrics were collected to describe the size structure of the focal UAS sub-group: length will be related to age using published length/age relationships for each species. Inference about age class may ultimately be used as key covariates for controlling and interpreting behavioral differences between groups and potential responses to sound.



Passive acoustic monitoring

Passive acoustic recordings were obtained using drifting, remote-deployed Loggerhead SNAP recorders with HTI-96 hydrophones (48 kHz sampling rate; flat frequency response in range of dolphin sounds) suspended to a depth of 10 m under shock-mounted surface floats with GPS tracking devices. High capacity (256 GB) flash memory allow continuous acoustic sampling and rapid offloading of large volumes of acoustic data. Three separate PAM recorders were strategically-placed and recovered from either RHIB *Ziphid* (in alsmost all instances) or from the *Magician* within the observation area based on the behavior and direction of travel of the focal group.

Group vocal activity, including call presence/absence, call type, and measurements of call rates, were determined from PAM recordings using standardized methods and multiple observers blind to experimental conditions in order to obtain broad-scale metrics of vocal behavior and potential responses to sound exposure by comparing control and experimental (exposure) periods. We have also been working with colleagues at the University of St. Andrews on a baseline assessment of differences in call characteristics between short- and long-beaked common dolphins. These differences are not documented within the scientific literature for these species. While this is not a primary focus of our analysis, through these research collaborations, this project has provided some important data from voucher samples of high signal-to-noise ratio recordings that are being analyzed and will be published, significantly advancing the field of bioacoustics and the ability to distinguish these species in acoustic monitoring efforts by the Navy and others.

Photo-ID

Photo-identification of individual animals was conducted outside the behavior sampling period (primarily during approaches for biopsies, see below), to help document the group/individuals present. This can be an effective method for tracking individuals, especially for bottlenose and Risso's dolphins, and cataloging the individuals that use these waters. This information is important to determine where observations or playbacks involve the same group of animals in multiple experiments, which was done on several occassions. While less effective for common dolphins, as opposed to bottlenose and Risso's, this was useful in some cases for this species as well. Photo-ID was also used document the individuals biopsied although again this will be most effective for bottlenose and Risso's dolphins.

Biopsy sampling

Biopsy samples were collected using conventional methods (small cross-bows) during either non-CEE periods or at variable times post-exposure following CEEs from groups of animals known to be exposed to MFAS. Post-sampling commenced not earlier than 30 min following CEEs and occurred at variable intervals (not continuously) for up to approximately 3h post sound exposure. Additional details of the sampling and analytical methods for biopsy sampling are provided in the parallel annual report from Dr. Kellar.

CEE Protocols

Methods for conducting controlled exposure experiments (CEEs) using the behavioral sampling methods described were generally similar to those used in SOCAL-BRS (see Southall *et al*., 2012; 2019a; 2019b). Given the generally transient nature of these species and the limited areas that can likely be effectively monitored from a fixed shore station and a limited number and acoustic recorders, and given the desire to track individuals within a single UAS flight, the overall time scale of CEEs was reduced in time relative to the tagged animal exposures in SOCAL-BRS to 10-min pre-exposure, exposure (or control), and post-exposure periods; total CEE sequences were thus 30-min in total duration.

The simulated MFAS source deployed from the RHIB *Musculus* is the same as used in SOCAL-BRS. Signals consisted of a 1-s total duration sequence of three tonal and frequency modulated elements from 3.5-4 kHz repeated on a 25-s duty cycle. Signals were transmitted for a maximum total of 10-min (24 total pings) provided that no permit-mandated shut-downs occurrred for animals occurring too close (within 200m) of the active sound source; this occurred on two occassions in 2018. No experimental ramp-up of source levels was used for this project - all exposures occur at a constant level (212 dB re: 1uPa). The absence of an experimental ramp-up is more representative of realistic Navy sonar sources. All experimental protocols and mitigation requirements (*e.g.*, source shut-down for any marine mammal coming within 200m of the source when active) were identical to those used in SOCAL-BRS (see Southall et al., 2012; 2013; 2019a; 2019b) and were consistent with all requirements of NMFS permit #19116 to B. Southall. Prior to CEEs, sources were positioned at a range determined from *in situ* propagation model estimates of 130-160 dB re: 1uPa received levels at the focal group.

WORK COMPLETED

2018 FIELD EFFORT: SYNTHESIS AND ACCOMPLISHMENTS (Logistics and Methodology):

- Weather conditions were workable for at least part of all days, with no major storm events. Some conditions limited sighting for shore-based teams (fog/clouds) and on-water conditions such as typical afternoon winds meant that most field effort and CEEs occurred in the mornings.
- Animal sightings on both east and west side operational areas off the north end of Catalina continued to be excellent with regular sightings of workable groups of all three species with observation stations adapted to multiple locations
- We continued to have successful coordination and field operations using the *M/V Magician* and had successful radio communications and coordination across research teams on four platforms.
- Wrigley Institute continued to serve as an excellent base of operations for the shore visual observation team station and mooring all research boats most nights
- Good interactions with interested local parties regarding the project to provide information publicly, including the Catalina Island Company (owns the land for Two Harbors (east side) visual station) and Catalina Island Conservancy**.**

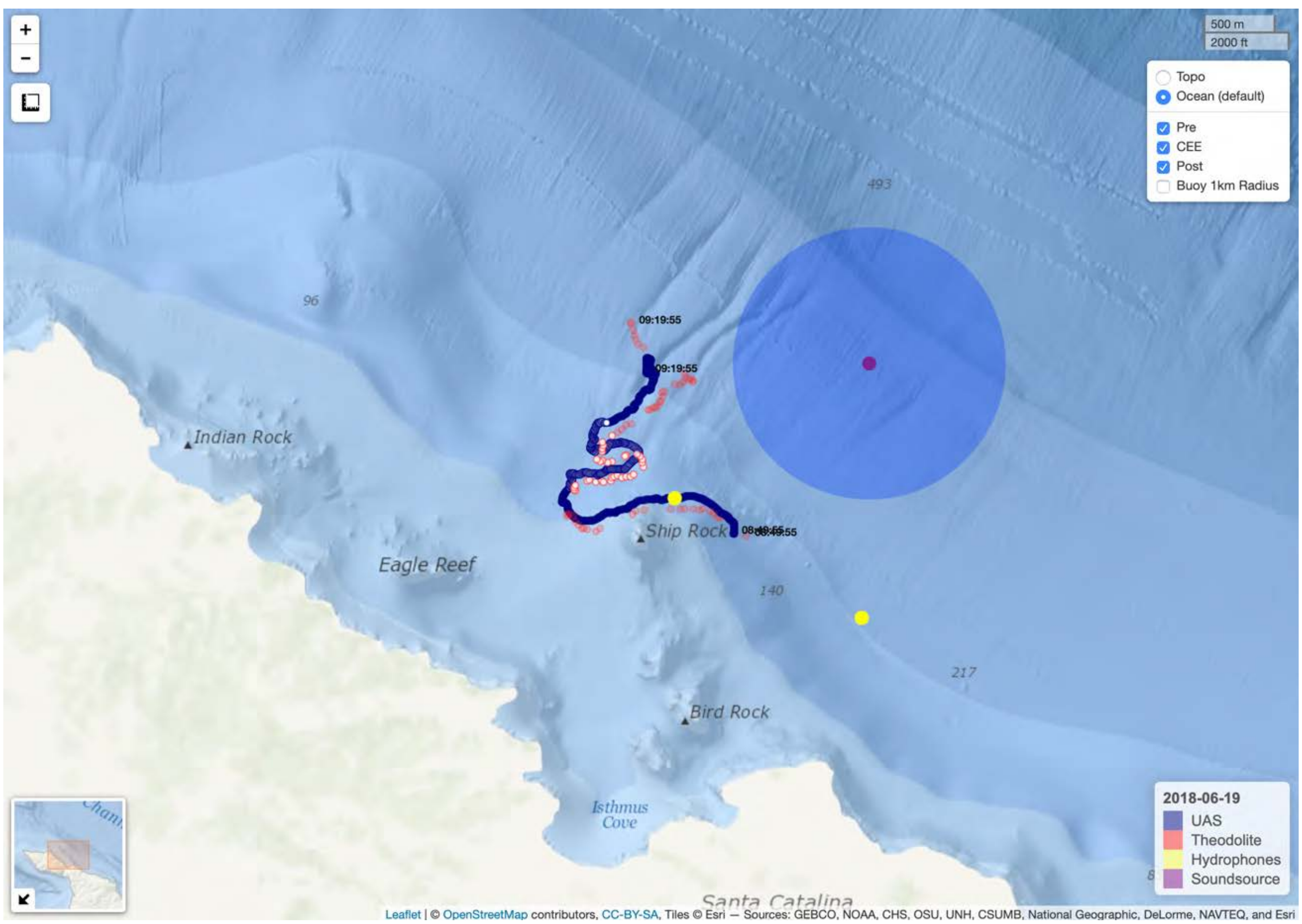
2018 FIELD EFFORT: SYNTHESIS AND ACCOMPLISHMENTS (Research Achievements):

- Applied field methods developed in 2017 within defined experimental and exposure contexts to extend sample sizes of MFAS CEEs for common, bottlenose, and Risso's dolphins
- 11 total CEE sequences (6 MFAS; 5 control) with long-beaked common dolphins (4 MFAS; 1 control), bottlenose dolphins (1 MFAS; 2 control), and Risso's dolphins (1 MFAS; 2 control)
- Safe, successful UAS flights completed for three focal species:
  - *16 total flights (7 common dolphin, 5 bottlenose dolphins, 4 Risso's dolphins)*
  - *50,000+* calibrated photo images collected across all focal species
  - Extensive and complex analytical effort
- > 30 successful theodolite tracks and focal group behavioral sampling from shore-based visual team for all three species. Fog/haze were limiting for some periods and groups too far offshore on west side, but successful transition of behavioral focal follows to vessel-based platform with focus in areas off southern side of Catalina
- Calibrated acoustic recordings of animal vocalizations and MFAS obtained with multiple PAM buoys all CEE sequences. Analysis is complex and challenging, but progressing well.
- >100 successful biopsy samples obtained for common and bottlenose dolphins; most following known noise exposure at strategically-selected post-exposure periods

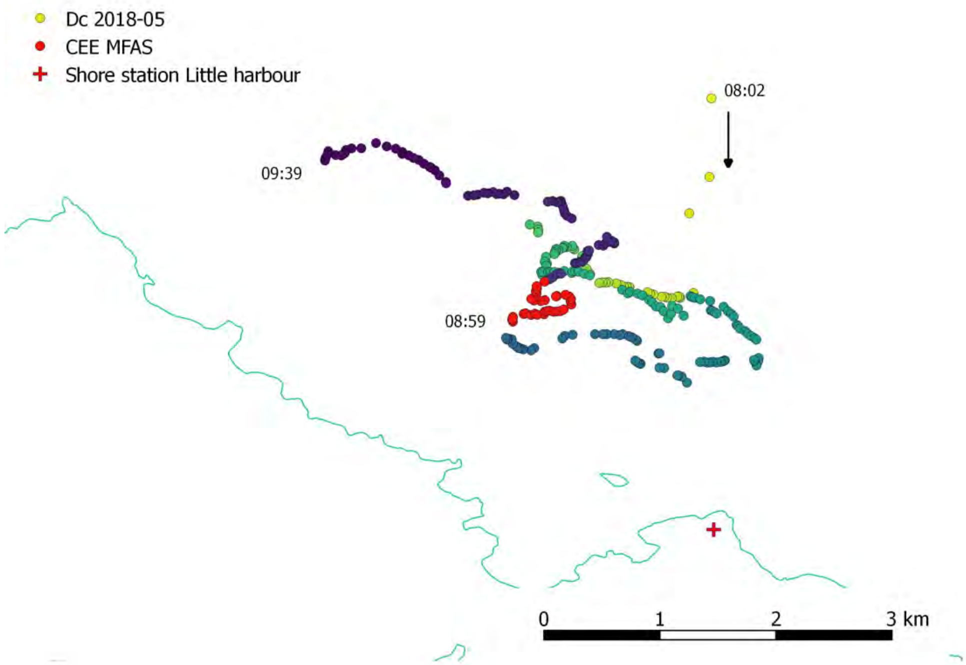
RESULTS

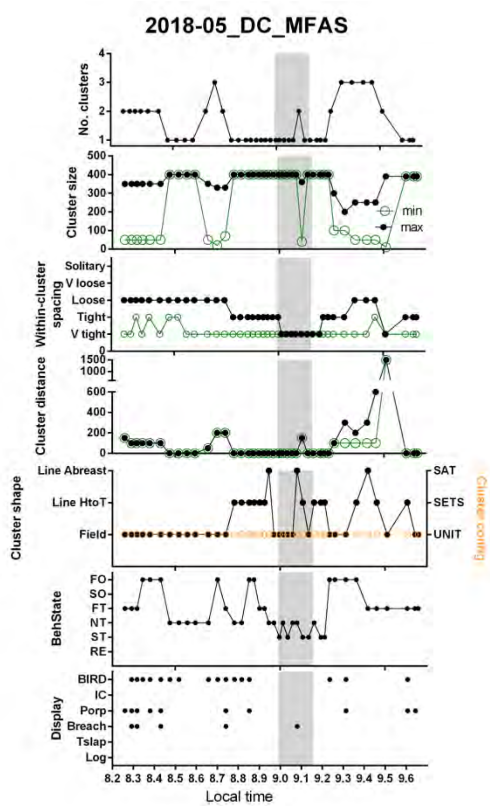
We documented baseline (undisturbed) group behavior of three delphinid cetacean species and quantified behavioral responses (using visual, photogrammetric, and acoustic methods) and physiological responses (using biopsy sampling) to MFAS in CEEs that more than doubled our sample size from 2017. As a pilot study designed to develop and evaluate these methods and provide initial behavioral response data to guide dedicated BRS' within species, this study was not expected to provide complete and definitive response results. We accomplished the development of methods and across both years conducted 20 total CEEs within these four species, which was substantially more than originally envisioned. Here we provide examples of detailed behavioral measurements that were obtained from each sampling platform for a selected CEEs in order to illustrate the nature of the analyses and also to demonstrate progress in analytical methods for all data types.

Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal
MFAS CEE 2018_05 (19 June 2018)
ALL METHODS (Integrated Map)

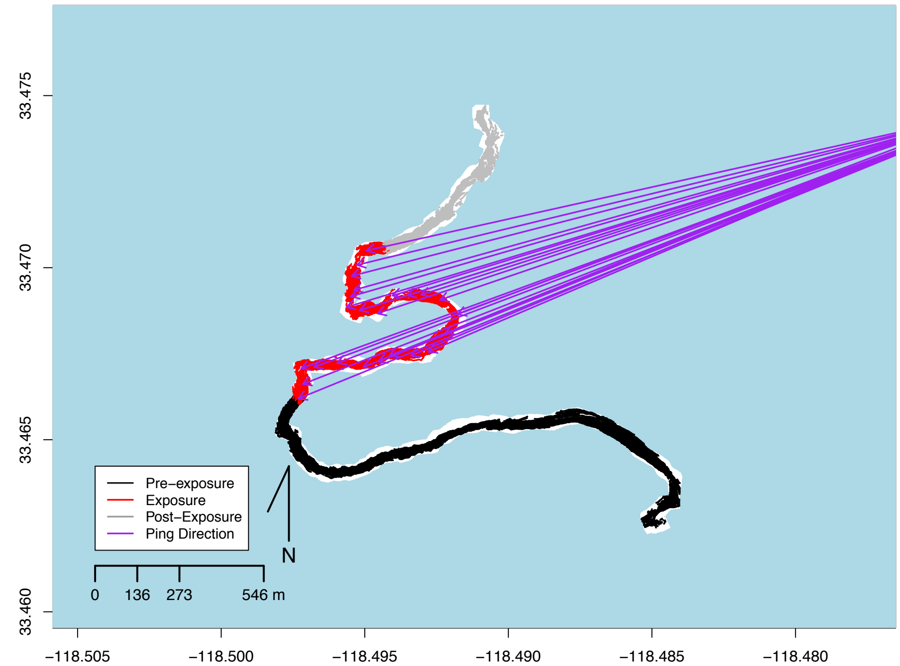


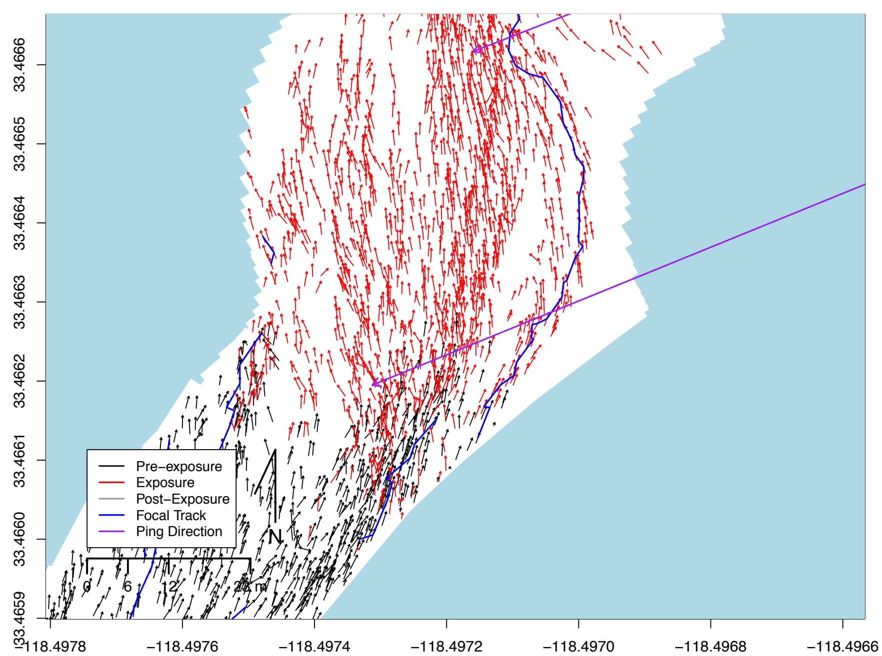
Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal
MFAS CEE 2018_05 (19 June 2018)
SHORE-BASED VISUAL SAMPLING (Theodolite; Group Behavior)



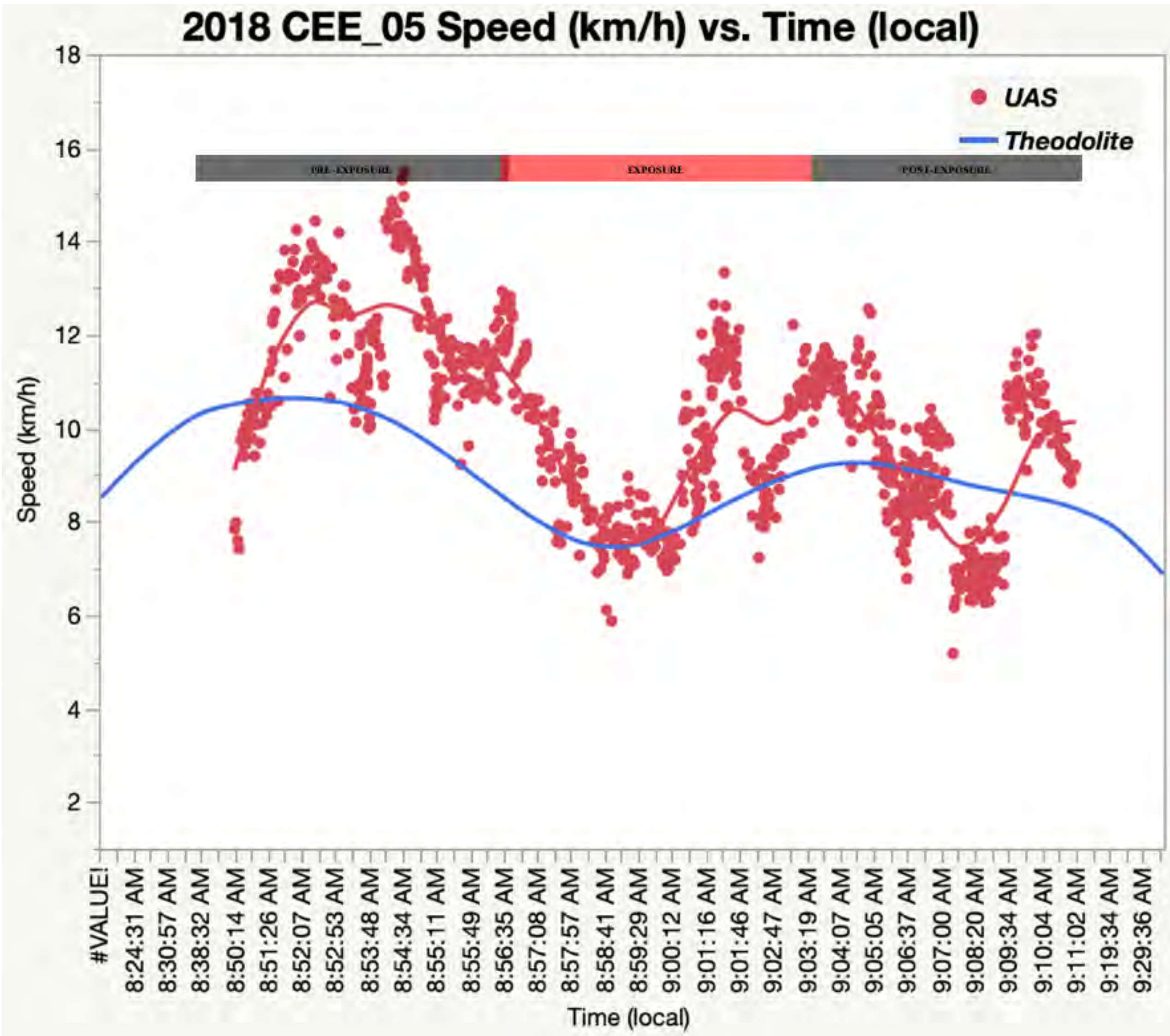


Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal
MFAS CEE 2018_05 (19 June 2018)
UAS Animal Tracking
(whole CEE track and zoomed in – purple lines demonstrate source direction for individual pings)

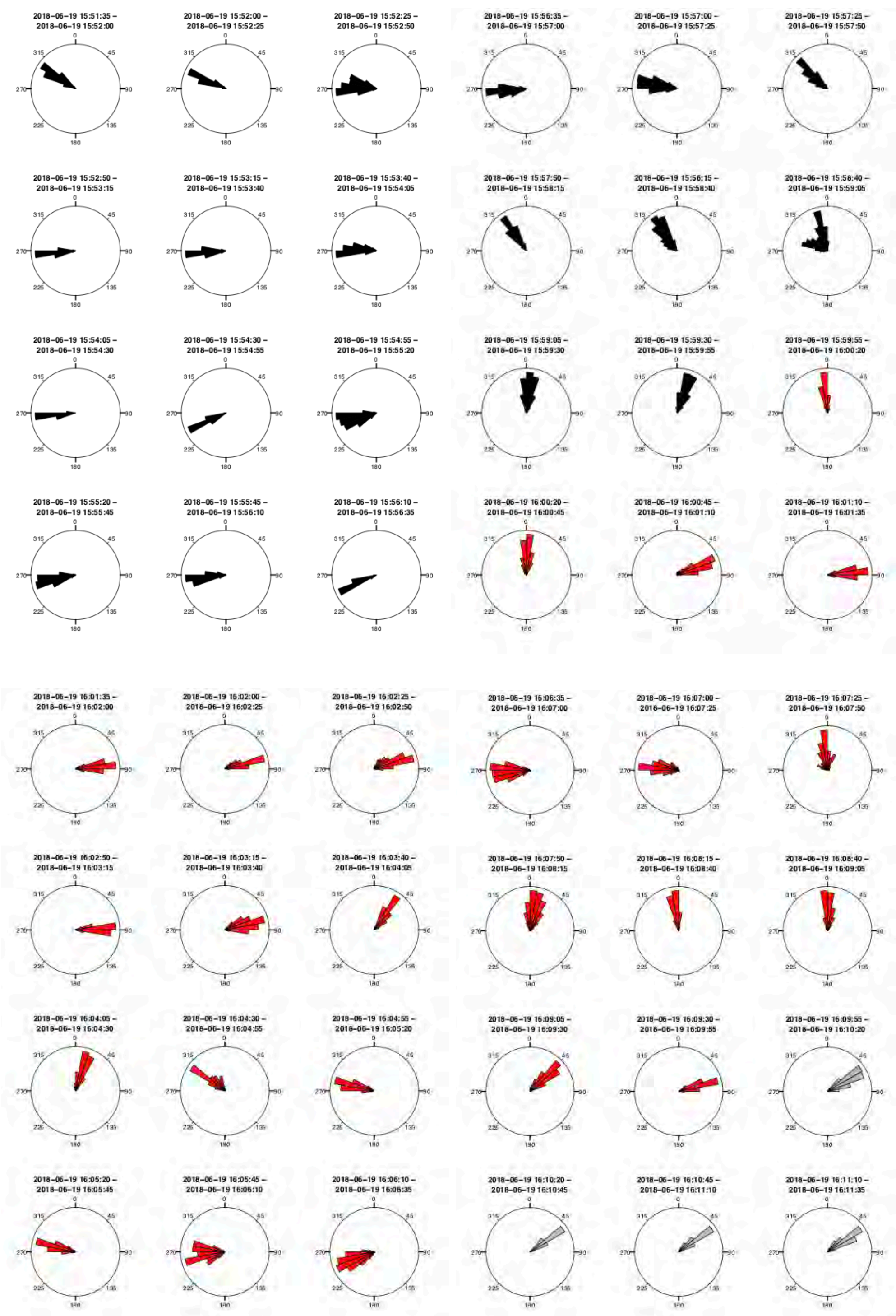




Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal
MFAS CEE 2018_05 (19 June 2018)
ALL METHODS (Speed calculated from both UAS and shore-based theodolite)

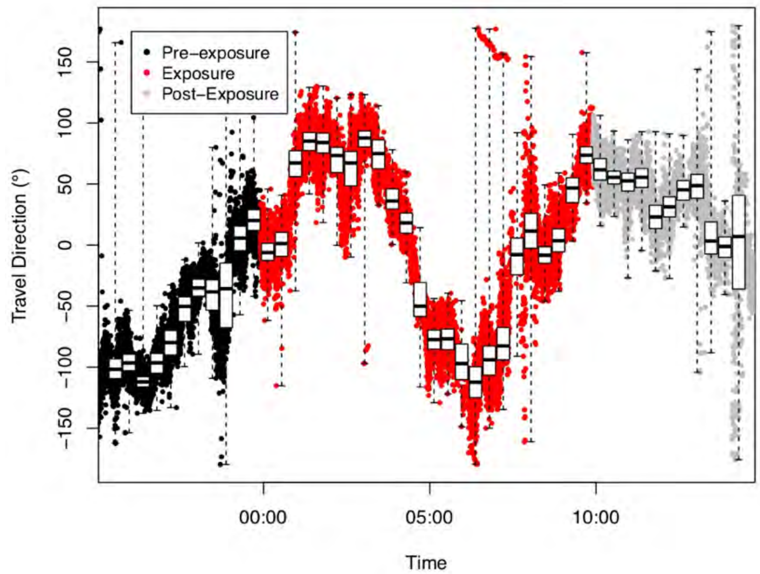


Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal
MFAS CEE 2018_05 (19 June 2018)
UAS Directionality – orientation of all indiovividuals during 25s periods before, during, after exposure



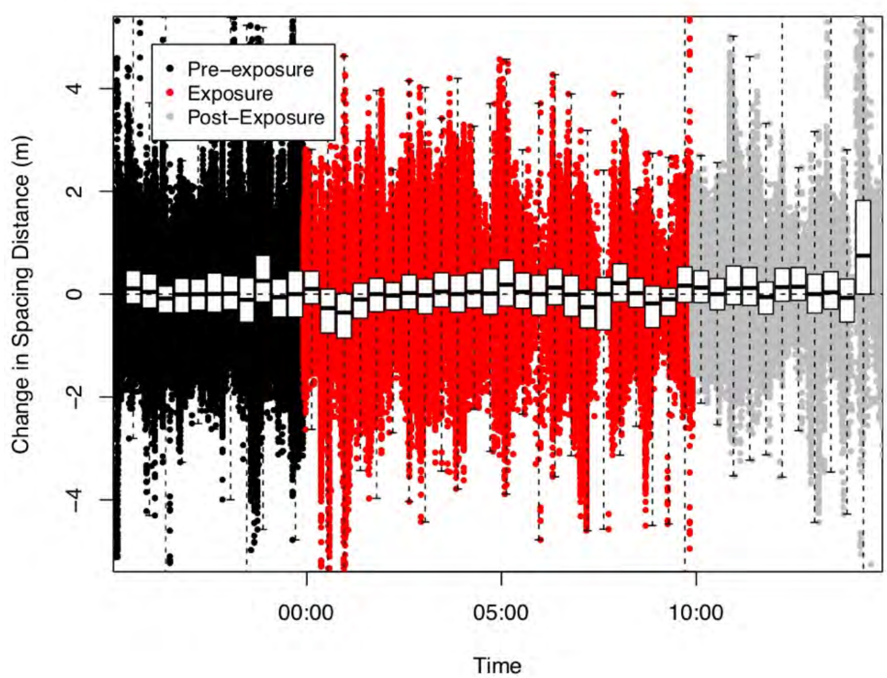
Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal

MFAS CEE 2018_05 (19 June 2018)
UAS Directionality (Median value for 25-s intervals shown as black line of box plots)

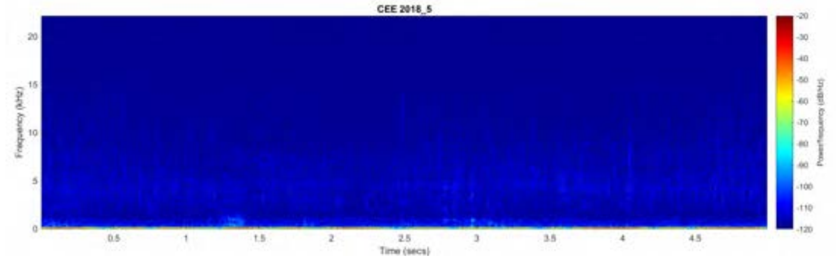


Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal

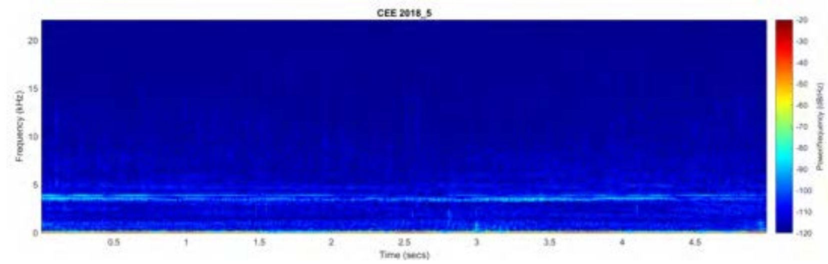
MFAS CEE 2018_05 (19 June 2018)
UAS sampling -Change in Individual Spacing (pair-wise calculations of inter-individual distance)



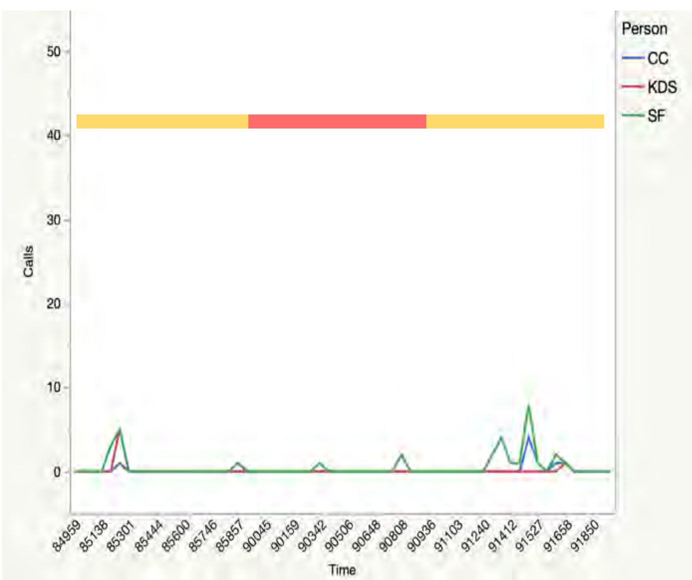
Results example: Long beaked common dolphin (D. capensis); n~400 whole group, n~200 UAS focal

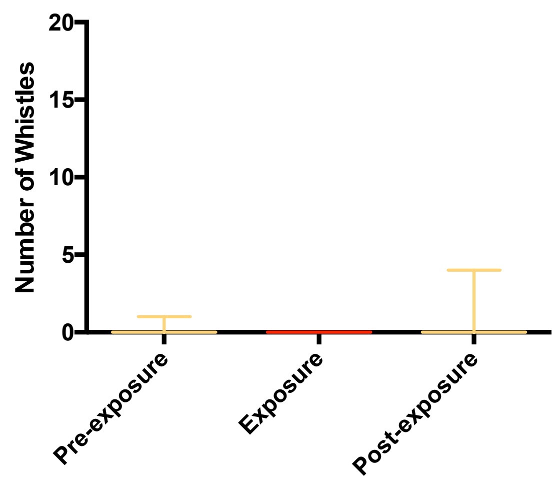


5-s sample prior to CEE



5-s sample following first ping of CEE





No vocal change detected duing CEE:
One-way ANOVA based mean counts of scorers across periods– ($F(2, 57) = 2.3$, $p > 0.1$)

OVERALL CONCLUSIONS

Given social nature of these species, group-sampling methods are more appropriate means of analyses than tag-based approaches. Once such methods were proven to be effective, CEE sequences were conducted (n=20 total across all focal species for both seasons; 11 in 2018 field effort) in both no noise (control) and MFAS exposure conditions. This pilot project developed methods and evaluated the feasibility of conducting CEEs for these challenging species. The integration of multiple methods was necessary to reveal complex nature of behavior and response.

These data represent a massive dataset on baseline physiology (size), baseline behavior in higher resolution than has ever been sampled, and the first-ever behavioral response data in known MFAS exposure conditions for these species. Preliminary results indicate strong responses in some but not all conditions, and suggest some species and context-dependent differences, which should be investigated further. Given the success in collecting fine-scale movement, behavioral, acoustic and physiological data in known conditions from this pilot effort, and the initial insights into response characteristics when they did occur, we are well positioned to add to this sample size and extend exposures to operational Navy sources in subsequent field efforts.

IMPACT/APPLICATIONS

We have successfully demonstrated the ability to monitor both broad-scale and relatively fine scale aspects of group behavior in several common delphinid cetaceans that have typically proven difficult or impossible to monitor with conventional tag sensors. We have obtained the first-ever CEE data on common delphinid species exposed by Navy MFAS in large numbers. There is particular interest in measuring behavior and behavioral responses of these species to military sonar systems, in part because they are commonly exposed in many Navy sonar operational areas and because due to their large numbers they comprise substantial proportions of estimated impacts (“takes”) of marine mammals from Navy training operations. Most previous assessments of sonar impacts in these species have come from anecdotal or uncontrolled observations rather than quantitative methods. The progress made in this feasibility study opens new doors to provide a more quantitative basis for the Navy to meet it’s mandated environmental compliance requirements and more accurately estimate the environmental effects of operations for some of the most common species exposed to sonar operations. Our results have direct relevance to Navy environmental compliance (e.g., derivation of risk functions for Navy EIS’), Navy fleet monitoring (e.g., species PAM recognition), and multiple other ONR/LMR funded efforts (*e.g.*, population consequences of disturbance).

RELATED PROJECTS

As noted above, this project involves a close collaboration among researchers from SEA, NOAA Fisheries Southwest Fisheries Science Center (SWFSC), Cascadia Research Collective (CRC), and Kelp Marine Research (KMR). The ONR grant referenced was issued to SEA and includes subcontracts to CRC and Kelp. Additional support for the project was provided under two separate ONR awards issued to SWFSC (PI: Dr. John Durban - N00014-18-IP-00021) CRC (PI: John Calambokidis – N00014-17-1-2887), and NUWC (PI: David Moretti - N0001418WX01327). This annual report for the overall project is intended to serve as the annual report for each of these awards.

A separate ONR award to SWFSC (PI: Dr. Nick Kellar) to investigate potential physiological stress responses to noise was also coordinated with this project following discussions with the ONR Marine Mammal Program Manager. This project is entitled "Measuring stress hormone levels and reproductive rates in four dolphin species relative to mid-frequency active sonar exposure within the greater region of the SOAR range, San Clemente Island, California (Award number: N00014-17-IP-00068 (1400620596)). This study examines blubber hormone levels in free-ranging dolphins (Delphinus delphis, D. capensis, Tursiops truncatus, and Grampus griseus) in areas adjacent to the U.S. Navy's Southern California Anti-submarine warfare Range (SOAR) with the intent to integrate these physiological measurements with behavioral response information in efforts to evaluate the potential effects of sonar on cetaceans. Measurements of reproductive and corticosteroid hormones from a massive sample size (n = 1436) of previously collected biopsies combined with sampling associated with controlled known exposures is providing data to examine the relationships between the following factors: 1) exposure to mid-frequency active sonar (MFAS – a potential disturbance), 2) measures of physiological stress (potential link between disturbance and population effects), and 3) reproductive rates (the population consequence).

Finally, we have recently been awarded a new ONR grant to support a follow-on study to both expand sample sizes for CEEs using the simulated MFAS source as well as extending these methods to operational Navy sonars from helicopter-dipping systems. This project will occur from FY19-21 and will directly apply and expand upon the current effort reported upon here to provide the first-ever behavioral response data for real Navy sonar operations with the species that are most commonly exposed to these sources.

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