

Delphinid behavioral responses to incidental mid-frequency active sonar

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Opportunistic observations of behavioral responses by delphinids to incidental mid-frequency active (MFA) sonar were recorded in the Southern California Bight from 2004 through 2008 using visual focal follows, static hydrophones, and autonomous recorders. Sound pressure levels were calculated between 2 and 8 kHz. Surface behavioral responses were observed in 26 groups from at least three species of 46 groups out of five species encountered during MFA sonar incidents. Responses included changes in behavioral state or direction of travel, changes in vocalization rates and call intensity, or a lack of vocalizations while MFA sonar occurred. However, 46% of focal groups not exposed to sonar also changed their behavior, and 43% of focal groups exposed to sonar did not change their behavior. Mean peak sound pressure levels when a behavioral response occurred were around 122 dB re: 1 μ Pa. Acoustic localizations of dolphin groups exhibiting a response gave insight into nighttime movement patterns and provided evidence that impacts of sonar may be mediated by behavioral state. The lack of response in some cases may indicate a tolerance of or habituation to MFA sonar by local populations; however, the responses that occur at lower received levels may point to some sensitization as well. © 2014 Acoustical Society of America.

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I. INTRODUCTION

The impact of mid-frequency active (MFA) sonar on marine mammals has been a topic of recent concern with mass strandings of beaked whales attributed to MFA sonar exposure (Cox *et al.*, 2005; D'Amico *et al.*, 2009), and other species demonstrating changes in the frequency or intensity of their vocalizations in the presence of low-frequency or MFA sonar (Fristrup *et al.*, 2003; Melcon *et al.*, 2012). Behavioral response studies have been conducted in the past on naval ranges with simulated MFA sonar signals, but the focal species in these studies has often been beaked whales and baleen whales (Tyack, 2011; DeRuiter *et al.*, 2013; Goldbogen *et al.*, 2013). While some recent behavioral response studies have expanded their focus to include dolphins (Tyack, 2009; Southall *et al.*, 2012), generally less attention has been given to smaller delphinid (dolphin and

porpoise) species. However, many of these species may utilize naval operation areas as part of their home ranges (e.g., Campbell *et al.*, 2010) and therefore are likely to be frequently exposed to MFA sonar.

Much work on delphinid responses to noise has been conducted in laboratory settings, investigating behavioral responses and temporary threshold shifts (TTS) of the auditory system to various sounds, including airguns, explosions, and tonals similar to MFA sonar (e.g., Finneran *et al.*, 2002; Finneran *et al.*, 2005; Mooney *et al.*, 2009). Southall *et al.* (2007) summarized all marine mammal studies prior to 2007 that examined behavioral responses to noise as well as physiological effects, including TTS and permanent threshold shifts (PTS). They found few behavioral responses in “mid-frequency cetaceans” (including dolphins) reported in the literature, and those responses that were reported occurred with received root mean square (RMS) sound pressure levels (SPL) ranging from 80 to 200 dB re: 1 μ Pa for non-pulse sounds (e.g., drilling, MFA sonar, pingers), with most responses between 100 and 130 dB_{rms} re: 1 μ Pa. While a behavioral response scale was developed, no specific threshold

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for behavioral responses was set by Southall *et al.* (2007) due to the complex relationship between context, behavioral state, and SPL during exposure, as highlighted by Ellison *et al.* (2011).

This paper aims to examine the behavioral response of free-ranging populations of five delphinid species to incidental U.S. Navy MFA sonar, as well as calculate SPL during MFA sonar events. Focal species included Pacific bottlenose dolphins (*Tursiops truncatus*), long- and short-beaked common dolphins (*Delphinus capensis* and *D. delphis*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), and Risso's dolphins (*Grampus griseus*). These species vary widely in their group size, seasonal migration patterns in the southern California Bight, foraging strategies, and tolerance toward vessels; therefore their response to MFA sonar is expected to vary as well. These animals were observed near the U.S. Navy's Southern California Anti-Submarine Warfare Range (SOAR) from 2004 through 2008. SOAR consists of 88 bottom-mounted hydrophones over approximately 1800 km² and is used for tactical range training and testing by the U.S. Navy (Falcone *et al.*, 2009b). The objectives of this study were to estimate and compare sound levels with and without sonar, to determine if a behavioral response was observed in delphinids that were present during periods of sonar, to determine the sound level when a response occurred, and to compare these levels with the levels reported by Southall *et al.* (2007). In addition, to determine from which direction the sonar was coming and to capture fine-scale movement patterns of dolphin groups exhibiting a behavioral response, acoustic array time-difference of arrival (TDOA) localization methods were employed using the 2008 dataset (Gassmann *et al.*, 2013; Wiggins *et al.*, 2013).

II. METHODS

A. Data collection

The Scripps Institution of Oceanography Marine Physical Laboratory's research platform Floating Instrument Platform (R/P FLIP) (Fisher and Spiess, 1963) was deployed in a stationary three-point mooring northwest of San Clemente Island, adjacent to the SOAR range, for four 1-

month periods in the fall of 2004, 2006, 2007, and 2008 (Fig. 1). R/P FLIP provided a stable platform from which visual observations of marine mammals were made concurrently with acoustic recordings from FLIP-mounted hydrophone arrays. Observations were conducted from the crow's nest of R/P FLIP, 26.5 m above the water line, in all directions during daylight hours in Beaufort sea state five or less in order to monitor the distribution and behavior of all marine mammals in the area. In addition, behavioral focal follows of delphinid groups that approached within 1 km on the face-side of R/P FLIP were conducted from the top deck, 15 m above the water line (Henderson *et al.*, 2011; Henderson *et al.*, 2012). Because observers were not informed when a sonar event was occurring, they were not monitoring for or recording reactions by the dolphins; therefore evaluations of potential dolphin reactions were performed during a *post hoc* analysis.

While sightings of all marine mammal species were recorded, the dolphin species of interest for this analysis were short-beaked common dolphins, long-beaked common dolphins, Pacific white-sided dolphins, bottlenose dolphins, and Risso's dolphins. Common dolphins are a tropical and warm temperate species, occurring in groups ranging from the tens to the thousands in coastal and inshore waters (Reeves *et al.*, 2002). Diel patterns of foraging behavior appear to be habitat- and regionally specific (Shane, 1990; Neumann and Orams, 2003), but prey often includes epipelagic schooling fish as well as myctophids and squid. Common dolphins are highly gregarious and have often been observed approaching vessels to bowride. Pacific white-sided dolphins are cool temperate species, distributed throughout the North Pacific. Group sizes also range from tens to hundreds along the coast and can extend into the thousands in open ocean waters (Reeves *et al.*, 2002). However, this species is most commonly observed in smaller groups in the southern California Bight (Henderson *et al.*, 2011), and their tolerance of vessels and other human activity may be dependent on their behavioral state. Two populations may overlap in the southern California Bight; one population appears to forage at night on myctophids in the scattering layer, while the other appears to forage during the day on epipelagic schooling fish

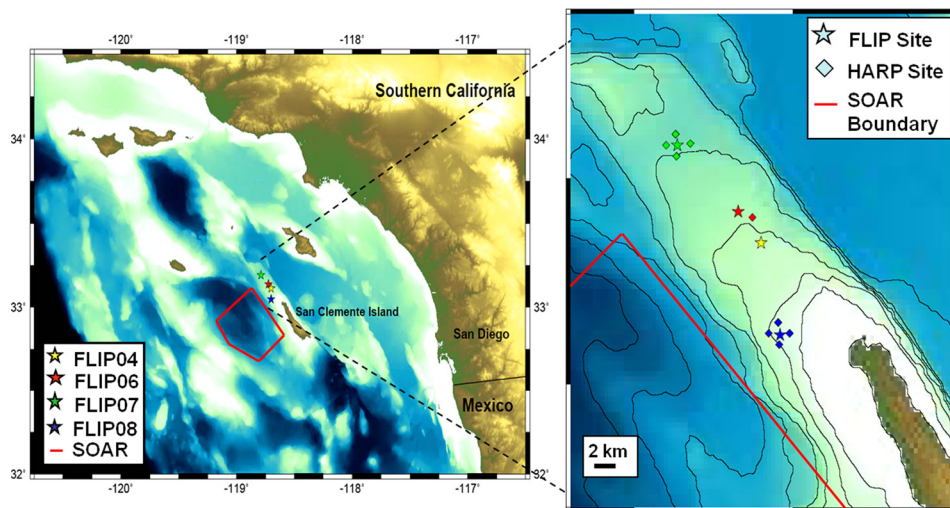


FIG. 1. (Color online) Map of southern California Bight with San Clemente Island and deployment sites of R/P FLIP and HARPs in 2004, 2006, 2007, and 2008. The outline indicates the SOAR range. The right panel shows bathymetric contour lines at 200 m intervals.

(Walker *et al.*, 1986; Lux *et al.*, 1997; Soldevilla *et al.*, 2008; Henderson *et al.*, 2011). Bottlenose and Risso's dolphins are globally distributed in tropical and temperate waters (Wells and Scott, 1999; Bravo Dubó, 2013), and both are commonly found in smaller groups inshore but can also form larger groups or loose aggregations in the tens to hundreds offshore (Reeves *et al.*, 2002). Bottlenose dolphins are catholic foragers, eating a wide variety of fish and squid species (e.g., Leatherwood and Reeves, 1990), while Risso's dolphins are specialists, foraging predominantly on squid (Würtz *et al.*, 1992; Baird, 2002). Bottlenose dolphins are also highly gregarious and often approach vessels to bowride, whereas Risso's dolphins in this region tend to avoid vessels.

Two six-channel hydrophone arrays in either a horizontal or L-shaped configuration with sensor spacing on the order of meters were deployed between 30 and 50 m depth to monitor and track marine mammals (Gassmann *et al.*, 2013). Within the arrays, HS150 (Sonar Research and Development Ltd., Beverly, U.K.) hydrophones were used, with a frequency response of 1–130 kHz \pm 2 dB and a sensitivity of -204 dB re 1 V/1 μ Pa, and were sampled at 192 kHz with 16-bit resolution and a 2 kHz high pass filter. The hydrophones were connected to custom-built preamplifiers and bandpass filtered electronic circuit boards designed to flatten ambient noise over all frequencies (Wiggins and Hildebrand, 2007). A MOTU 896HD IEEE 1394 audio interface (Mark of the Unicorn, Cambridge, MA) was used to digitally convert the analog signals from the R/P FLIP hydrophones with gain on all channels set to maximize signal input while avoiding clipping. In the 2004, 2006, and 2007 R/P FLIP array deployments, the sound analysis and recording software program ISHMAEL (Mellinger, 2001) was used to record the digitized hydrophone data to computer hard drive. In 2008, the data were recorded to computer hard drives using a custom program written in MATLAB (Mathworks, Natick, MA).

In addition to the R/P FLIP arrays, high-frequency acoustic recording packages (HARPs) were deployed on the seafloor near R/P FLIP in 2006–2008 to provide additional lower noise acoustic recordings of nearby marine mammals. These data had lower noise levels than the R/P FLIP arrays, as the HARPs were on the seafloor resulting in less noise from the sea surface and from noises associated with R/P FLIP. HARPs are autonomous long-term recorders with single calibrated hydrophones buoyed about 10 m above the seafloor and sample at 200 kHz (Wiggins and Hildebrand, 2007). A single HARP was deployed 1 km from the face-side of R/P FLIP in 2006 at a depth of 622 m, while in 2007 and 2008, four HARPs were clock synchronized and deployed in a large aperture array approximately 1 km away in the cardinal directions around R/P FLIP. In 2007, the mean HARP depth was 874 m, while in 2008, the mean HARP depth was 349 m.

Acoustic recordings aboard R/P FLIP and on the HARPs were conducted continuously throughout the deployments to record all marine mammal vocalizations. Delphinid vocalizations are composed of mid-frequency tonal whistles, occurring between 5 and 20 kHz; high-frequency echolocation clicks, typically from 20 to 100 + kHz, and burst pulse calls

(Richardson *et al.*, 1995; Nakamura and Akamatsu, 2004; Au and Hastings, 2010). These high-frequency vocalizations attenuate rapidly with distance and are highly directional; this further reduces their detection range when their beam is not directed at the receiver. Janik (2000) estimated whistles to have a detection range of approximately 4–20 km based on source level, ambient noise, and transmission loss. These detection distances were supported in our conclusions based on observed distances at the time of initial acoustic detections, while clicks were detected up to 1–2 km. Thus when delphinid vocalizations were recorded on R/P FLIP arrays, the animals were assumed to be within 1–10 km of R/P FLIP.

MFA sonar, which presumably occurred on or near SOAR, was opportunistically recorded on both the R/P FLIP hydrophones and the HARPs, and the direction of the source was estimated for 2008 data using the HARP array (Gassmann *et al.*, 2013; Wiggins *et al.*, 2013). The MFA sonar systems most likely used were AN/SQS 53C and AN/SQS 56 hull-mounted systems. The 53C has center frequencies of 2.6 and 3.3 kHz and a nominal source level of 235 dB re: 1 μ Pa at 1 m, while the 56 sonar has center frequencies of 6.8, 7.5, and 8.2 kHz, and a nominal 223 dB re: 1 μ Pa at 1 m source level (D'Spain *et al.*, 2006). An incident of MFA sonar was counted as any sonar tonal signal in the 2–8 kHz range separated by less than 1 h. As a result, multiple bouts of sonar, potentially from different sources, could be considered the same incident, and multiple exposures to dolphin groups could occur in a single incident. The received peak SPLs were calculated for each sonar exposure period using recordings from the HARPs.

B. Behavioral responses

Recorded behavioral states included travel, forage, mill/rest, and social/surface active (see Henderson *et al.*, 2011; Henderson *et al.*, 2012 for details). Following Shane (1990), groups were characterized by animals in apparent association, moving in the same direction and generally carrying out the same activity. Group focal follows were conducted using the instantaneous sampling method (Altmann, 1974; Mann, 1999) with behavioral states and associated events (e.g., high arch dives, tail slaps) of the greater part of the group recorded every 1–3 min or upon the next surfacing if the group was underwater (e.g., Mann, 1999). In addition, bearing, distance, group size, group spacing, orientation toward R/P FLIP, and direction of travel were also recorded for each behavioral sample.

For this *post hoc* analysis, all groups were examined that were visually observed and/or acoustically recorded to co-occur with sonar (either observed before and during a period of MFA sonar or during and after a period of MFA sonar). A behavioral response to sonar was defined as either a change in surface behavior or a change in vocal behavior within 5 min of the onset or cessation of MFA sonar. A surface behavioral response was considered to have occurred if the behavioral state of the animals or their direction of travel changed. To determine whether a 5-min window was an appropriate time metric for a surface behavioral response, analysis of variance (ANOVA) analyses with an alpha of

0.05 were conducted using the focal follow data to compare the typical rate of behavioral state changes in dolphin groups in the presence versus the absence of sonar. A vocal behavioral response was defined as a change to or from a lack of vocalizations when animals were present or a change in the rate or intensity of calls. Determinations of an acoustic response by dolphins were made using the hydrophones deployed from R/P FLIP. Both surface and acoustic behavioral responses corresponded to the response scores of four and above (of nine) developed by Southall *et al.* (2007). Because this analysis was done *post hoc*, determinations of a behavioral or acoustic response were conservative such that if another explanation for the observed change was also possible (e.g., clicking began after sonar ended, but the group was also within 1 km of the hydrophone for the first time), the instance was not counted as a response to sonar.

To determine whether the presence of MFA sonar impacted the presence of dolphins in the area, an analysis of the number of sightings on days with sonar versus days without sonar was conducted using a two-way ANOVA for within and across year data. In addition, a similar two-way ANOVA within and across years was used to compare the number of hours per night of vocalizations for nights with and without sonar.

C. Sound pressure levels

Peak SPLs were calculated as dB_{peak} re: $1 \mu\text{Pa}$ over a 5-s window for the frequency band 2–8 kHz using HARP recordings (e.g., Wiggins and Hildebrand, 2007; Melcon *et al.*, 2012). All HARP hydrophones were calibrated prior to deployment, and representative hydrophones were calibrated at the U.S. Navy's Transducer Evaluation Center (TRANSDEC) anechoic pool in San Diego, CA, to confirm laboratory tests. SPL was calculated during the entire exposure period. An ANOVA was used to determine if the intensity of the SPL was different during MFA sonar exposure when animals were present and when they were absent. SPL was also calculated for 5–10 min of MFA sonar recordings corresponding to the onset of behavioral responses for daytime groups. These values were compared against those found by Southall *et al.* (2007) for behavioral responses of mid-frequency cetaceans to nonpulsed anthropogenic sound sources.

D. Localizations

Using the 2008 recordings from the R/P FLIP hydrophone array allowed tracking of nearby echolocating dolphin groups, while the seafloor HARP array provided estimated bearing angles to distant MFA sonar signals. Both of these results provide additional information to assess if sonar elicited behavioral responses in dolphins. To estimate the direction of MFA sonar, the four clock-synchronized HARPs were treated as a large aperture array, and TDOAs of sonar pings were measured by manually picking ping first arrival times from the waveforms of the four recordings and calculating arrival time-lags (Wiggins *et al.*, 2013). Sets of these measured TDOAs were differenced with model-based calculated TDOAs for all bearing angles, squared, and then

minimized to estimate the direction to the sonar source (e.g., Tiemann *et al.*, 2004). Because the sonar source was well beyond the extent of the HARP array, potentially leading to large location uncertainties, we did not attempt to provide an exact position of the sonar source; rather, approximate bearing angles to the sonar were used to gauge if the animals were exhibiting a response (e.g., moving away from the source or approaching the source).

Due to the high directionality of the echolocation clicks, dolphins were localized using the closely spaced R/P FLIP hydrophones rather than the widely spaced HARPs. Two L-shaped arrays at 36 m depth and a vertical line array (VLA) at 122 m depth were used and a propagation-model based TDOA method was employed (Gassmann *et al.*, 2013). For the range estimates, the dolphins were assumed to be near the surface to avoid click mismatching between the VLA and the L-shaped arrays because the time intervals between clicks recorded on one hydrophone (<10 ms) are much shorter than the time differences between the arrays (tens of ms) due to the larger spacing between arrays.

These localizations were conducted for all groups with presumed behavioral responses to MFA sonar, allowing us to determine the distance and movement patterns of nighttime groups as well as provide finer-scale track lines of daytime groups than were obtained using visual sightings alone. Pacific white-sided and Risso's dolphins have distinct spectral peak-and-notch structure to their clicks (Soldevilla *et al.*, 2008), allowing them to be acoustically identified even without concurrent visual confirmation. On the other hand, the clicks of bottlenose and common dolphins lack this structure, while their whistles are very similar in shape, making them difficult to distinguish acoustically. However, bottlenose dolphins generally forage during the day (e.g., Shane *et al.*, 1986), while common dolphins have been shown to forage predominantly at night in southern California waters (Goold, 2000; Henderson *et al.*, 2012). Therefore while only Pacific white-sided and Risso's dolphin groups encountered acoustically at night were designated as such, it is likely that most of the unidentified dolphin groups at night were common dolphins.

III. RESULTS

The number of sightings for all dolphin species across all R/P FLIP deployments is summarized in Table I. A total of 540 delphinid group sightings were recorded between 2004 and 2008. Of the groups, 411 were common dolphins, 29 of which were observed concurrently with MFA sonar. Only 14 Risso's dolphin groups and 15 bottlenose dolphin groups were observed, and of those, only 3 of each species co-occurred with MFA sonar. One hundred Pacific white-sided groups were seen with ten concurrent with MFA sonar. Fifty incidents of 2–8 kHz MFA sonar were recorded in the same time period, and 22 of these sonar incidents corresponded with delphinid sighting (Table II). Exposure periods ranged in length from 4 to 793 min (mean 194 min). A possible response occurred in 26 groups of dolphins. In addition, there were 22 nighttime periods where delphinid vocalizations co-occurred with MFA sonar with 17 possible acoustic

TABLE I. Number of sightings of dolphin species from R/P FLIP in 2004, 2006, 2007, and 2008 along with the number of groups exposed to sonar and the number of surface and/or acoustic behavioral responses.

Species	2004 sightings	2006 sightings	2007 sightings	2008 sightings	Total sightings	Sightings with MFA sonar	Responses to MFA sonar
Long-beaked common dolphin	7	1	2	0	10	1	0
Short-beaked common dolphin	37	35	9	19	100	5	4
Common dolphin (unidentified sp.)	101	136	28	36	301	24	11
Risso's dolphin	4	10	0	0	14	3	0
Pacific white-sided dolphin	2	78	9	11	100	10	9
Bottlenose dolphin	2	12	1	0	15	3	2
Total	153	272	49	66	540	46	26

responses, although concurrent sightings were not possible at night to observe a behavioral response or confirm species identification (Table II). Fifteen groups of common dolphins (five short-beaked, ten *Delphinus* sp.), nine Pacific white-sided dolphin groups, and two bottlenose dolphin groups demonstrated a possible surface and/or acoustic behavioral response to MFA sonar. In addition, there were 16 nighttime groups presumed to be common dolphins but visually unconfirmed and one nighttime group of Pacific white-sided dolphins with possible acoustic responses. Although there were five groups of Risso's dolphins that were observed shortly before or shortly after an incident of MFA sonar, none were observed concurrently with sonar, and so no behavioral responses were obtained for this species. Group sizes for the groups observed during an MFA sonar incident ranged from 2 to 1000 with median sizes of 50 for common dolphins, 15 for Pacific white-sided dolphins, 31 for bottlenose dolphins, and 6 for Risso's dolphins.

A. Rates of behavioral state change

The results of the behavioral state change analysis are summarized in Table III. The mean duration of focal-follow observations was very similar for groups not exposed to sonar, groups exposed to sonar without a response, and groups that demonstrated a response to sonar, although the maximum observation durations were much shorter when sonar was present. The mean time between behavioral changes within an observation period was slightly lower when sonar was present and was even shorter for groups with a behavioral response [Fig. 2(a)]. While an ANOVA indicates that these differences are not significant ($F = 0.47$, $p = 0.63$), paired t -tests show that the difference in the time between behavioral changes is significantly different between groups

that demonstrated a behavioral response to sonar and those that were not exposed to sonar ($t = -2.36$, $p = 0.02$, power = 0.99). Similarly, the ratios of the time between changes to the overall duration were smallest for groups with a behavioral response [Fig. 2(b)]. In this case, an ANOVA reveals that these results approached significance at an alpha value of 0.05 ($F = 2.99$, $p = 0.054$). In addition, paired t -tests demonstrate that the ratio of change rate to duration was significantly different between groups that demonstrated a behavioral response and those that were exposed to sonar but did not show a response ($t = -2.51$, $p = 0.04$, power = 0.99). A significant difference was also noted between groups that demonstrated a behavioral response and those that were not exposed to sonar ($t = -5.17$, $p < 0.001$, power = 1). Overall these results indicate that groups exposed to sonar changed their behavior at a faster rate than groups not exposed to sonar and that groups with noticeable behavioral shifts in response to sonar responded within the 5-min window used for analysis.

The frequency at which different species changed their behavior during focal follows was also compared between groups exposed to MFA sonar and groups not exposed to sonar. It should be noted that this analysis does not distinguish between those animals that changed their behavior in response to sonar and those that may have naturally changed their behavior in the presence of sonar. Out of a subset of 56 day-time focal follow groups, 21 were observed concurrently with sonar and 35 were observed in the absence of sonar. Of those groups, 50% of the common dolphin groups exposed to sonar changed their behavior, while 35% of the groups not exposed to sonar changed their behavior. The lone group of bottlenose dolphins exposed to sonar altered behavior, while 25% of the groups not exposed to sonar changed behavior. No Risso's dolphin groups were observed

TABLE II. The number of incidents of 2–8 kHz MFA sonar along with the number of possible behavioral responses. The incidents of MFA sonar can include multiple sightings or multiple bouts of vocalizations, while the number of sightings or nighttime groups with possible responses is unique.

Year	No. of incidents MFA sonar	Incidents with sightings	No. of sightings with response	Nighttime incidents with vocalizations	Nighttime groups with acoustic response
2004	7	5	0	2	1
2006	9	6	12	3	0
2007	9	4	4	5	6
2008	25	7	10	12	10
Total	50	22	26	22	17

TABLE III. Rates of behavioral change when sonar is present or absent. Duration of focal-follows and times of observation until a behavioral change are given in minutes, the ratio of the rate of change to the duration of the observation is given as a percentage, where 100% indicates that the behavioral state changed at every recorded observation and 0% indicates that the behavioral state remained the same throughout the focal-follow.

	Groups without sonar	All groups with sonar	Groups with behavioral response
Mean duration	15.4	9.4	16.4
Minimum duration	2.0	4.0	2.0
Maximum duration	128.0	23.0	48.0
Mean time to change	7.0	5.6	3.6
Minimum time to change	0.5	2.0	1.0
Maximum time to change	96.0	15.0	9.0
Mean ratio (change to duration) (%)	33.7	44.6	15.0
Minimum ratio (change to duration) (%)	0.8	9.0	2.0
Maximum ratio (change to duration) (%)	100.0	100.0	23.0

concurrently with sonar, and of the Risso's groups not exposed to sonar, 40% changed behavior. Finally, 75% of the Pacific white-sided dolphin groups exposed to sonar changed their behavior, while 100% of the Pacific white-sided groups that were not exposed to sonar changed their behavior during focal follow observations.

B. Behavioral response to MFA sonar

When sonar began, surface group responses ranged from no change to groups splitting, changing behavioral states (e.g., mill to travel), changing direction of travel, and disappearing when sonar began. Acoustic responses when sonar began included either a cessation of vocalizations, an

increase in the intensity of vocalizations, or a combination of both. When sonar ended, dolphin groups that were present but mostly silent would increase their vocalizations (Fig. 3), often with an initially more intense burst of calls. One example of a possibly strong response was a group of Pacific white-sided dolphins passing R/P FLIP when a period of 3 kHz MFA sonar exposure began. The most intense vocalizations were recorded at this time, although it was not the closest point of approach (CPA) of the group, when vocalizations are typically at their most intense and abundant if the group is approaching the hydrophones. After this period of sonar, most of the group left the area; however, a mother and calf pair remained, circling R/P FLIP for almost 2 h before another group (or the same group) of Pacific white-sided dolphins returned and the mother-calf pair joined them.

Table IV summarizes overall species-specific responses. Generally, Pacific white-sided dolphins began vocalizing or increased the intensity of their vocalizations when sonar

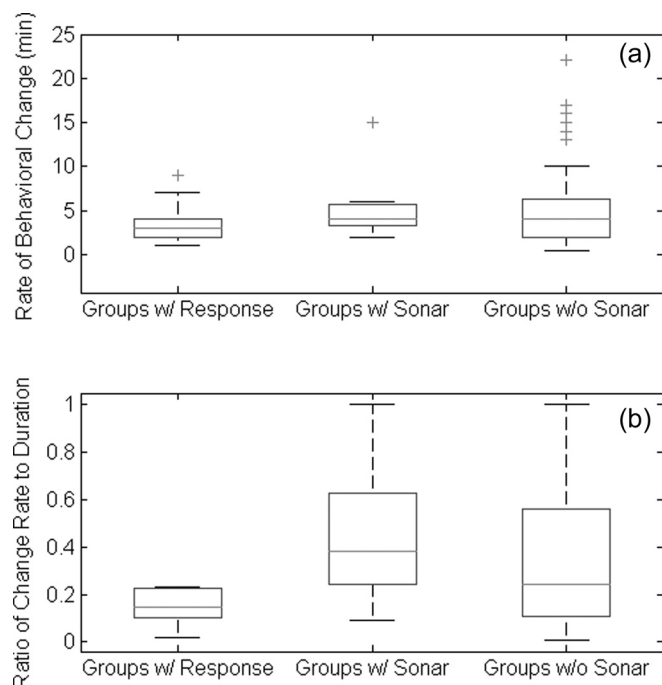


FIG. 2. Boxplots of groups with no sonar exposure, all groups that co-occurred with sonar, and groups that exhibited a behavioral response to the sonar for (a) rates of behavior change (in minutes) and (b) ratios of the rate of behavioral change over duration of observation. The center line of each box indicates the median value, while the edges are the 25th and 75th percentiles and the whiskers cover about 99% of the data. Outliers are indicated by crosses.

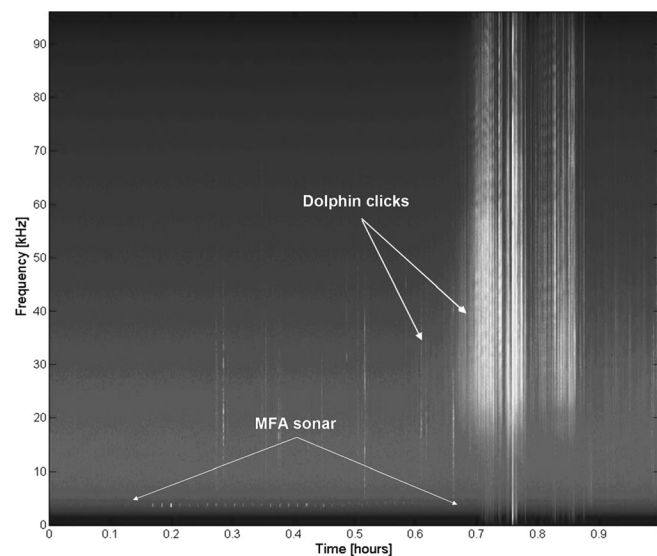


FIG. 3. Example of an acoustic response to MFA sonar; a 1 h spectrogram depicts an incident of 3-kHz MFA sonar occurring at night. Dolphins appear to be present based on the few clicks that occur during the sonar. Within 5 min of the sonar ending, a bout of intense clicking begins with clicks extending from about 18 to 96 kHz. Note: The vertical lines from < 10–50 kHz are from noise associated with R/P FLIP and are not dolphin clicks.

TABLE IV. Species-specific behavioral responses to MFA sonar from 2004 to 2008 off San Clemente Island.

Species	Number of groups	Type of response	Description of response
Common dolphin	2	Surface	Change in behavioral state or direction of travel
Common dolphin	8	Acoustic	Vocalizations more intense or no/few vocalizations when present
Common dolphin	5	Both	Change in direction of travel and rate of vocalization
Pacific white-sided dolphin	2	Surface	Group splits; Mother/calf pair separated from group after sonar exposure
Pacific white-sided dolphin	3	Acoustic	Increased vocalizations after sonar, or more intense vocalizations during sonar
Pacific white-sided dolphins	4	Both	Change in behavioral state and rate of vocalizations
Bottlenose dolphin	1	Acoustic	Increase intensity of vocalizations after sonar
Bottlenose dolphin	1	Surface	Change in behavioral state and then disappeared
Nighttime groups	17	Acoustic	Cessation of vocalizations or increase in intensity after sonar begins; beginning of vocalizations after sonar ends

stopped and, when sonar began, the dolphins usually stopped vocalizing and often left the area. One group of bottlenose dolphins was observed milling prior to the sonar event, and when the sonar began, the group split and began traveling at a moderate speed. Common dolphins displayed a wider range of responses, including changing their behavioral state or direction of travel when sonar stopped, increasing the intensity of vocalizations when sonar began, vocalizing very little or not at all during sonar, or a combination of the above.

Figure 4 demonstrates an example of a behavioral change in the track line of one common dolphin sighting in 2008. The group was traveling southeast in a dispersed formation until the sonar began. The group immediately formed a tight parade line formation and changed their direction of travel to northwest, away from the direction of MFA sonar and SOAR.

To examine whether MFA sonar impacted the overall presence and habitat use of dolphins in the area near the SOAR range, a two-way ANOVA was conducted across all 4 yr on the number of sightings per day on days when sonar

was present versus the number of sightings per day on days without sonar. The number of sightings on days with or without sonar were not significantly different ($F = 1.63$, $p = 0.2$). However, the across year variation was significantly different [$F = 19.97$, $p < 0.01$; Fig. 5(a)], with more sightings in 2004 and 2006 than in 2007 and 2008. Similarly, a two-way ANOVA conducted across years with HARP data (2006–2008) on the number of hours of vocalizations per night on nights with sonar versus nights without sonar showed that again the hours of vocalization with or without sonar were not significantly different ($F = 0.02$,

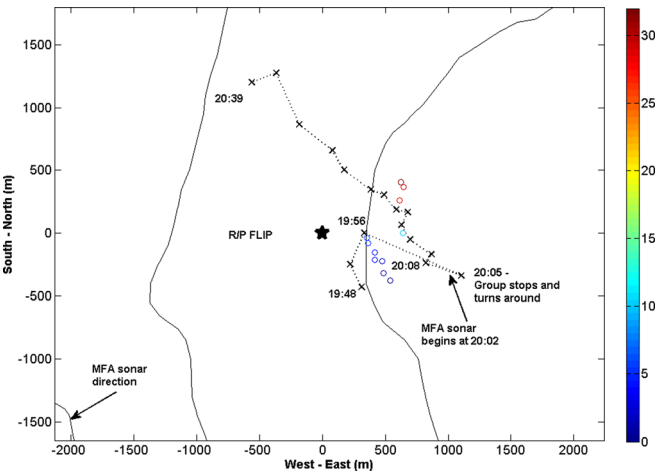


FIG. 4. (Color online) Trackline of a group of common dolphins visually observed October 27, 2008. Beginning at 19:48, they were traveling north and then east in a dispersed configuration until the onset of MFA sonar from the southwest at which time they change their direction of travel to northwest, away from SOAR, in a parade line formation. Contour lines are the 200 and 400 m bathymetric isopleths. The circles indicate the location of vocalizations localized from the R/P FLIP arrays. These also show the animals approaching R/P FLIP, turning away and then passing again as they move northwest; the color of the circles represents time in minutes from the start time of the localization at 19:50:58.

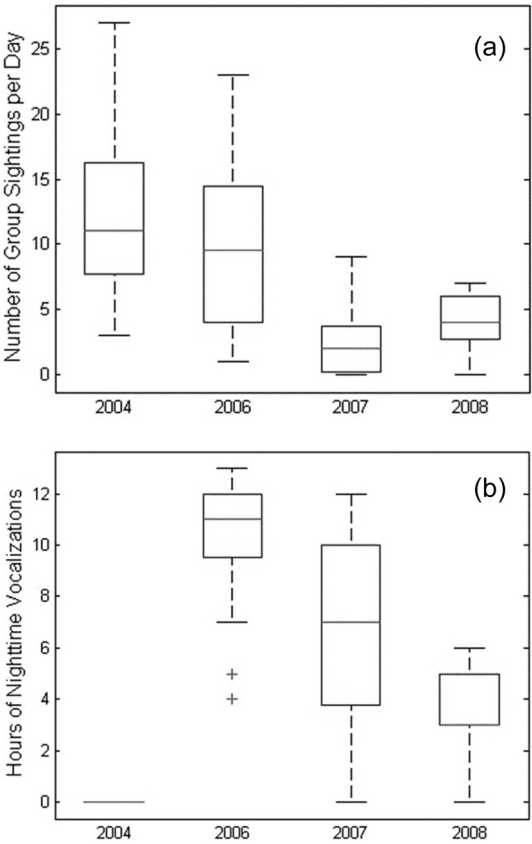


FIG. 5. Boxplots showing significant inter-annual difference across years for (a) the number of sightings per day and (b) the number of hours with vocalizations per night. The center line of each box indicates the median value, while the edges are the 25th and 75th percentiles and the whiskers cover about 99% of the data. Outliers are indicated by crosses.

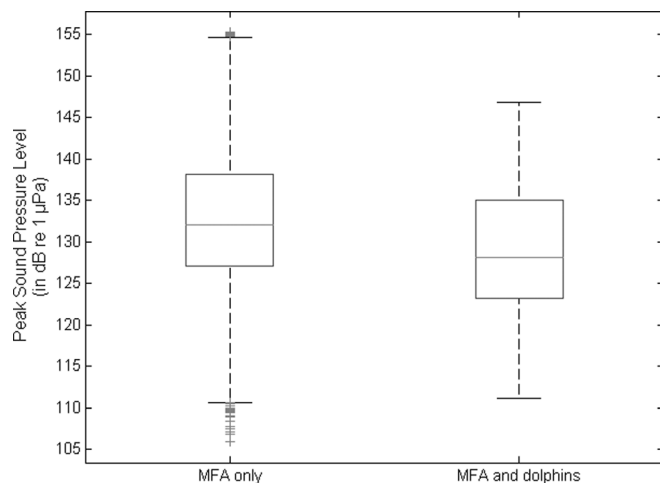


FIG. 6. Peak sound pressure levels in dB re: 1 μ Pa in the 2–8 kHz band for periods of sonar exposure when dolphins were present and periods of sonar exposure with no dolphins present. The center line of each box indicates the median value, while the edges are the 25th and 75th percentiles and the whiskers cover about 99% of the data. Outliers are indicated by crosses.

$p = 0.9$), but the across-year variation was significantly different for all 3 yr [$F = 34.64$, $p < 0.01$; Fig. 5(b)].

C. Sound pressure levels

A paired t -test of SPL for periods of dolphins vocalizing in the presence of MFA sonar versus periods of MFA sonar only revealed that the sound intensity was the highest in the case of MFA sonar with no dolphins present ($F = 95.97$, $p = 0$; Fig. 6). When no dolphins were present (or were not vocalizing), the mean SPL of MFA sonar was 132.3 dB_{Peak} re: 1 μ Pa with a maximum SPL of 155.4 dB_{Peak} re: 1 μ Pa, while the mean SPL when dolphins were present was 128.6 dB_{Peak} re: 1 μ Pa, with a maximum SPL of 146.8.

Sonar exposure values in SPL were calculated for the three main types of response to sonar: A behavioral change, no vocalizations in the presence of sonar, and vocalizations increasing in intensity when sonar began, and these were shown to be significant ($F = 10.63$, $p < 0.001$). MFA sonar SPL values were lowest when vocalizations increased in intensity with a mean SPL of 113.6 dB_{Peak} re: 1 μ Pa and a maximum of 120.9 dB_{Peak} re: 1 μ Pa. When behavior changed, the mean SPL was 121.3 dB_{Peak} re: 1 μ Pa and a maximum of 132.0 dB_{Peak} re: 1 μ Pa, while when vocalizations ceased or began, the SPL values were the highest with a mean of 123.0 dB_{Peak} re: 1 μ Pa and a maximum of 141.8 dB_{Peak} re: 1 μ Pa (Fig. 7).

D. Localizations

The direction of MFA sonar was estimated for 11 events in 2008 using the HARP array, 6 at night and 5 during the day, all associated with a behavioral response by a group of dolphins (Table V). In addition, five of those nighttime delphinid groups and two of the day-time sightings were localized using the R/P FLIP hydrophone arrays. Seven of the 11 sonar events occurred to the south or southwest of R/P FLIP, 1 to the west-southwest, and 1 to the west-northwest; all of these events are presumed to come from in or near SOAR (Table V). The two events that

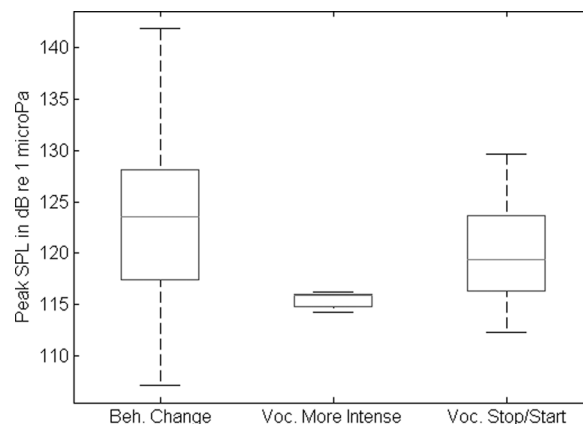


FIG. 7. Boxplot of peak sound pressure levels (in dB re 1 μ Pa) for each of the three main observed categories of behavioral and acoustic responses to MFA sonar: A change in behavioral state, the beginning or cessation of vocalizations as sonar stopped or started, or an increase in vocalization intensity. The center line of each box indicates the median value, while the edges are the 25th and 75th percentiles and the whiskers cover about 99% of the data. Outliers are indicated by crosses.

occurred toward the east-southeast were in the upper range of the MFA sonar frequency bandwidth and came from a faster moving source than the other events.

Four of the five nighttime localized groups appeared to move from the north to the south as they passed R/P FLIP. Two of these groups only began clicking when the MFA sonar ceased; the localizations show these groups moved in small subgroups from north to south only after the sonar had ended (Fig. 8). However, this north-to-south movement was also observed for the two groups exposed to sonar coming from the east-southeast. These groups also seemed to move north-to-south just after sonar had ended (or during a gap in sonar activity). In contrast, the two day-time sightings that were localized both visually and acoustically moved from the southeast to the northeast, and both begin fast traveling away from SOAR after sonar had begun (Fig. 4). The acoustic and visual tracks show similar movement patterns within the errors of each method.

IV. DISCUSSION

Delphinids exposed to MFA sonar near San Clemente Island exhibited varying levels of behavioral response; however, a uniform or consistent response was not observed. More than half of the groups exposed to MFA sonar demonstrated a surface or acoustic behavioral response. As these analyses were conducted *post hoc*, it is possible that more subtle behavioral responses occurred that were not recorded, and so this analysis could have underestimated the level of response. Alternately, while the behavioral change-rate analysis found differences between groups exposed to sonar and groups not exposed to sonar, the differences were small; therefore it may be that the number of behavioral responses was overestimated by assuming that a change within 5 min indicated a response.

Many of the acoustic responses were recorded at night when it was not possible to observe whatever surface behavior might be occurring. Nighttime acoustic responses were evaluated conservatively and so were likely underestimated.

TABLE V. Bearing estimates of the direction of MFA sonar using HARP time difference of arrivals (TDOAs) and dolphin groups using R/P FLIP array TDOAs of echolocation clicks for 2008 data. Times are given in GMT.

Date	Sighting number	Sonar time	Dolphin vocalization time	Travel direction (wrt R/P FLIP)	MFA sonar direction
10/22	Night	10:45 – 11:55	10:25 – 13:35	North → South	SSW
10/28	Night	2:15 – 4:15	1:50 – 3:13	Remain Southeast	SW
11/2	Night	7:40 – 8:15	7:50 – 9:00	North → South	ESE
11/2	Night	8:40 – 9:05	9:00 – 9:20	some North, some South	ESE
11/3	Night	3:40 – 5:25	3:30 – 4:55, 5:25 – 6:00	N/A	WSW
11/7	Night	2:00 – 2:30	2:08 – 2:47	North → South	SW
10/27	27/28	13:15 – 14:45	14:15 – 14:55	N/A	SSW
10/27	30	20:05 – 20:45	19:45 – 20:45	Southeast → Northwest	SW
10/28	35/36	15:40 – 17:18	17:00 – 17:30	N/A	S
10/28	38	18:39 – 19:08	18:50, briefly	N/A	S
10/31	50	16:09 – 16:34	15:55 – 16:50	Southeast → Northeast	N/A (low SNR)
11/11	96/97	16:30 – 19:20	18:50 – 19:08	N/A	WNW

Many of the delphinid species in the area forage at night (Walker and Jones, 1993; Heise, 1997; Osnes-Erie, 1999), and so sonar events occurring at night likely have a different impact than those occurring during the day. For example, in one study, foraging animals ignored sources of noise while resting animals avoided them (Wartzok *et al.*, 2003). Croll *et al.* (2001) found whales responded more to changes in prey and oceanographic features while foraging than to low-frequency sonar; however, Cummings (2009) found that anthropogenic noise has been shown to disrupt foraging behavior. Goldbogen *et al.* (2013) found that the response of blue whales (*Balaenoptera musculus*) to simulated MFA sonar was dependent on their behavioral state; surface feeding animals did not respond, whereas deep-feeding whales did respond by terminating their diving or prolonging their time at mid-water.

Diel patterns in day- and nighttime behavior and group size for common dolphins in this area have been demonstrated previously (Henderson *et al.*, 2012; Wiggins *et al.*, 2013); the localizations conducted in this study further support the idea that the impact of MFA sonar varies with behavior and time of day. Four of the five nighttime groups that were localized all moved from north to south in multiple small sub-groups after the sonar ceased or during a quiet period between bouts of sonar. This behavior was observed regardless of whether the sonar was coming from SOAR to the southwest or from a source off-range to the east. Therefore it could be that the animals were not responding to the sonar, and their occurrence after the sonar ended was coincidental. In that case, it would be an indication that the dolphins are not as heavily impacted by sonar during foraging behavior as they are during other behavioral states.

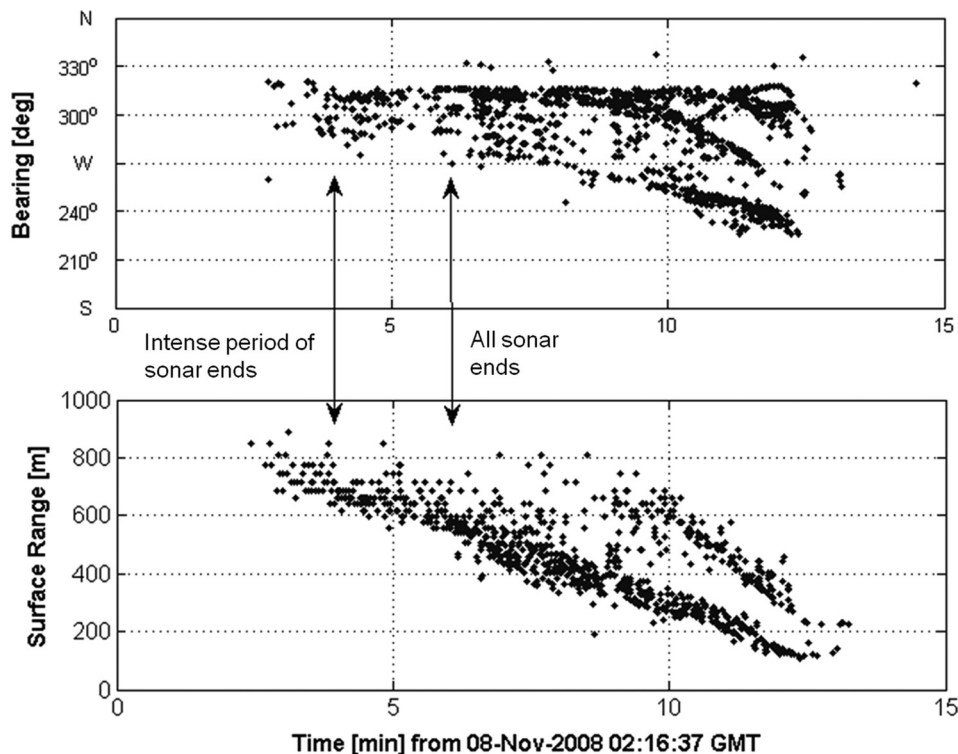


FIG. 8. Nighttime group of dolphins approaching R/P FLIP from the north on the east side, heading south. Dolphins are within 1 km and vocalize some before an intense period of MFA sonar ends; after the sonar ends, two subgroups of dolphins head south toward SOAR.

However, the localizations showed that the animals were typically already within 1 km of R/P FLIP when they started vocalizing after the sonar ended. Hence they were more likely already in the area but not vocalizing until the cessation of the sonar. This may indicate that these dolphins typically forage nightly in the deep basin west of San Clemente Island but wait to forage until sonar has ended. The idea of relative impact related to the context of the exposure and the behavioral state (e.g., [Ellison et al., 2011](#)) is further supported by the localizations of the two daytime sightings. Both groups changed from moderate to fast travel north or northeast away from the range as soon as the MFA sonar began, and one group emitted their most intense vocalizations as soon as the sonar began although their CPA did not occur until almost 10 min later. Therefore it appears that traveling dolphins demonstrated a stronger response to MFA sonar than foraging dolphins.

An examination of the MFA sonar SPL values at the onset of behavioral responses reveals similar results to those reviewed by [Southall et al. \(2007\)](#). Most behavioral responses in [Southall et al. \(2007\)](#) occurred at received sound pressure levels between 100 and 130 dB_{rms} re: 1 μ Pa. In the present study, mean received SPLs for all behavioral responses were similar, ranging from 113 to 123 dB_{peak} re: 1 μ Pa, or approximately 107–117 dB_{rms} re: 1 μ Pa. These were the received levels on the seafloor HARPs; this suggests the MFA sonar source could be up to or greater than 100 km away, and received levels for the animals would be only slightly higher or lower depending on their location relative to the sound source and R/P FLIP. Additional details, such as the distance proximity of the sonar source, the direction the sonar vessel was traveling, and the number of vessels that were producing sonar, were unknown. The proximity and number of vessels could have an additional impact on dolphins that was not accounted for in this analysis. For example, the proximity to a sound source could lead to different responses even if the received level was similar as was observed for beaked whales exposed to simulated and real MFA sonar ([DeRuiter et al., 2013](#)). At sonar received levels over about 147 dB_{peak} re: 1 μ Pa, dolphins were no longer present; this could indicate some avoidance of the area and would represent an additional behavioral response. Tagging work on Cuvier's beaked whales (*Ziphius cavirostris*) in the San Clemente Basin exposed to MFA sonar has shown that they left the area for a period of time but returned within days ([Falcone et al., 2009a](#); [Falcone et al., 2009b](#)).

While no significant intra-annual difference in the number of sightings on days with or without sonar was observed, the number of sightings across years was significantly different. This may indicate that seasonal and inter-annual oceanographic variability impacts behavior and habitat use more than the presence of sonar (e.g., [Croll et al., 2001](#)). Both common dolphins and Pacific white-sided dolphins have been shown to vary their use of the southern California Bight on a seasonal basis ([Dohl et al., 1986](#); [Walker et al., 1986](#); [Soldevilla et al., 2011](#)). In addition, the year-to-year sighting rates of different species vary with sea surface temperature, chlorophyll, and other oceanographic parameters (e.g., [Gaskin, 1968](#); [Van Waerebeek et al., 1998](#)). This inter-

annual variability has been shown to be further influenced by the *El Niño*/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), and significantly impacts the occurrence and distribution of species throughout the food web ([McGowan, 1985](#); [Benson et al., 2002](#)). On the other hand, some amount of site fidelity for the waters around San Clemente and Santa Catalina Islands has been demonstrated by bottlenose dolphins and possibly Risso's dolphins ([Campbell et al., 2010](#)).

The lack of a consistent response to MFA sonar may indicate that animals that only use the area seasonally (i.e., common and Pacific white-sided dolphins) are more impacted by sonar, while those animals frequently exposed (i.e., bottlenose and Risso's dolphins) may have habituated to the sound or at the least are tolerant of it ([Richardson and Wursig, 1997](#); [Wartzok et al., 2003](#); [Bejder et al., 2009](#)), or they may even be attracted to it ([Bowles et al., 1994](#)). Habituation commonly occurs when a recurring signal does not cause harm or overt stress as has been demonstrated in animals repeatedly exposed to acoustic harassment devices (AHDs) used to deter seals and porpoises from entangling in fishing nets ([Wartzok et al., 2003](#)). Alternatively, the observed behavioral responses occurred at received levels on the lower end of those reported by [Southall et al. \(2007\)](#); this may signify that some animals have become sensitized to the ongoing MFA sonar in the SOAR area and could be affected at lower received levels than other populations ([Richardson and Wursig, 1997](#); [Wartzok et al., 2003](#)).

It is difficult to determine the full impact of MFA sonar on delphinids with this limited dataset, suggesting further observations of all species around the SOAR range would help to identify species- and population-specific responses to MFA sonar, which could help inform mitigation measures as appropriate. An ongoing behavioral response study (BRS) occurring in the southern California Bight may provide some insight ([Southall et al., 2012](#)). However, the BRS study and others like it introduce additional confounding factors (e.g., the presence of multiple vessels, tagging the animals) that could lead to behavioral responses that are not directly related to sonar. Additional opportunistic methods, such as those employed in this study, should be included in future BRS studies that could help reduce possible confounding factors. In addition, a comparison of localizations from day- and nighttime dolphin groups not exposed to sonar with those demonstrating a response to sonar, or focal follow observations designed to observe reactions to sonar, would be useful to further examine the idea that dolphins' responses to sonar are mediated by the context of the exposure.

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