JASA ARTICLE

Comparison of the marine soundscape before and during the COVID-19 pandemic in dolphin habitat in Sarasota Bay, FL[a)]

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ABSTRACT:
During the COVID-19 pandemic, changes in vessel activity and associated noise have been reported globally. Sarasota Bay is home to a large and increasing number of recreational vessels as well as a long-term resident community of bottlenose dolphins, *Tursiops truncatus*. Data were analyzed from two hydrophones to compare the soundscape during the COVID-19 pandemic to previous years (March–May 2020 and 2018/2019). Hourly metrics were calculated: vessel passes, 95th percentile sound levels [125 Hz and 16 kHz third octave bands (TOBs), and two broader bands: 88–1122 Hz and 1781–17 959 Hz], and dolphin whistle detection to understand changes in vessel activity and the effect on wildlife. Vessel activity increased during COVID-19 restrictions by almost 80% at one site and remained the same at the other site. Of the four sound level measures, only the 125 Hz TOB and 88–1122 Hz band increased with vessel activity at both sites, suggesting that these may be appropriate measures of noise from rapid pass-bys of small vessels in very shallow (<10 m) habitats. Dolphin whistle detection decreased during COVID-19 restrictions at one site but remained the same at the site that experienced increased vessel activity. The results suggest that pandemic effects on wildlife should not be viewed as homogeneous globally.

 https://doi.org/10.1121/10.0015366

(Received 14 July 2022; revised 16 October 2022; accepted 6 November 2022; published online 2 December 2022)

[Editor: James F. Lynch] Pages: 3170–3185

I. INTRODUCTION

Over the past half century, human activities have changed marine soundscapes (Hildebrand, 2009). Low frequencies are often dominated by commercial shipping and seismic exploration, whilst smaller vessels and sonar contribute to mid-frequency bands at a more localized scale (Hildebrand, 2009). Global ship traffic approximately doubled from 1950 to 2000 (Jones, 2019), and underwater ambient sound levels have increased by as much as 3 dB per decade in some areas (20–80 Hz and 200–300 Hz, Andrew *et al.*, 2002; 30–50 Hz, McDonald *et al.*, 2006). However, on rare occasions, regional changes in human behavior have shown that this upward trend in anthropogenic noise can be reversed. Following the events of September 11, 2001, reductions in ship traffic in the Bay of Fundy, Canada, led to a 6 dB decrease in underwater noise (50 Hz–20 kHz; Rolland *et al.*, 2012), whilst in the Salish Sea, voluntary commercial vessel slowdowns led to reductions in broadband (10 Hz–100 kHz) noise of 1.2–2.5 dB (Joy *et al.*, 2019).

More recently, the COVID-19 pandemic slowed human activity globally, which is termed the anthropause (Rutz *et al.*, 2020). During the spring of 2020, various restrictions were imposed across the globe to tackle the virus outbreak, leading to a reduction in anthropogenic noise in several terrestrial (e.g., Derryberry *et al.*, 2020) and marine (e.g., Pine *et al.*, 2021) environments. As economic activity decreased, the resulting slowdown in trade led to a 44% reduction in marine traffic globally (March *et al.*, 2021) with regional reductions in tanker vessels (Breeze *et al.*, 2021), fishing vessels (Depellegrin *et al.*, 2020), tourism vessels (Gabriele *et al.*, 2021), and recreational vessels (Basan *et al.*, 2021; Breeze *et al.*, 2021). Consequently, reductions in underwater sound have followed with decreases in low frequency noise of 1.0 dB in the third octave bands (TOB), centered at 63 Hz off of California (Ryan *et al.*, 2021), 1.6 dB (power density at 100 Hz) off of British Columbia (Thomson and Barclay, 2020), 1.2 dB (10 Hz–1 kHz) in the Baltic Sea (Basan *et al.*, 2021), and 4.0 dB (111–140 Hz) off of the Bahamas (Dunn *et al.*, 2021). Such reductions in noise have corresponded with changes in animal acoustic signals, such as a reduction in fish repertoire (Bertucci *et al.*, 2021) and decreased amplitude and lower minimum frequency of bird calls (Derryberry *et al.*, 2020).

To date, studies on COVID-19-induced changes in the marine environment have largely focused on low frequency noise in offshore shipping lanes, as well as in areas with other large vessels such as ferries (De Clippele and Risch, 2021) and cruise ships (Gabriele *et al.*, 2021).

[a)]This paper is part of a special issue on COVID-19 Pandemic Acoustic Effects.

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However, human behavior was also altered in coastal areas when restrictions were imposed on social and recreational activities. Although some studies have found changes in recreational vessel activity (Basan *et al.*, 2021; Breeze *et al.*, 2021), they likely underestimated the magnitude of the change as vessel traffic was quantified using automatic identification systems (AIS), which few recreational vessels use (Hermannsen *et al.*, 2019). Any changes in vessel activity are likely to be reflected in the underwater soundscape as small, recreational vessels are capable of emitting underwater noise as low as 125 Hz and over 100 kHz in frequency (Hermannsen *et al.*, 2019; Li *et al.*, 2015) and can elevate received sound levels up to 50 dB in frequency bands from 125 Hz to 16 kHz close to passing vessels (Hermannsen *et al.*, 2019). Increases in vessel activity and noise levels may have a negative impact on local marine life, including fish and marine mammals (Erbe *et al.*, 2016a; Erbe *et al.*, 2019; Nowacek *et al.*, 2007; Popper and Hawkins, 2016; Slabbekoorn *et al.*, 2010; Tyack, 2008). Noise produced by vessels can cause auditory masking, which is interference with the way in which marine mammals receive acoustic signals and important for communication, social interaction, foraging, and navigation (Erbe *et al.*, 2016a).

This study focusses on Sarasota Bay, FL, a shallow, coastal bay encompassed by Sarasota and Manatee counties, where the human population has more than tripled and the number of registered boats has quadrupled since 1970 (Powell and Wells, 2011). Sarasota Bay is also home to a well-known, long-term resident community of approximately 160 bottlenose dolphins (*Tursiops truncatus*) that have been studied by the Sarasota Dolphin Research Program since 1970 (Wells, 2009, 2014). Local human population growth and increased vessel use have led to increased exposure of the bottlenose dolphins to interactions with recreational fishing, boating, and coastal tourism operations with a vessel passing within 100 m of the dolphins every 6 min (Nowacek *et al.*, 2001). Collisions between dolphins and vessels are tightly clustered with periods of higher-than-normal boating activity (Wells and Scott, 1997) and can lead to changes in the social network of an injured individual (Greenfield *et al.*, 2021).

Bottlenose dolphins produce three types of sound. Two of the sounds are broadband, echolocation clicks and burst-pulsed sounds, and the third is the whistle, a frequency-modulated narrow-band sound (Caldwell *et al.*, 1990). Whistles are used to convey identity information (Janik *et al.*, 2006), facilitate group cohesion (Janik and Slater, 1998; Quick and Janik, 2012), and address conspecifics (King and Janik, 2013). Although whistles can propagate over hundreds of meters (Jensen *et al.*, 2012), sounds are attenuated to a much greater degree in the shallow seagrass habitats of Sarasota Bay (Quintana-Rizzo *et al.*, 2006). As well, noise emitted from small vessels, even at slow speeds, has the potential to reduce the range over which bottlenose dolphins communicate (Jensen *et al.*, 2009).

The aim of this study was to document changes in recreational vessel use in Sarasota Bay during the COVID-19 pandemic and measure any corresponding changes in sound levels and potential impact on wildlife. Despite this being an unforeseen event, a rich acoustic dataset exists as a result of the installation of a network of hydrophones at passive acoustic monitoring stations from 2017 onward, providing a rare opportunity to examine local changes in recreational vessel activity and resultant changes in the soundscape during a unique time in human history. We expected that during COVID-19-induced restrictions, recreational vessel activity and subsequent ambient sound levels would decrease, leading to an increase in dolphin whistle detection due to a combination of decreased masking by vessel noise and increased use of the local area due to reduction in vessels causing displacement of animals (Bejder *et al.*, 2006; Lusseau, 2005; Rako *et al.*, 2013).

II. METHODS

A. Acoustic data collection

Sarasota Bay is located on the central west coast of Florida and consists of a system of sheltered waterways and shallow bays, separated from the Gulf of Mexico by a series of barrier islands. The bathymetry of the bay varies from depths of <1 m over sandbars and seagrass meadows up to 10 m in waterways connecting to the Gulf of Mexico (Buckstaff, 2004). A network of passive acoustic listening stations (PALS) has been deployed in Sarasota Bay, FL, beginning in 2017. PALS are land-based, solar-powered passive acoustic monitoring devices, designed by Loggerhead Instruments, Inc. (Sarasota, FL), that continuously record and collect acoustic data from the marine environment using a submerged HTI-96-min hydrophone (sensitivity, -180 dB V/μPa; pre-amplifier gain, $+2$ dB; flat frequency response range, 2 Hz–30 kHz; High Tech Inc, Long Beach, MS; Rycyk *et al.*, 2020). Raw acoustic data, consisting of 5 min WAV files, are stored on microSD cards located within the PALS. Each file is time-stamped with UTC time (derived from cell network), which was converted to local time [Eastern Daylight Time (EDT)/Eastern Standard Time (EST)] prior to data processing and analysis.

The submerged hydrophones were connected to the land-based system via a cable that rested on the seafloor, and the recorders were set to sample continuously at 44.1 kHz, 16-bit resolution. Hydrophones were calibrated before deployment and new, recalibrated hydrophones were deployed if any issues were detected when data were retrieved. More than ten stations are now active in the bay, but only two stations were analyzed in this study (Fig. 1) as these had sufficient data collected during the COVID-19 pandemic period (1 March–31 May 2020), as well as comparable data from preceding years (1 March–31May 2018 or 2019). The hydrophone at Longboat Key (LBK; 27.419236° N, $-82.65464°$ W) was at a depth of $\sim$3.5 m, 2 m away from the seawall, where the seabed slopes deeper toward the channel. The hydrophone at Phillippi Creek Mouth (PCM; 27.271234° N, $-82.54273°$ W) was located on Siesta Key at a depth of $\sim$0.5 m on a sandy bottom that slopes steeply into

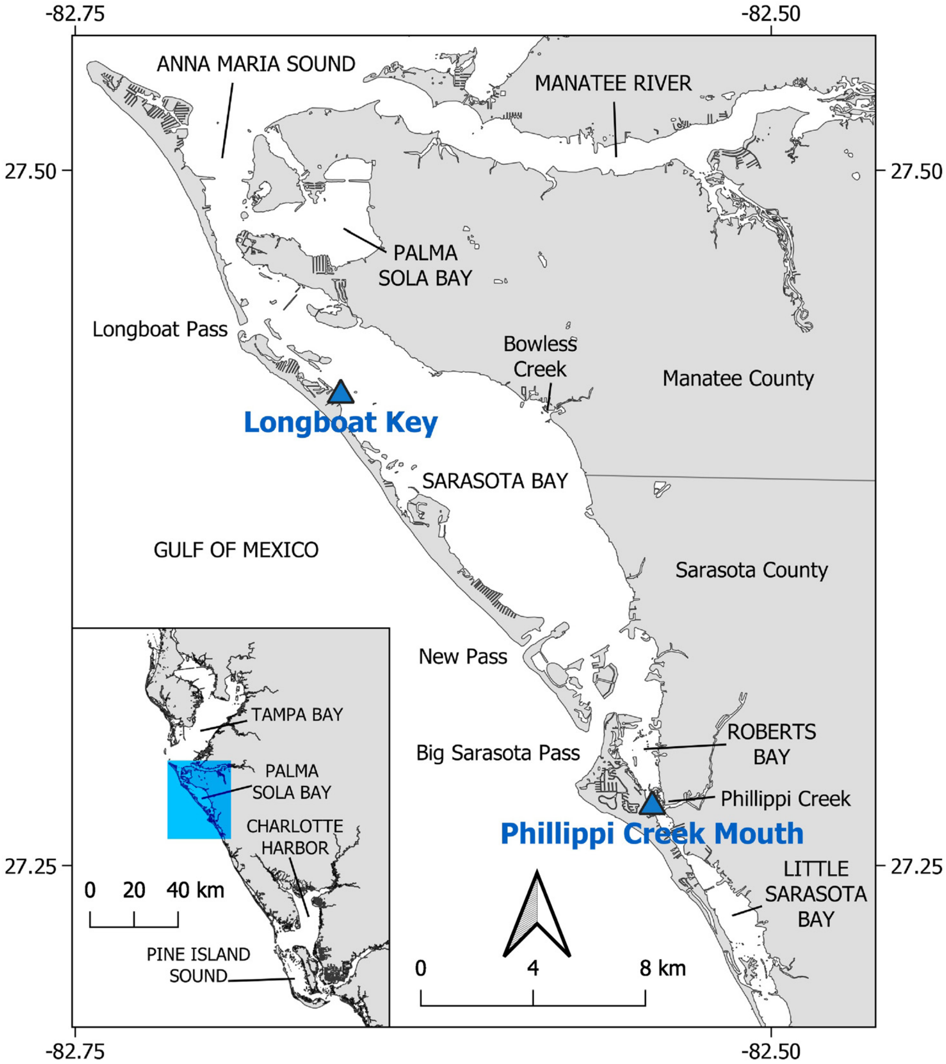

FIG. 1. (Color online) Locations of the PALS (blue triangles) installed in Sarasota Bay.

the boat channel. Both sites have a tidal range of less than 1 m. The two stations are close to the Intracoastal Waterway but have different activity patterns of vessels. LBK is in an unrestricted vessel speed area of the Intracoastal Waterway with a lot of personal recreational vessels housed nearby. PCM is at the intersection of a narrow constriction of the Gulf Intracoastal Waterway and Phillippi Creek that causes a bottleneck for vessels where boat traffic is heavy but speed is restricted; the site is frequented by many tourist vessels.

B. Vessel data

To aid in efficient processing of vessel pass counts, long-term spectral averages (LTSAs) were generated in PAMGuard (version 2.01.05; Gillespie *et al.*, 2009) at 1 s measurement intervals using 512 point fast Fourier transform (FFT) data. LTSAs were visually scanned for interference patterns, which represent a vessel passing the hydrophone, and annotated using PAMGuard's spectrogram annotation module. Vessel passes were only counted during the first 5 min of each hour due to the large volume of data collected, and the counts were used to represent the vessel pass rate during each hour of the day. Analysis of vessel passes during full hours of a random 5% subsample of the data (generated in *R* using the dplyr package; Wickham *et al.*, 2022) from each site was used to determine that the count of vessel passes within the first 5 min was representative of the full hour.

C. Ambient sound data

Masking occurs when the perception of one sound is affected by the presence of another sound within the same auditory filter band (Gelfand, 2004). Following Jensen *et al.* (2009), we approximated the delphinid auditory system as a bank of TOB filters as this is generally accepted as a reasonable approximation for the frequency bands over which mammalian ears integrate sound. Our analysis assumes that sound in one TOB has the potential to mask communication signals in that same TOB but not any other TOB, such as those on either side. As this study aims to understand changes in the soundscape due to small recreational vessels, TOBs centered at 125 Hz and 16 kHz were examined. TOBs centered at 63, 100, and 125 Hz are commonly used in studies looking at noise levels in relation to large commercial vessels (e.g., Breeze *et al.*, 2021; De Clippele and Risch, 2021;

Dunn *et al.*, 2021; Gospić and Picciulin, 2016; La Manna *et al.*, 2019; Ryan *et al.*, 2021) as well as in management frameworks to regulate vessel noise (e.g., European Marine Strategy Framework Directive, European Commission, 2010; Technical Sub-Group on Underwater Noise, Dekeling *et al.*, 2013). Although this study focused on small recreational vessels, the 125 Hz TOB was used for comparison. The 16 kHz TOB was also used as Hermannsen *et al.* (2019) found that small motorized vessels contributed high levels of noise in this band as they travelled at high speeds due to increased levels of broadband cavitation noise. Bottlenose dolphins are also around 60 dB more sensitive to sound in the 16 kHz TOB compared to the very low frequency TOBs commonly used as a measure of large commercial vessel activity (see Fig. 2 in Southall *et al.*, 2019). Two broadband sound levels were also calculated: a low frequency band (88–1122 Hz) to capture low frequency vessel noise and a high frequency band (1781–17959 Hz), which overlaps with the frequency range of dolphin whistles (Richardson *et al.*, 1995), which are thought to convey important information on the identity of the whistle owner (Janik *et al.*, 2006).

Third octave levels (TOLs) were computed using PAMGuard's Noise Band Monitor module. TOLs were quantified as 10 s averaged root mean square sound pressure levels in dB re 1 μPa measured in TOBs. Broadband sound measures were calculated by summing TOLs; a low broadband sound level (88–1122 Hz) summed TOLs centered at 100–1000 Hz and a high broadband sound level (1781–17 959 Hz) summed TOLs centered at 2–16 kHz. TOLs were converted to spectrum level (dB re 1 $\mu\text{Pa}^2\,\text{Hz}^{-1}$) for comparison of the full recording bandwidth between years.

D. Dolphin whistle data

The sampling rate used in this study (44.1 kHz) captures the bandwidth in which most anthropogenic noise overlaps with dolphin vocal communication signals (whistles; Fig. 2). The low sampling rate and presence of snapping shrimp clicks meant dolphin echolocation clicks (peak energy $\sim$20 to $>$100 kHz; Jones *et al.*, 2020) could not be accurately identified. Potential whistles were identified by processing recordings with PAMGuard's Whistle and Moan Detector using the spectrogram format (FFT length, 512; hop size, 256 samples).

Initial exploration of contours identified from the Whistle and Moan Detector suggested a high proportion of false detections; therefore, the contours were further classified. To do so, a random sample of 5% of data from both sites was manually scanned and contours identified by the Whistle and Moan Detector were visually inspected and labelled as either "true whistle" or "non-whistle." Most non-whistle contours came from fish sounds much lower in frequency than true whistles or propeller cavitation that overlapped in frequency with true whistles but spanned a much smaller frequency range. Therefore, the lowest frequency of the whistle contour and frequency range of the whistle contour were used for further classification.

Receiver operating characteristic (ROC) curves were computed for different cutoff thresholds for low frequency (0–5000 Hz) and minimum frequency (0–2500 Hz) ranges of the detected contours. ROC curves were plotted for each site separately due to differences in background sound conditions. Although the area under curve (AUC) can be used to determine the best ROC curve, in this circumstance, it was not appropriate as the priority was to minimize false positive detections. Therefore, the curves were visually inspected to determine the best frequency thresholds. The following criteria were used to define whistles: minimum frequency $>$3400 and 4600 Hz and frequency range $>$2000 and 1900 Hz for whistle segments from LBK and PCM, respectively. All of the contours detected in PAMGuard that were outside of these criteria were classified as non-whistles and removed from further analysis.

The Whistle and Moan Detector identifies tonal sounds within the recordings, often identifying segments of whistles rather than whole whistle contours due to interfering sounds such as echolocation clicks or overlapping whistles produced by other animals (Gillespie *et al.*, 2013).

Consequently, the number of contours is unlikely to reflect the true number of whistles present. As well, as whistle production is highly dependent on behavior, group size, and calf presence (Heiler *et al.*, 2016; La Manna *et al.*, 2019; Marley *et al.*, 2017), dolphins may be present but remain undetected if they are not whistling (pseudo-absence). Therefore, the dataset was then converted to whistle detection/pseudo-absence during each hour of the day. A 5% subset of data from each site was manually scanned to check the success of the classification criteria and suggested that 90% of hours at LBK and 96% of hours at PCM were correctly classified as either having whistles present or absent.

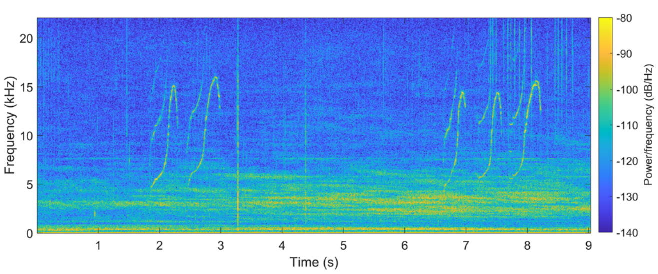

FIG. 2. (Color online) A representative spectrogram of the soundscape in Sarasota Bay, showing dolphin whistles and a vessel pass.

E. Statistical analysis

1. General approach

All statistical analyses were conducted in *R* (version 1.4.1103; R Core Team, 2020). Data were modelled separately for each site. Vessel pass counts were analyzed to determine if there was a change in vessel activity in the period between before and during the COVID-19 pandemic. Vessel count data were analyzed with generalized linear models (GLMs) using the MASS package (Venables and Ripley, 2002). Sound levels and whistle detection/pseudo-absence were then analyzed to understand their relationship with vessel activity and whether they changed before vs during the COVID-19 pandemic. As sound level and whistle detection were likely to be temporally autocorrelated across adjacent hours, generalized estimating equations (GEEs) were used. GEEs are an extension of GLMs, which relax the assumption of independence between observations, allowing for temporal autocorrelation in the data to be modelled (Photopoulou *et al.*, 2011). GEEs were fit to the data using the geepack package (Halekoh *et al.*, 2006). Only data during the daytime were modelled as recreational vessel use occurs primarily during the day. As well, high levels of fish chorusing occur during the night (Locascio and Mann, 2008), therefore, sound levels during the night are unlikely to reflect anthropogenic activity. Data exploration suggested most vessel activity occurred between 7 am and 9 pm, therefore, all of the data outside of these hours were removed from analysis.

Environmental variables were obtained from National Oceanographic and Atmospheric Administration (NOAA, 2022a, 2022b) and included rain (inches, daily total), wind (m/s, daily average), temperature (°F, daily maximum), and tide height (hourly). Prior to fitting models, correlations between independent variables were examined using cor.test from the stats package. As temperature and day of study were found to be highly positively correlated, only temperature was retained in the models as this is more likely to influence boaters' use of the water, sound levels, and dolphin use of an area. Sample size during April at LBK was low in both years due to technical issues with the hydrophones; however, GLMs and GEEs do not make any assumptions about distribution of independent variables. The model fit was explored using Akaike's Information Criterion (AIC; in the case of GLMs), quasi-likelihood information criterion (QIC; in the case of GEEs), plots of Pearson's residuals vs fitted values, plots of fitted values vs observed value, and quantile-quantile plots and histograms of the residuals. As GEEs are not likelihood-based models, AIC scores cannot be calculated. Therefore, QIC is used as an information criterion balancing goodness of fit and model complexity (Pan, 2001); a lower QIC value suggests a better fit of the model.

2. Vessel data

The response variable for the vessel pass data was the hourly vessel pass rate, scaled up from the number of vessels counted in the first 5 min of each hour. A negative binomial error distribution with log link function was used as it allows for a variance that is larger than the mean. The overdispersion parameter was calculated (variance/mean) and estimated to be 1.21 and 1.25 for the LBK and PCM data, respectively, suggesting a negative binomial error distribution was appropriate. Explanatory variables were year, day type (weekday or weekend), hour (representing an hour of the day, 7–20), rain, wind, temperature, and tide height. The covariate for hour of the day entered the model as the square of the hour to accommodate the nonlinear relationship between the vessel passes and hour of the day.

3. Ambient sound data

Hourly 95th percentile of ambient sound level reflects the sound level in the noisiest 5% of the data and is, therefore, more likely to reflect short duration, loud sounds such as vessel passes (Gabriele *et al.*, 2021). Hourly 95th percentile TOLs/broadband sound levels (calculated over 10 s intervals) represented the response variable in the sound level models. Sound levels were modelled using the hourly rate of vessel passes, year, day type, hour, wind, rain, temperature, and tide as explanatory variables to determine potential predictors of ambient sound.

The GEEs were run four times at each site for each TOB centered at 125 Hz and 16 kHz, and a low (88–1122 Hz) and high (1781–17959 Hz) frequency broadband sound level. A Run's test of model residuals confirmed that there was autocorrelation present in the data ($p < 0.001$); therefore, a blocking structure was used to model this correlation. To select clusters for the model blocking period (ID), plots were made using the autocorrelation function of model residuals over time. Correlation of hourly observations showed a clear daily pattern, therefore, separate days were treated as independent and a new variable, "day," representing each day of the study period, was used to define clusters of data points within which residuals were allowed to be autocorrelated.

The 95th percentile TOLs were found to be normally distributed, thus, they were modelled with a Gaussian distribution and identity link function. The GEEs were fit with multiple correlation structures (AR-1, exchangeable, unstructured) and Pan's QIC (Pan 2001) was used to investigate the most suitable correlation structure. QIC scores for competing models with different correlation structures were very similar. Therefore, an autoregressive (AR-1) correlation structure was implemented as the association among observations was assumed to be time dependent. No variable was excluded based on its significance as this study only aimed to identify whether temporal variation existed and not to model the cause of any such variation. This approach has been taken for similar studies aiming to understand variation in underwater soundscapes (Marley *et al.*, 2016).

4. Dolphin whistle data

Presence of dolphin whistles in consecutive hours on consecutive days form a time-series of observations which cannot be considered serially independent (Photopoulou *et al.*, 2011). Binomial GEEs were fit to the data for each site separately with explanatory variables: high frequency broadband sound (1781–17 959 Hz), hourly rate of vessel passes, year, day type, hour, wind, rain, temperature, and tide height.

A Run's test of model residuals confirmed autocorrelation in the data ($p < 0.001$); therefore, a blocking structure was used to model this correlation. Plots made using the autocorrelation function of model residuals over time showed a clear pattern of autocorrelation over the diel cycle, falling to zero after around 24 h; therefore, days were treated as independent and a new variable, day, representing each day of the study period, was used to define clusters of data points within which residuals were allowed to be autocorrelated. An auto-regressive correlation structure (AR-1) was used as the association among observations was assumed to be time dependent: whistle detection in an hour affects the probability of detection in the second hour but has less effect on the probability for the third hour and so on (Bailey *et al.*, 2013).

III. RESULTS

Underwater sound data were collected from 1 March to 31 May 2018 and 2020 at LBK and 1 March to 31 May 2019 and 2020 at PCM. Not all of the site/year combinations provided a complete dataset due to technical issues with the hydrophones or lack of solar power (Table I, Fig. 3). When hydrophones were not operating, this was usually for a number of days at a time (i.e., not occasional hours); therefore, when hydrophones were operating, they collected full-day datasets for the vast majority of the study period. The PALS at LBK were installed in late 2017. Although the hydrophone was operating at LBK throughout the study period in 2019, initial data exploration showed high occurrence of electrical noise throughout, spanning frequencies up to ~10 kHz that could not be compensated for; the 2019 data were, therefore, discarded from analysis. The PALS at LBK were fixed in November 2019, which allowed data collection throughout 2020. The PALS at PCM were installed in late 2018 and collected data throughout 2019 and 2020.

A. Vessel data

The linear model suggested that the vessel passes counted within the first 5 min of the hour were representative of the full hour with a strong positive correlation between the variables ($p < 0.05$, $R^2 = 0.87$ and 0.82 for LBK and PCM, respectively; Fig. 4). When comparing vessel pass rates between years, the GLM showed clear evidence of an increase in vessel activity at LBK in 2020 during the COVID-19 pandemic ($x^2 = 0.5$, $p < 0.001$; percent deviance = 15%; Table VI); the overall mean vessel pass rate increased by almost 80% when compared to 2018 (Table II). At PCM, the difference in detection of vessel passes between years was much less with a mean decrease in hourly vessel activity of −2.8% across the study period (Table II). However, the GLM showed no evidence of a significant change in vessel activity at PCM between the years ($x^2 = 0.04$, $p = 0.43$; percent deviance = 14%; Table VII). When comparing vessel activity within months during the pandemic (2020), at both sites fewer vessel passes were detected at the hydrophones during April than during March and May (Fig. 5). At LBK, almost twice the number of vessel passes were detected during March and May in 2020 compared to those during 2018 [Table II, Fig. 5(a)]; this pattern was absent in April, although limited data were available for this month (see Table I).

TABLE I. Hours of acoustic data collected each month from two PALS in Sarasota Bay, FL, during the COVID-19 pandemic (spring 2020) and previous years. Values shown are day-time hours between 7 am and 9 pm with % coverage below.

		March	April	May
LBK	2018	392	62	349
		90%	16%	80%
	2020	342	153	433
		77%	38%	100%
PCM	2019	434	420	434
		100%	100%	100%
	2020	333	420	322
		77%	100%	74%

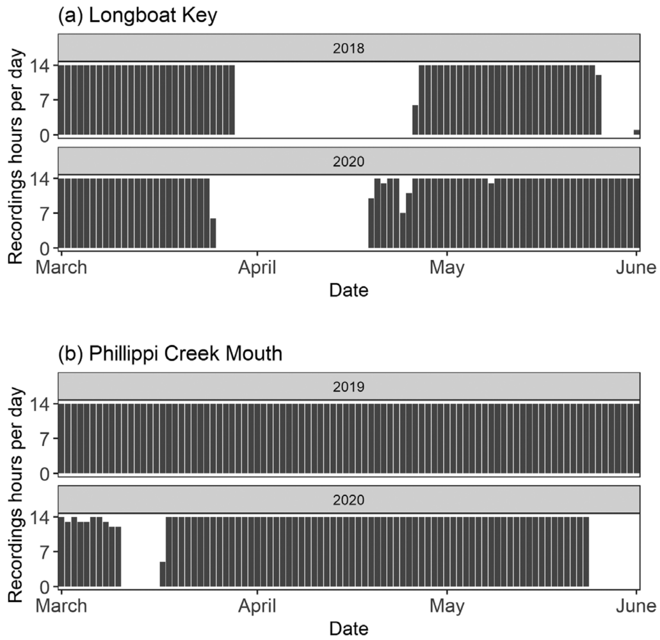

FIG. 3. Hours of acoustic data collected from PALS at (a) LBK and (b) PCM in Sarasota Bay, FL, before (March–May 2018/2019) and during (March–May 2020) the COVID-19 pandemic.

B. Ambient sound data

Sound levels across the study period varied within and between sites (Figs. 6 and 7). There was a prominent peak in the sound level in the 63 Hz TOB at LBK pertaining to electrical noise in the system. At LBK, sound levels in TOBs below 630 Hz were higher in 2020 but sound levels in TOBs above 630 Hz were lower in 2020; at PCM, sound levels in TOBs below 630 Hz were lower in 2020 but in sound levels TOBs above 630 Hz were higher.

At LBK, only the models of 125 Hz TOL and low frequency broadband sound level showed a significant effect of vessel passes per hour on sound level ($x^2 = 0.03$, $p < 0.05$ and $x^2 = 0.02$, $p < 0.01$; Table III; for full results, see Table VIII). However, in both models, there was no significant change in sound level between years (Fig. 8). The models of

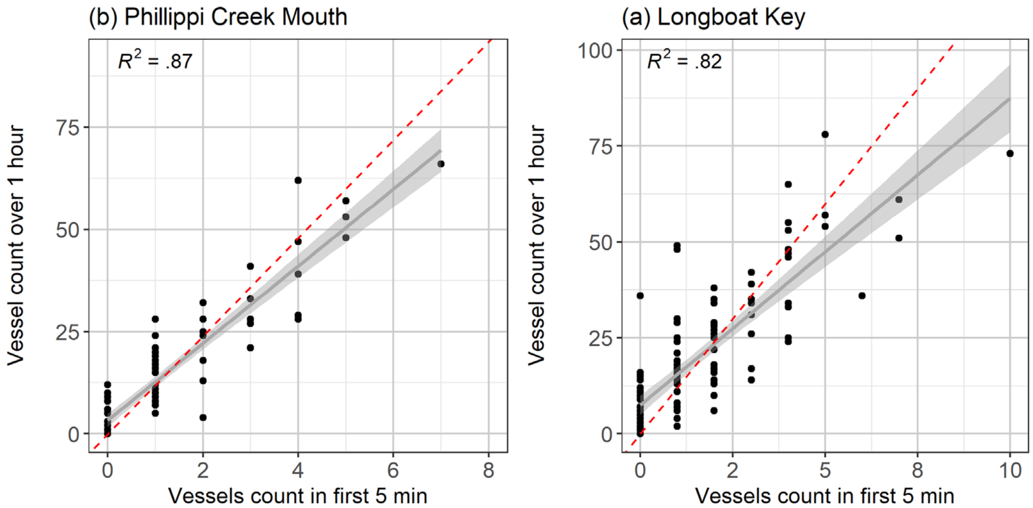

FIG. 4. (Color online) The vessels counted within the first 5 min were representative of the vessels counted within the full hour at both sites. Points show raw data with a linear regression (dark gray line) and 95% confidence intervals (gray shading); the red hashed line shows a perfect relationship between the two variables; R^2 values are shown for both sites.

sound level in the 16 kHz TOB and high frequency broadband sound level did show an increase during the pandemic ($x^2 = -2.8$, $p < 0.001$ and $x^2 = -3.7$, $p < 0.001$, respectively; Fig. 8) but no significant difference with vessel passes per hour.

At PCM, all of the models showed a significant increase in sound level with vessel passes per hour (Table IV; for full results, see Table IX). Both models of lower frequency measures found similar trends in sound levels. The GEE indicated that sound level in the 125 Hz TOB significantly increased with vessel passes per hour but decreased during the pandemic in 2020 ($x^2 = 0.04$, $p < 0.001$ and $x^2 = -5.5$, $p < 0.001$; Fig. 9, Table IV); similarly, the low frequency broadband sound level increased with vessel passes per hour and decreased during the pandemic in 2020 ($x^2 = 0.05$, $p < 0.001$ and $x^2 = -2.8$, $p < 0.001$; Fig. 9, Table IV). Models indicated a different pattern for the higher frequency measures. Sound level in the 16 kHz TOB increased significantly with vessel passes per hour and increased during the pandemic in 2020 ($x^2 = 0.02$, $p < 0.001$ and $x^2 = 1.7$, $p < 0.001$; Fig. 9, Table IV); high frequency broadband sound also increased with vessel passes per hour ($x^2 = 0.03$, $p < 0.001$) and during the pandemic in 2020 ($x^2 = -3.2$, $p < 0.001$; Fig. 9, Table IV).

TABLE II. The mean hourly vessel pass rate per month at two hydrophone stations in Sarasota Bay, FL, before the COVID-19 pandemic (2018 and 2019) and during the COVID-19 pandemic (2020).

		March	April	May	Overall
LBK	2018	12.5	19.5	13.2	13.4
	2020	24.6	19.2	25.3	24.0
	% change	+96.2%	−1.7%	+91.1%	+79.6%
PCM	2019	26.0	21.0	20.7	22.6
	2020	24.8	16.8	25.7	21.9
	% change	−4.8%	−20.0%	+24.5.0%	−2.8%

C. Dolphin whistle data

At LBK, dolphin whistles were detected on 91.5% of recording days in 2018 and 86.8% of recording days in 2020. At PCM, dolphin whistles were detected on 76.1% of recording days in 2019 and 51.3% in of recording days 2020. There were more whistle-positive hours earlier on in the study period at LBK, whereas PCM showed no clear pattern (Fig. 10).

The GEE model for LBK indicated a significant positive correlation between whistle detection and vessel passes per hour ($x^2 = 0.01$, $p < 0.05$; Table V; for full results see Table X) and no significant change in whistle detection before and during the pandemic or with high frequency broadband sound (1781–17 959 Hz). The GEE model at PCM indicated a significant decrease in whistle detection during the pandemic in 2020 ($x^2 = -0.6$, $p < 0.001$; Table V; for full results, see Table XI) and no significant relationship with high frequency broadband sound or vessel passes per hour. Whistle detection at both sites decreased with temperature ($x^2 = -0.04$, $p < 0.01$ and $x^2 = -0.05$, $p < 0.001$ for LBK and PCM, respectively; Table VII), but no significant relationships were found with any other environmental variables. The models fitted the data poorly based on the concordance correlation coefficients (0.04 and 0.03 for LBK and PCM, respectively), which indicated there was only 4% and 3% agreement between the fitted values under the model and observed data, respectively, therefore, the models should be treated with caution.

IV. DISCUSSION

Across the globe, human activity became restricted in early 2020 to combat the spread of COVID-19. In the ensuing months, many studies across the globe have reported decreases in large vessel activity and, subsequently, low frequency noise levels (Basan *et al.*, 2021; De Clippele and Risch, 2021; Dunn *et al.*, 2021; Gabriele *et al.*, 2021;

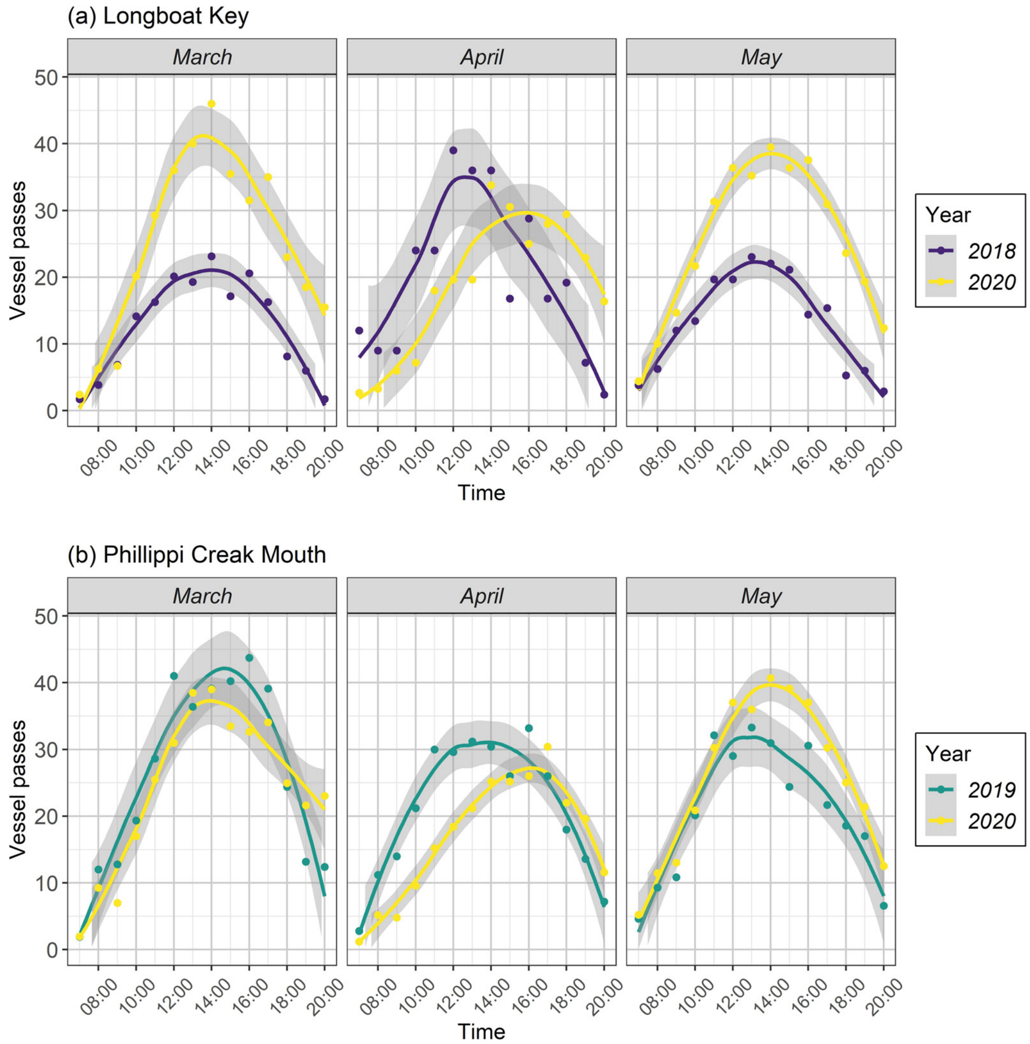

FIG. 5. (Color online) The vessel pass rate between 07:00 and 21:00 as measured at two hydrophone stations in Sarasota Bay, FL, before (2018 and 2019) and during (2020) the COVID-19 pandemic. Data from (a) LBK and (b) PCM (NB: Limited data were available for April at LBK).

Ryan *et al.*, 2021; Thomson and Barclay, 2020). More recently, Miksis-Olds *et al.* (2022) found that the total number of vessels in deep, offshore waters of the U.S. continental shelf remained fairly constant, although vessel composition changed: more pleasure craft, fishing vessels, and sailboats but fewer cargo vessels and tankers were present in 2020 (during the pandemic) compared to previous years. The results found here in the shallow, coastal area of Sarasota Bay, FL, contrast with those results found in places where decreased or constant vessel activity was found compared to an increase at one site in this study.

Across the study period (March–May), there was no overall change in vessel activity at one site and an 80% increase at the other site when comparing data from 2020 to previous years. In Florida, outdoor recreational activities, such as walking, biking, hiking, fishing, hunting, running, and swimming, were permitted throughout the lockdown, whereas indoor recreational activities and opening of gyms, bars, and restaurants were not (Office of the Governor of Florida, 2020a,b). The restrictions on indoor activities are likely the cause of the increase in recreational boat activity at LBK, where vessel traffic is largely made up of local, personal recreational vessels. Florida also has the greatest number of saltwater recreational anglers in the U.S. (U.S. Department of the Interior and U.S. Department of Commerce, 2006), and boat sales reportedly increased at the onset of the pandemic (McKnight, 2021). Therefore, this change in human behavior could have contributed to the large increase in vessel activity at LBK. At PCM, a lot of the vessel traffic is made up of tourist vessels that had reduced movements during the pandemic restrictions, which may be why increases in vessel traffic were not seen here.

When comparing vessel activity during the COVID-19 pandemic (March–May 2020), the pattern in vessel activity largely corresponds with the progression of the pandemic: on March 13th, a national emergency was declared in the U.S., yet, restrictions in the state of Florida did not come in force until April 3rd, potentially leading to the decrease in vessel activity during April compared to March of the same year. The results from April at LBK should be treated with caution due to the limited data available throughout the

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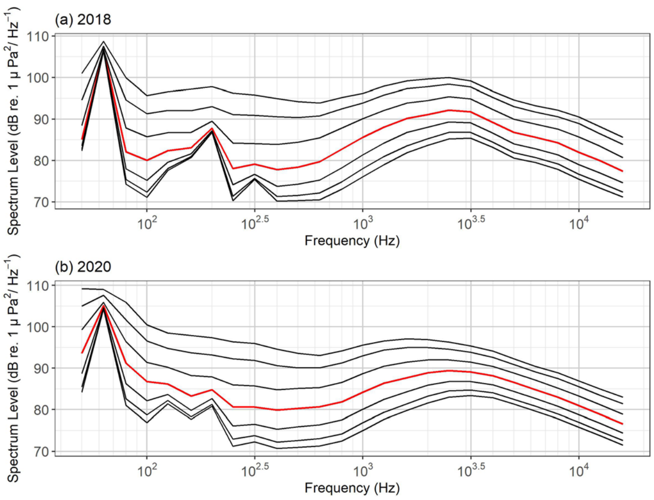

FIG. 6. (Color online) The power spectrum density (PSD) percentile plots comparing the soundscape at LBK, showing (a) before (March–May 2018) and (b) during the COVID-19 pandemic (March–May 2020). The *n*th percentile gives the value that the sound level was at or below *n*% of the time: the 50th (red) percentile is the median, whilst the 95th, 90th, 75th, 25th, 10th, and 5th percentiles (top to bottom) are shown in black.

TABLE III. The results from the GEE models showing the change in sound levels before (March–May 2018) and during the COVID-19 pandemic (March–May 2020) at LBK. Significance level is indicated by "*" $p < 0.05$, "***" $p < 0.001$. For full model results, see Table VIII in the Appendix.

Model term	Coefficient estimate	SE	Wald	Pr(>|W|)
125 Hz TOB				
Intercept	99.2	2.8	34.9	$<2 \times 10^{-16}$***
Hourly vessel passes	0.03	0.01	2.2	0.03*
2020 (baseline, 2018)	0.2	0.4	0.4	0.68
16 kHz TOB				
Intercept	114.2	0.6	191.0	$<2 \times 10^{-16}$***
Hourly vessel passes	−0.002	0.003	−0.8	0.42
2020 (baseline, 2018)	−2.8	0.09	−31.4	$<2 \times 10^{-16}$***
Low frequency broadband sound				
Intercept	116.79	1.88	62.12	$<2 \times 10^{-16}$***
Hourly vessel passes	0.02	0.008	2.5	0.01*
2020 (baseline, 2018)	−0.6	0.3	−2.0	0.04*
High frequency broadband sound				
Intercept	126.8	0.4	295.7	$<2 \times 10^{-16}$***
Hourly vessel passes	0.001	0.002	0.5	0.63
2020 (baseline, 2018)	−3.7	0.06	−57.2	$<2 \times 10^{-16}$***

month during both years; however, data from 2020 at PCM followed the same broad pattern. As the use of personal recreational vessels was still permitted during the restrictions, the reductions were not of the magnitude seen in other areas, such as the Hauraki Gulf, New Zealand's busiest coastal waterway, which became almost completely devoid of recreational vessels following the enforcement of a strict national lockdown (Pine *et al.*, 2021). Following the lifting of the Florida restrictions, vessel activity increased from April to May at both sites to above levels in May of previous years. This increase in May corresponds with the end of the statewide restrictions that were lifted on April 30th, as well as the reopening of local boat ramps (closed during 28 March–4 May in Sarasota City, near the PCM site, and 26 March–13 April in Manatee County, where LBK is located). Similar results were found in the Baltic Sea, where more recreational boating than ever before was recorded toward the end of 2020—thought to be due to an increase in national recreational boating as international travel restrictions limited foreign holidays (Basan *et al.*, 2021). This contrasts with the large decrease in recreational vessels seen in Halifax Harbor, Nova Scotia, in July 2020, four months after restrictions were first applied (Breeze *et al.*, 2021).

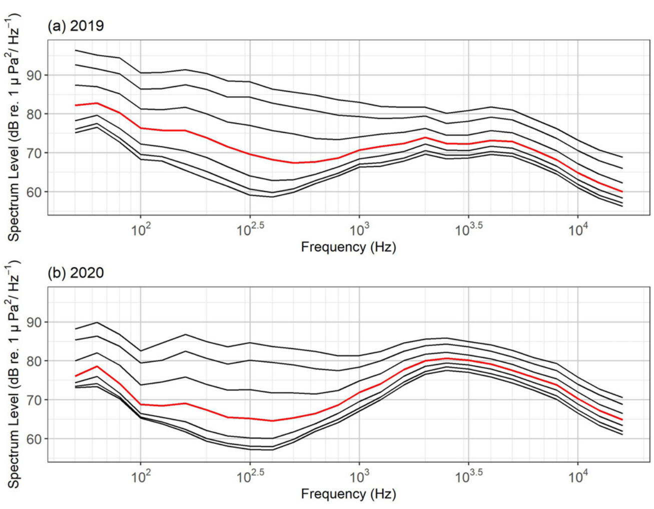

FIG. 7. (Color online) The PSD percentile plots comparing the soundscape at PCM, showing (a) before (March–May 2019) and (b) during the COVID-19 pandemic (March–May 2020). The *n*th percentile gives the value that the sound level was at or below *n*% of the time: the 50th (red) percentile is the median, whilst the 95th, 90th, 75th, 25th, 10th, and 5th percentiles (top to bottom) are shown in black.

Both low frequency sound measures (125 Hz TOB and 88–1122 Hz broadband) showed a significant positive correlation with vessel activity at both sites. Low frequency TOBs (63, 100, and 125 Hz) are commonly used as measures of large vessel noise (Dekeling *et al.*, 2013; European Commission, 2010; Ryan *et al.*, 2021; Thomson and Barclay, 2020), however, some studies point toward the lack of correlation between very low frequencies and small recreational vessels (Hermannsen *et al.*, 2014; Hermannsen *et al.*, 2019) due to poor propagation of low frequency sound in shallow areas (Erbe *et al.*, 2016b; Hermannsen *et al.*, 2014). Interestingly, higher frequency sound levels (16 kHz TOB and 1781–17 959 Hz band) showed significant relationships with vessel activity at only one site despite many studies showing positive trends up to frequencies of 37.5 kHz (Haviland-Howell *et al.*, 2007; Hermannsen *et al.*, 2019; Rako *et al.*, 2013). However, in this study, we were unable to estimate vessel speed, which is known to be correlated with noise level in the 16 kHz TOB (Hermannsen *et al.*, 2019) and could, therefore, have helped explain patterns in sound levels seen when vessels passed the hydrophone.

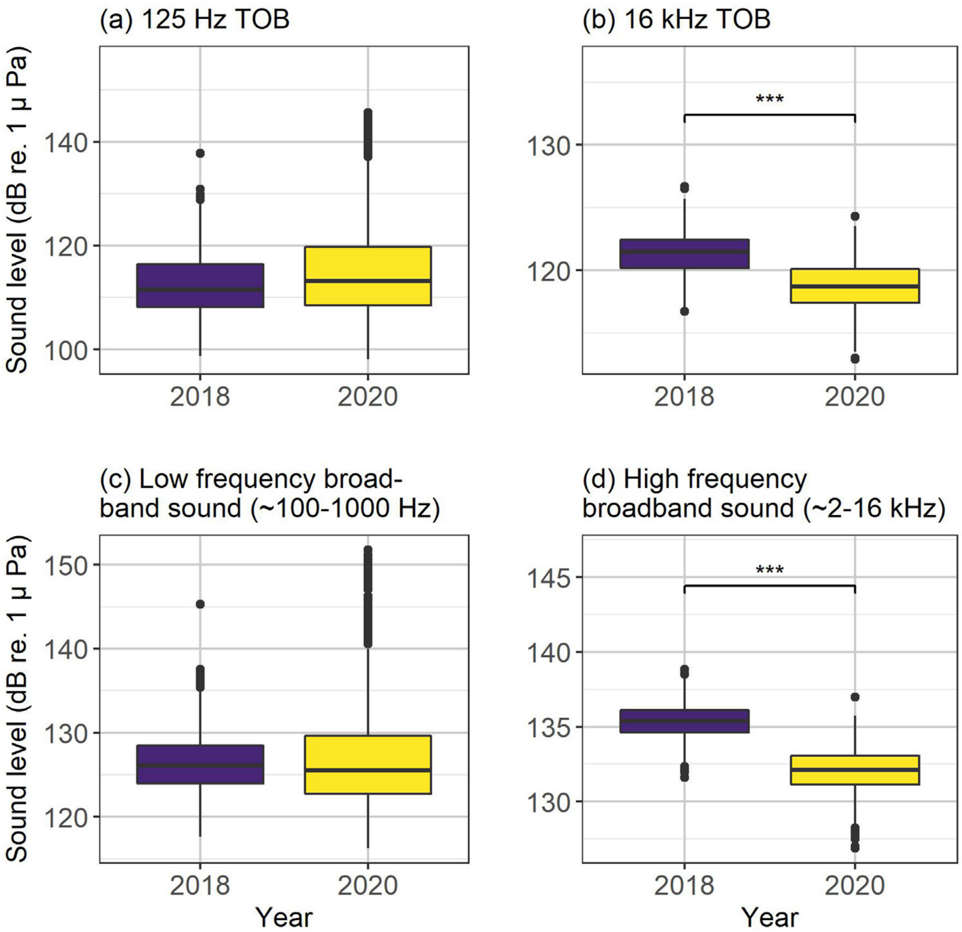

FIG. 8. (Color online) Hourly 95th percentile sound levels in two TOBs and two broader band levels at LBK in Sarasota Bay, FL, before (March–May 2018) and during the COVID-19 pandemic (March–May 2020). The significance level of $p<0.001$ is indicated by "***." Box plots show median values (solid horizontal line), first and third quartiles (box outline), minima and maxima (whiskers), and outliers (points).

In similar studies on larger vessel types, the median and 95th percentile sound levels correlated well with vessel activity (Basan *et al.*, 2021; Breeze *et al.*, 2021; De Clippele and Risch, 2021; Dunn *et al.*, 2021; Gabriele *et al.*, 2021; Thomson and Barclay, 2020). However, larger ships in deeper, offshore areas produce near-constant low frequency noise that can propagate over large distances. Here, small recreational vessels were only visible on the spectrogram for ∼20 s and will only raise ambient sound levels for a very short period, which, when averaged over an hour, will have a small effect. The higher frequency sounds of small recreational vessels also attenuate more quickly. At PCM, where higher frequency sound levels (16 kHz TOB and 1781–17 959 Hz band) correlated with vessel activity, boats were generally travelling at slower speeds than those at LBK, where there was no significant relationship between higher frequency sound levels and vessel activity. Therefore, although slower boats at PCM may be contributing less noise at higher frequencies, ambient sound levels would have been raised for a longer period. Similar results were found by Rycyk *et al.* (2022), who studied manatee detection of boats in the study area; faster boats produced higher levels of noise but were detectable much later than slower boats because of the greater distance they travel in a shorter time, moving into and beyond detection range more quickly. In this study, an averaging window of 10 s was used, but for very quick vessel passes, an even shorter window or higher percentile may be more appropriate to measure recreational vessel activity. Despite a lack of relationship between some sound measures and vessel activity, the short, loud sounds

TABLE IV. The results from the GEE models showing the change in sound levels before (March–May 2019) and during the COVID-19 pandemic (March–May 2020) at PCM. Significance level is indicated by "**" $p<0.01$, "***" $p<0.001$. For full model results, see Table IX in the Appendix.

125 Hz TOB				
Intercept	88.3	2.03	43.6	$<2\times10^{-16}$***
Hourly vessel passes	0.04	0.01	5.4	7×10^{-8}***
2020 (baseline, 2018)	−5.5	0.3	−21.1	2×10^{-90}***
16 kHz TOB				
Intercept	99.2	1.4	71.0	$<2\times10^{-16}$***
Hourly vessel passes	0.01	0.01	3.0	0.003**
2020 (baseline, 2018)	1.7	0.2	9.6	$<2\times10^{-16}$***
Low frequency broadband sound				
Intercept	99.5	1.7	57.9	$<2\times10^{-16}$***
Hourly vessel passes	0.05	0.006	7.4	1×10^{-13}***
2020 (baseline, 2018)	−2.7	0.2	−12.4	$<2\times10^{-16}$***
High frequency broadband sound				
Intercept	116.1	1.2	97.9	$<2\times10^{-16}$***
Hourly vessel passes	0.03	0.004	6.3	3×10^{-10}***
2020 (baseline, 2018)	3.1	0.2	20.4	$<2\times10^{-16}$***

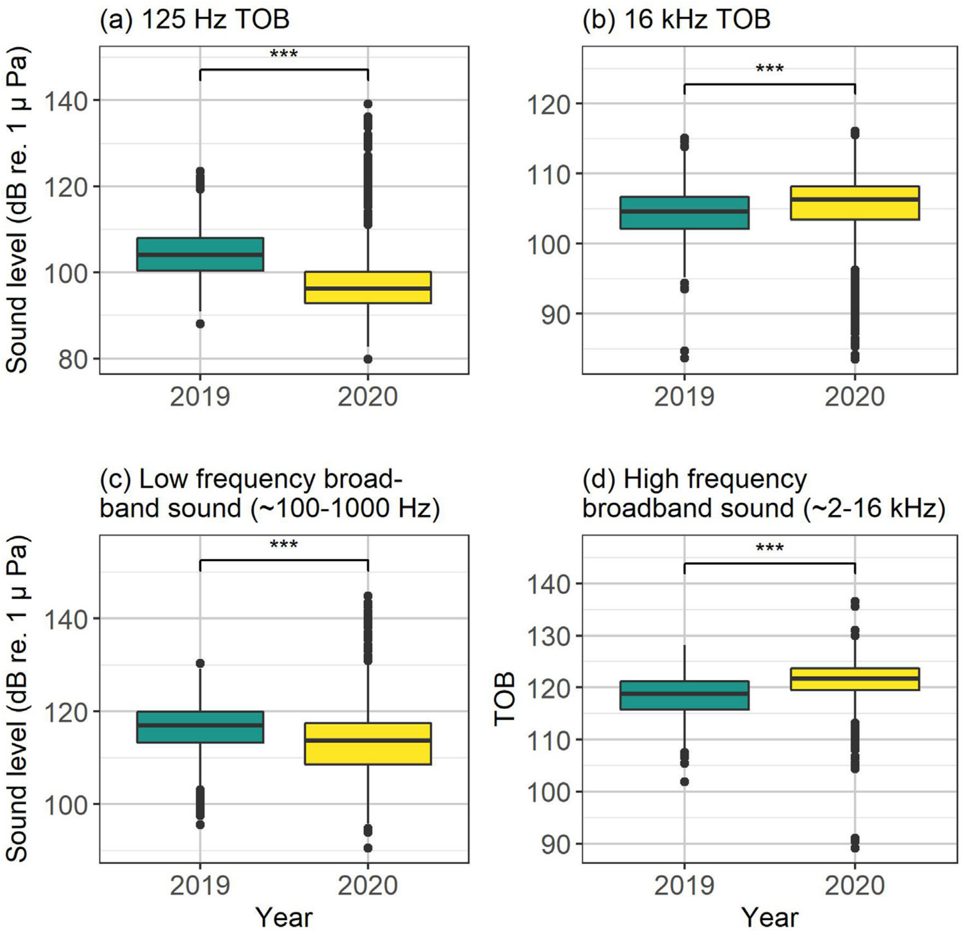

FIG. 9. (Color online) Hourly 95th percentile sound levels in two TOBs and two broader band levels at PCM in Sarasota Bay, FL, before (March–May 2019) and during the COVID-19 pandemic (March–May 2020). The significance level of $p < 0.001$ is indicated by "***." Box plots show median values (solid horizontal line), first and third quartiles (box outline), minima and maxima (whiskers), and outliers (points).

of passing vessels still have the potential to effect communication of bottlenose dolphins by leading to changes in whistle amplitude (Kragh *et al.*, 2019) or frequency characteristics (Gospić and Picciulin, 2016).

There was potential that during periods of increased vessel activity, fewer whistles would be detected due to masking from vessel noise. However, hourly whistle detection showed the opposite pattern and increased with vessel activity at LBK, suggesting that masking bias was not an issue in detecting whistles. This result potentially highlights the response documented by Buckstaff (2004) that individual dolphins increase whistle rate at the onset of vessel approaches. These communication signals are then likely to lead to behavioral responses such as decreasing inter-animal

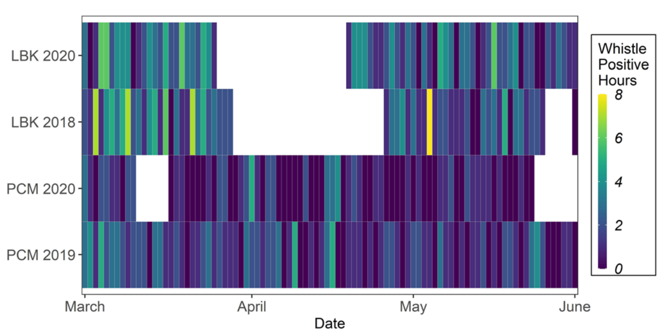

FIG. 10. (Color online) Bottlenose dolphin whistle-positive hours per day at two stations in Sarasota Bay, FL, during the COVID-19 pandemic (March–July 2020) and previous years (March–July 2018 and March–July 2019). Only data from 7 am–9 pm are included (maximum whistle-positive hours per day = 14). Blank periods show times with missing data due to faults with the hydrophones. LBK refers to the Longboat Key station; PCM refers to the PCM station.

TABLE V. The results from the binomial GEE models using AR-1 correlation structures, investigating temporal patterns of bottlenose dolphin whistle detection/pseudo-absence at two hydrophone stations in Sarasota Bay, FL, during the COVID-19 pandemic (spring 2020) and previous years. Significance level is indicated by: "*" $p < 0.05$, "***" $p < 0.001$.

Model term	Coefficient estimate	SE	Wald	Pr(>|W|)
LBK				
Intercept	6.5	3.7	1.8	0.076
High frequency broadband sound level	−0.04	0.03	−1.5	0.14
Hourly vessel passes	0.01	0.002	2.5	0.01*
2020 (baseline, 2018)	−0.1	0.1	−1.1	0.28
PCM				
Intercept	−2.0	2.9	−0.7	0.50
High frequency broadband sound level	0.03	0.02	1.2	0.23
Hourly vessel passes	0.004	0.005	0.8	0.44
2020 (baseline, 2018)	−0.6	0.2	−3.7	0.00025***

distance (Nowacek *et al.*, 2001) or altering behavioral state from activities such as foraging and socializing to travelling (Arcangeli and Crosti, 2009; Constantine *et al.*, 2004; Lusseau, 2003; Marley *et al.*, 2017; Steckenreuter *et al.*, 2012; Stensland and Berggren, 2007) in response to the oncoming vessel. The lack of change in whistle detection between 2018 and 2020 at LBK suggests dolphins did not avoid the area during the pandemic despite an increase in vessel activity of ∼80%. Site avoidance is a common response to increasing vessel activity found in bottlenose dolphin populations elsewhere (La Manna *et al.*, 2013; Rako *et al.*, 2013; Steckenreuter *et al.*, 2012) but may occur over a longer time scale than that studied here (Bejder *et al.*, 2006). Or, as vessel activity around the dolphins in the area is already so high (Nowacek *et al.*, 2001), the changes found here may not be great enough to influence site use.

It should be noted that the use of whistles alone does limit the inferences able to be drawn about dolphin abundance as whistle production is highly dependent on behavior, group size, and calf presence (Heiler *et al.*, 2016; La Manna *et al.*, 2019; Marley *et al.*, 2017). Differences in bathymetry, bottom type, and depth may impact propagation distance of signals of interest (Quintana-Rizzo *et al.*, 2006) and, therefore, limit comparison between sites; however, it does not impact analyses within sites where data were sampled continuously across the tidal cycle at the same location. As well, the models of whistle detection fitted the data very poorly, potentially due to missed detections; hence, there may be stronger drivers of whistle detection and dolphin presence that are not clear here. Although no significant change in whistle detection was found to correspond with the increase in vessel activity at LBK, dolphins may have still responded to the change in vessel presence. Bottlenose dolphins have been found to change whistle characteristics, such as amplitude (Kragh *et al.*, 2019) and frequency parameters (Gospić and Picciulin, 2016; Luís *et al.*, 2014; La Manna *et al.*, 2019; May-Collado and Wartzok, 2008), in response to vessel noise, neither of which were measured in this study. In other studies, animals that experienced a decrease in anthropogenic activity during the COVID-19 pandemic also modified their vocal characteristics: bottlenose dolphins produced whistles that were longer in duration and less modulated (Gagne *et al.*, 2022), songbirds produced higher performance songs with lower amplitude (Derryberry *et al.*, 2020), and fish reduced their repertoire size (Bertucci *et al.*, 2021).

At the onset of the pandemic, the media were filled with stories of reduced anthropogenic pressures on wildlife, cleaner air and water, and wildlife reclaiming former habitats. It was initially thought that restrictions in place across the globe would lead to a decrease in anthropogenic impacts and, thus far, studies have found dramatic decreases in recreational vessel activity (Pine *et al.*, 2021), large vessel activity (March *et al.*, 2021), sound levels (Derryberry *et al.*, 2020; Thomson and Barclay, 2020), CO_2 emissions (Le Quéré *et al.*, 2020), and myriad other anthropogenic stressors. However, other studies have found increases in potentially harmful anthropogenic activities, such as use of fishing, sailing, and pleasure craft (Miksis-Olds *et al.*, 2022). When compared alongside the current literature, this study further highlights the need for local assessments of changes in human behavior and impacts on wildlife, which are unlikely to be homogenous across the globe. Studying disturbance of animals, such as coastal dolphins, requires a much more local approach compared to large baleen whales, which are known to respond behaviorally to vessels over 1 km away (Tsujii *et al.*, 2018). At hydrophone stations within 20 km of each other, this study has found increases and consistently high recreational vessel activity when comparing the COVID-19 period to previous years. Projects like the International Quiet Ocean Experiment (Tyack *et al.*, 2021) and the COVID-19 Bio-Logging Initiative (Rutz *et al.*, 2020) will hopefully bring together results from across the globe and lead to sampling strategies that are adequate to map out changes in anthropogenic stressors and responses of wildlife.

ACKNOWLEDGMENTS

Mote Scientific Foundation provided funding for the initial development of PALS. We thank R. Moskovitz, N. Moskovitz, J. Holbrook, and K. Holbrook for providing support and a location for installation of the PALS at LBK, and M. Maguire for providing the PCM site. We also acknowledge the Disney Conservation Fund, Charles and Margery Barancik Foundation, and Rick and Nancy Moskovitz Foundation for providing operating support for the Sarasota Bay Listening Network. P.L.T. acknowledges support by the Office of Naval Research (Grant Nos. N000142012697 and N000142112096) and the Strategic Environmental Research and Development Program (Grant Nos. RC20-1097, RC20-7188, and RC21-3091).

APPENDIX

Tables VI–XI are included herein.

TABLE VI. The results of Poisson GLMs investigating temporal patterns of vessel pass rate at LBK in Sarasota Bay, FL, before (March–May 2018) and during the COVID-19 pandemic (March–May 2020). Significance level is indicated by: "***" $p < 0.001$.

Model term	Coefficient estimate	SE	z-value	Pr(>|z|)
Intercept	0.6	0.4	1.7	0.09
2020 (baseline, 2018)	0.5	0.1	10.2	$<2 \times 10^{-16}$***
Weekend (baseline, weekday)	0.4	0.1	7.7	3×10^{-14}***
I(hour^2)	0.001	0.0002	3.4	0.0006***
Rain	−1.0	0.1	−12.2	$<2 \times 10^{-16}$***
Wind	−0.1	0.01	−9.3	3×10^{-20}***
Temperature	0.02	0.004	5.3	2×10^{-7}***
Tide	2.0	0.2	12.3	$<2 \times 10^{-16}$***

TABLE VII. The results of Poisson GLMs investigating temporal patterns of vessel pass rate at PCM in Sarasota Bay, FL, before (March–May 2019) and during the COVID-19 pandemic (March–May 2020). Significance level is indicated by: "**" $p < 0.01$, "***" $p < 0.001$.

Model term	Coefficient estimate	SE	z-value	Pr(>|z|)
Intercept	1.7	0.3	5.7	1×10^{-8}***
2020 (baseline, 2018)	0.03	0.04	0.8	0.41
Weekend (baseline, weekday)	0.4	0.04	9.7	$<2 \times 10^{-16}$***
I(hour^2)	0.002	0.0002	11.2	$<2 \times 10^{-16}$***
Rain	−1.0	0.07	−14.4	$<2 \times 10^{-16}$***
Wind	−0.1	0.007	−11.8	$<2 \times 10^{-16}$***
Temperature	0.01	0.003	3.1	0.002**
Tide	2.0	0.1	15.9	$<2 \times 10^{-16}$***

TABLE VIII. The results from the GEE models using AR-1 correlation structures on sound levels at LBK in Sarasota Bay, FL, before (March–May 2018) and during the COVID-19 pandemic (March–May 2020). Significance level is indicated by: "*" $p < 0.05$, "**" $p < 0.01$, "***" $p < 0.001$.

Model term	Coefficient estimate	SE	Wald	Pr(>|W|)
125 Hz TOB				
Intercept	99.2	2.8	34.9	$<2 \times 10^{-16}$***
Hourly vessel passes	0.03	0.01	2.2	0.03*
2020 (baseline, 2018)	0.2	0.4	0.4	0.68
Weekend (baseline, weekday)	3.0	0.5	6.3	3×10^{-10}***
I(hour^2)	0.006	0.002	3.2	0.001**
Rain	−2.3	0.6	−4.1	5×10^{-5}***
Wind	0.8	0.1	10.5	$<2 \times 10^{-16}$***
Temperature	0.04	0.03	1.1	0.27
Tide	5.4	1.3	4.1	4×10^{-5}***
16 kHz TOB				
Intercept	114.2	0.6	191.0	$<2 \times 10^{-16}$***
Hourly vessel passes	−0.002	0.003	−0.8	0.42
2020 (baseline, 2018)	−2.8	0.09	−31.4	$<2 \times 10^{-16}$***
Weekend (baseline, weekday)	0.2	0.1	1.9	0.06
I(hour^2)	0.004	0.0004	11.0	$<2 \times 10^{-16}$***
Rain	0.2	0.12	1.8	0.08
Wind	−0.07	0.017	−4.1	4×10^{-5}***
Temperature	0.1	0.007	13.5	$<2 \times 10^{-16}$***
Tide	−1.8	0.28	−6.5	1×10^{-10}***
Low frequency broadband sound				
Intercept	116.79	1.88	62.12	$<2 \times 10^{-16}$***
Hourly vessel passes	0.02	0.008	2.5	0.01*
2020 (baseline, 2018)	−0.6	0.3	−2.0	0.04*
Weekend (baseline, weekday)	2.3	0.3	7.3	3×10^{-13}***
I(hour^2)	0.002	0.001	1.8	0.06
Rain	−1.6	0.4	−4.4	1×10^{-5}***
Wind	0.5	0.05	9.1	$<2 \times 10^{-16}$***
Temperature	0.04	0.02	1.8	0.078
Tide	4.1	0.9	4.	3×10^{-6}***
High frequency broadband sound				
Intercept	126.8	0.4	295.7	$<2 \times 10^{-16}$***
Hourly vessel passes	0.001	0.002	0.5	0.63
2020 (baseline, 2018)	−3.7	0.06	−57.2	$<2 \times 10^{-16}$***
Weekend (baseline, weekday)	0.2	0.07	3.2	0.002**
I(hour^2)	0.002	0.0003	10.0	$<2 \times 10^{-16}$***
Rain	0.04	0.08	0.5	0.62
Wind	−0.02	0.01	−1.3	0.2
Temperature	0.1	0.01	20.6	$<2 \times 10^{-16}$***
Tide	−0.7	0.2	−3.7	0.0002***
Intercept	126.8	0.4	295.7	$<2 \times 10^{-16}$***

TABLE IX. The results from the GEE models using AR-1 correlation structures on noise levels at PCM in Sarasota Bay, FL, before (March–May 2019) and during the COVID-19 pandemic (March–May 2020). Significance level is indicated by: "**" $p < 0.01$, "***" $p < 0.001$.

Model term	Coefficient estimate	SE	Wald	Pr(>|W|)
125 Hz TOB				
Intercept	88.3	2.03	43.6	$<2 \times 10^{-16}$***
Hourly vessel passes	0.04	0.01	5.4	7×10^{-8}***
2020 (baseline, 2018)	−5.5	0.3	−21.1	2×10^{-90}***
Weekend (baseline, weekday)	2.2	0.3	7.4	3×10^{-13}***
I(hour^2)	0.005	0.001	3.8	0.0002***
Rain	−2.0	0.4	−5.7	1×10^{-8}***
Wind	−0.1	0.05	−1.6	0.1
Temperature	0.1	0.02	5.7	2×10^{-8}***
Tide	8.9	0.9	9.9	$<2 \times 10^{-16}$***
16 kHz TOB				
Intercept	99.2	1.4	71.0	$<2 \times 10^{-16}$***
Hourly vessel passes	0.01	0.01	3.0	0.003**
2020 (baseline, 2018)	1.7	0.2	9.6	$<2 \times 10^{-16}$***
Weekend (baseline, weekday)	0.6	0.2	3.1	0.002**
I(hour^2)	−0.001	0.001	−0.7	0.46
Rain	0.9	0.2	3.5	0.0004***
Wind	−0.2	0.04	−4.4	1×10^{-5}***
Temperature	0.1	0.02	4.0	7×10^{-5}***
Tide	0.3	0.6	0.5	0.65
Low frequency broadband sound				
Intercept	99.5	1.7	57.9	$<2 \times 10^{-16}$***
Hourly vessel passes	0.05	0.006	7.4	1×10^{-13}***
2020 (baseline, 2018)	−2.7	0.2	−12.4	$<2 \times 10^{-16}$***
Weekend (baseline, weekday)	2.1	0.3	8.2	4×10^{-16} ***
I(hour^2)	0.005	0.001	4.9	9×10^{-7}***
Rain	−1.01	0.3	−3.3	0.0008***
Wind	−0.1	0.04	−3.4	0.0007***
Temperature	0.1	0.02	6.5	1×10^{-10}***
Tide	10.4	0.8	13.7	$<2 \times 10^{-16}$***
High frequency broadband sound				
Intercept	116.1	1.2	97.9	$<2 \times 10^{-16}$***
Hourly vessel passes	0.03	0.004	6.3	3×10^{-10}***
2020 (baseline, 2018)	3.1	0.2	20.4	$<2 \times 10^{-16}$***

TABLE IX. (*Continued*)

Model term	Coefficient estimate	SE	Wald	Pr(>|W|)
Weekend (baseline, weekday)	1.1	0.2	6.3	2×10^{-10}***
I(hour^2)	−0.01	0.001	−11.2	$<2 \times 10^{-16}$***
Rain	0.8	0.2	4.0	8×10^{-5}***
Wind	−0.2	0.03	−7.8	8×10^{-15}***
Temperature	0.04	0.01	2.8	0.005***
Tide	3.7	0.5	7.0	3×10^{-12}***

TABLE X. The results from the GEE models using AR-1 correlation structures on whistle detection at LBK in Sarasota Bay, FL, before (March–May 2018) and during the COVID-19 pandemic (March–May 2020). Significance level is indicated by: "*" $p < 0.05$, "**" $p < 0.001$.

Model term	Coefficient estimate	SE	*z*-value	Pr(>|z|)
Intercept	6.5	3.7	1.8	0.076
High frequency broadband sound level	−0.04	0.03	−1.5	0.14
Hourly vessel passes	0.01	0.002	2.5	0.01*
2020 (baseline, 2018)	−0.1	0.1	−1.1	0.28
Weekend (baseline, weekday)	−0.2	0.09	−2.3	0.019*
I(hour^2)	0.01	0.01	0.8	0.40
Rain	0.01	0.01	0.7	0.47
Wind	−0.03	0.1	−0.3	0.75
Temperature	−0.02	0.01	−3.4	0.0008***
Tide	−0.4	0.2	−1.9	0.058

TABLE XI. The results from the GEE models using AR-1 correlation structures on whistle detection at PCM in Sarasota Bay, FL, before (March–May 2019) and during the COVID-19 pandemic (March–May 2020). Significance level is indicated by: "***" $p < 0.001$.

Model term	Coefficient estimate	SE	*z*-value	Pr(>|z|)
Intercept	−2.0	2.9	−0.7	0.50
High frequency broadband sound level	0.03	0.02	1.2	0.23
Hourly vessel passes	0.004	0.005	0.8	0.44
2020 (baseline, 2018)	−0.6	0.2	−3.7	0.00025***
Weekend (baseline, weekday)	−0.3	0.2	−1.4	0.16
I(hour^2)	0.003	0.02	0.2	0.88
Rain	0.03	0.03	1.0	0.32
Wind	−0.004	0.2	−0.02	0.98
Temperature	−0.05	0.01	−3.7	0.0002***
Tide	0.8	0.5	1.6	0.12

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