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Responses of Bottlenose Dolphins (*Tursiops truncatus*) to Construction and Demolition of Coastal Marine Structures

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Abstract

Construction and demolition activities are commonplace in offshore and coastal waters, in habitats that are important feeding and breeding grounds for marine mammals. In Sarasota Bay, Florida, the construction of a large fixed-span bridge was completed in July 2003, followed by two in-air explosions and a final underwater explosion to demolish the pre-existing drawbridge. Boat-based surveys were conducted to compare distribution of bottlenose dolphin (*Tursiops truncatus*) sightings during bridge construction and demolition to historical sighting records. Additionally, underwater sound pressure levels were monitored at six listening stations to the north and south of the bridge. Dolphin density in the vicinity of the bridge was significantly higher after construction was completed than during construction. The few bottlenose dolphins that used the waters in the general vicinity of the bridge during construction did not appear to avoid the bridge, suggesting that some bottlenose dolphins may still have preferred the habitat around the bridge despite the construction and demolition noise. During the underwater detonation, the small sample of observed bottlenose dolphins decreased nearest neighbor distance, increased group size, and exhibited heading changes. The underwater explosion, which was contained by a steel coffercell, was quieter under water than were both in-air explosions, also measured under water. Based on these results, in-air explosions occurring close to water level (< 5 m) should be considered for their potential to effect marine mammals. These explosions and persistent noise associated with construction and/or demolition operations could have contributed to the change in density of the bottlenose dolphins observed near the bridge.

Key Words: bottlenose dolphin, *Tursiops truncatus*, behavior, bridge, distribution, explosion, noise

Introduction

Of all of the anthropogenic noise sources in the marine environment, construction and demolition noise and their effects have received perhaps the least attention, and yet they are commonplace activities in many offshore and coastal waters. In the Gulf of Mexico alone, thousands of oil production platforms have been constructed since the mid-1900s, and more than 100 of the older rigs are being removed each year (Klima et al., 1988). Coastal development involves the construction of bridges, causeways, piers, and other structures at the water's edge. Further development leads to the replacement of existing structures and removal of the older structures. These activities occur within the geographic ranges of a variety of marine animals, but little work has been done to evaluate their impact on marine mammals.

Indeed, even in one of the most comprehensive reviews of anthropogenic noise in the ocean, Richardson et al. (1995) found only one documented case in which the potential effects of coastal construction on a cetacean species were explored. The pace of such work has not changed substantially. Early work with bowhead whales (*Balaena mysticetus*) indicated that they avoid areas of heavy industrial activity. Richardson et al. (1985) examined distribution patterns of bowhead whales exposed to oil and gas exploration and production in the Beaufort Sea relative to historical records and noted shifts in habitat usage. In another study, bowhead whales were distributed farther from a drilling rig than they would be under a random scenario (Schick & Urban, 2000). At a construction site in waters off western Hong Kong, groups of Indo-Pacific humpback dolphins (*Sousa chinensis*) doubled their swim speed during periods of active pile driving; however, abundance estimates in the area did not change significantly (Würsig et al., 2000).

Although they documented responses, neither of the latter two studies measured or modeled the levels or characteristics of the noise that the animals experienced.

Three studies since 1995 have reported concurrent behavioral and acoustic data during coastal construction activities. Todd et al. (1996) examined the distribution, resighting rate, and residency of humpback whales (*Megaptera novaeangliae*) in Newfoundland waters before, during, and after exposure to underwater explosions and did not notice marked behavioral reactions to the detonations. Importantly though, the rate of entrapment in fishing nets equipped with acoustic alarms increased at the onset of underwater drilling activity and sequences of explosions, suggesting a decline in orientation ability. Finneran et al. (2000) measured the auditory and behavioral responses of two captive bottlenose dolphins and a captive beluga whale (*Delphinapterus leucas*) to simulated underwater explosions. None of the animals showed hearing threshold shifts in response to even the loudest stimulus (replicate of 500 kg explosive at 1.7 km range), but all showed behavioral responses during the experiment. Finally, Madsen & Møhl (2000) reported that sperm whales (*Physeter macrocephalus*) showed no behavioral or acoustic responses to distant detonations resulting in received levels (RL) of ≤ 179 dB rms re 1 μPa.

There have been more studies in recent years that have documented the behavioral effects of pile driving specifically on marine mammal populations (harbor porpoises [*Phocoena phocoena*], Tougaard et al., 2009; Brandt et al., 2012; ringed seals [*Phoca hispida*], Blackwell et al., 2004). Harbor porpoises in the North German Sea avoided close ranges and responded to pile driving sounds at distances > 21 km (Tougaard et al., 2009). Additionally, Brandt et al. (2012) noted that harbor porpoise acoustic activity was reduced up to 70 h after pile driving at a distance of 2.5 km from the site. For this study, a sound exposure level (SEL) of 167 dB re 1 μPa^2-s was measured at 720 m from the pile driving site. Blackwell et al. (2004) documented that ringed seals swam as close as 46 m to the pile driving site despite that the noise generated by this activity could be heard up to 3 km away under water. Sound pressure levels (SPLs) were < 180 dB re 1 μPa at all distances measured and, in this case, the ringed seals were habituated to the construction noise.

In Sarasota Bay, Florida, the construction of a large fixed-span bridge and subsequent demolition of the existing drawbridge provided the opportunity to investigate the potential effects of marine building on coastal bottlenose dolphins. In the absence of data clearly indicating no jeopardy, or data clearly relating effects to distance from the activity, it is important for biologists and regulatory agencies to develop a better understanding of the potential adverse effects of such wide-scale activities on these animals. Following the model from Richardson et al. (1985) of an "opportunistic experiment" to examine the behavior of marine mammals before, during, and after construction activities, the objectives of this study were to (1) document distributions of dolphins relative to an area of marine construction/demolition and compare these distributions to historical distributions; (2) describe sound levels of construction/demolition and relate them to bottlenose dolphin distributions; and (3) during the acute (explosive) phase, relate bottlenose dolphin behavior to the explosion and associated sound levels at the animals.

An extensive long-term database was used to quantitatively define the bottlenose dolphins' patterns of habitat use in Sarasota Bay before construction (Scott et al., 1990; Wells, 1991, 2003), and these data were compared with similar data collected during and after demolition. Standard photographic identification surveys for bottlenose dolphins were conducted for 2 wks each month through these waters for the decade preceding the study. These surveys were continued, and data collection efforts were intensified relative to the bridge project schedule, and related to behaviors and distribution patterns of the bottlenose dolphins in response to the noise generated by the construction and demolition activities. Additionally, sound levels were monitored throughout the study area during and after these activities. Bottlenose dolphin focal follows were conducted to describe and document behavioral responses to the underwater explosion event.

Methods

Study Area

The study area included waters up to 4.9 km to the north and 3.4 km to the south of the Ringling Bridge, a bridge that connects mainland Sarasota, Florida, to Bird Key to the west (Figure 1). A four-lane drawbridge, which had been in place for several decades, was replaced with a six-lane fixed bridge with a minimum clearance over the water of about 20 m, constructed immediately to the north of the existing bridge. The study area included open bay and channel habitats up to 5 m deep, as well as shallower patchy and continuous seagrass meadows. Waters throughout this region have been used extensively by a long-term resident community of bottlenose dolphins, which have been studied since 1970 (Scott et al., 1990; Wells, 1991, 2003).

Boat-Based Dolphin Surveys

Bottlenose dolphin surveys were conducted using standardized techniques. A minimum of two

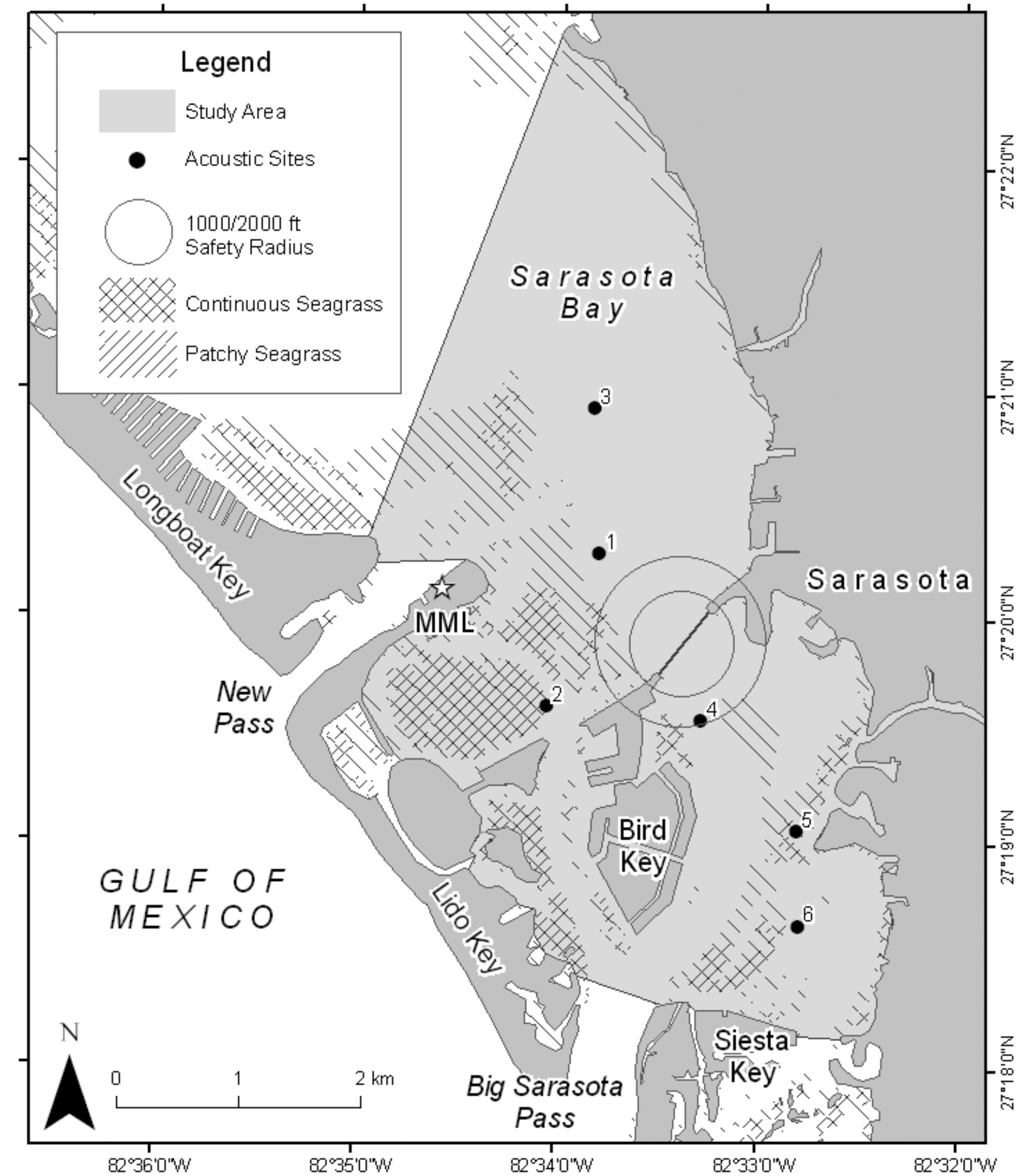

Figure 1. Map of study area (boundaries denoted by solid lines) showing numbered locations of acoustic monitoring sites and defined safety radius around the construction area; a safety radius of 0.6 km was issued under a Florida Fish and Wildlife Conservation Commission permit to the constructors for the underwater explosion initially. After the addition of a coffercell and use of smaller charges than originally planned, the safety radius was reduced to 0.3 km.

observers (up to six) on a 6-m outboard-powered, center console vessel scanned the waters while moving at a speed of approximately 33 km/h. Bottlenose dolphins were approached for identification photographs and for collection of environmental and biological data. Surveys were conducted at least six times/mo. All surveys that passed within bottlenose dolphin-sighting range (this area was chosen as one in which the observers had good visibility without obstruction) of the original Ringling drawbridge were used. The project was divided into three phases: (1) pre-construction

(April 2001 to July 2002, for which archived survey data were used); (2) construction, including the demolition of the old bridge, further stratified into both chronic (drilling) activities and acute (in-air and underwater explosions) periods (September 2002 to November 2003); and (3) post-construction, after completion of construction and demolition (December 2003 to May 2004). To remove the confounding variable of seasonal fluctuation in distribution documented in Sarasota Bay by Irvine et al. (1981), we used a subset of data comparing only the months of December through May for 2001-2002 vs 2002-2003 vs 2003-2004 for the three phases. The number of surveys and distance covered within the study area during each phase are outlined in Table 1.

Acoustic Monitoring Sites

Acoustic recordings were not available from the period preceding construction, but recordings were obtained during the construction and post-construction (for ambient levels) phases of the project. Underwater sound levels were recorded at six listening stations within a small study area to the north and south of the Ringling drawbridge. Sites ranged from 0.6 to 2.5 km from the bridge and over seagrass meadows and in channels (Figure 1). Acoustic surveys were conducted over 21 d in total during the construction and demolition phases. At each site, a hydrophone (High Tech Inc., Model HTI-96-MIN; sensitivity: -170 dB re 1V/μPa; frequency response: 2 Hz to 30 kHz ± 1 dB) was lowered to a water depth of 1 m below the surface and connected to a Creative NOMAD Jukebox 3 (frequency response: 20 Hz to 20 kHz ± 0.5 dB; sampling rate: 48 kHz) to record sound levels for 5 min. Recordings were collected at all six listening stations consecutively on each survey day. Opportunistically, underwater recordings of two in-air explosions were obtained at a distance of 0.6 km (the predetermined safety radius used by the constructors) from the bridge on 30 September and 21 October 2003.

Focal Animal Follows

Focal dolphin behavioral follows were conducted on 17 November 2003, the planned day of the underwater explosion. Four vessels were deployed to survey the study area and locate bottlenose dolphins—two to the north and two to the south side of the bridge. Bottlenose dolphins were sighted in the area, and two survey boats began focal follows. Respiration data were collected continuously throughout the follows. The observation vessels maneuvered at slow, consistent speeds during follows. A previous study conducted on focal bottlenose dolphins of the Sarasota community showed that the observation vessel did not have a significant effect on the respiration rate (measured as inter-breath intervals [IBI]), regardless of distance between the focal bottlenose dolphin and observation vessel (S. M. Nowacek et al., 2001). Geographical location, activity state, group size, nearest neighbor distance (measured in m), and group membership were recorded at 3-min intervals. Both focal follows began 2 h before and ended 30 min after the underwater detonation. A hydrophone was deployed from each boat (including the two boats without bottlenose dolphins) to record the sound levels at varying distances from the bridge. At the instant of the detonation, survey boats were 1.83 km (with a focal bottlenose dolphin), 0.95 km, 0.80 km, and 0.73 km (with a focal bottlenose dolphin) from the bridge.

Data Analyses

The sighting data were stratified into three phases: (1) pre-construction, (2) construction/demolition, and (3) post-construction/demolition (Table 1). The

Table 1. Bottlenose dolphin survey and acoustic monitoring efforts during the three phases of the project; chronic demolition refers to drilling and other building noises, and acute demolition refers to in-air and underwater explosions.

Data recording condition	Phase	Dates	Surveys	Total distance (km)	Bottlenose dolphins sighted	Acoustic recordings
Sighting	Pre-Construction	Dec. 2001-May 2002	54	197	97	--
Sighting	Construction	Dec. 2002-May 2003	45	148	102	--
Acoustic	Demolition-Chronic	Sept. 2003-Nov. 2003	--	--	128	87
Acoustic	Demolition-Acute	30 Sept., 21 Oct., 17 Nov. 2003	--	--	15	2
Sighting/Acoustic	Post-Construction	Dec. 2003-May 2004	48	156	107	11

acoustic data were stratified into three modified phases: (1) demolition-chronic (drilling events), (2) demolition-acute (explosion events [in-air and underwater]), and (3) post-construction/demolition (defined in Table 1). It was not possible to categorize the sighting and acoustic data into the same phases because there were no acoustic data preceding the construction phase. Additionally, sighting data were controlled for seasonal variability in distribution so some periods, such as the demolition-chronic for the acoustic phase, did not overlap with the months of available sighting data. One of the original objectives was to obtain indications of the animals' behavior relative to the construction and demolition noise, both chronic and acute, and by distance from the bridge. However, this was not possible because the sighting and acoustic phases analyzed were not during the same months of the year, with the exception of the post-construction/demolition phase (Table 1). Nonetheless, it was still possible to characterize and relate the acoustic environment during and after the building and removal of underwater structures while bottlenose dolphins were using the habitat areas surrounding the Ringling Bridge.

Distribution and Density Analyses—Geographical Information System (GIS) analyses were used to determine if distribution and density within the study area changed over the course of bridge construction. To minimize distortion of distance and area measurements, data were reprojected into a NAD 83 UTM 17N coordinate system. A cost/distance grid was created for the study area, measuring the distance from each grid cell (400 m^2 each) to the bridge. An *ArcGIS VBA* extension script, "Gridspot," extracted the distance of each sighting from the bridge using the cost/distance grid. A non-parametric Kruskal-Wallis ANOVA was performed to test the null hypothesis that there was no significant difference in the distance of sightings to the bridge among the three construction phases (pre-, during, and post-construction).

To determine if density within the study area changed over the course of bridge construction, bottlenose dolphins per unit effort (in this case km^2 surveyed) was calculated for the three phases of the study and compared using a Kruskal-Wallis ANOVA. An effective strip-width of 280 m was calculated using *Distance* (Thomas et al., 2003) to buffer the survey tracks recorded by the Global Positioning System (GPS). The total area surveyed for each construction phase was then calculated (using *VBA* script). Sighting density, in bottlenose dolphins sighted per km^2, was then determined by dividing the number of bottlenose dolphins seen in each zone by the area surveyed within that zone.

Acoustic Analyses—Underwater spectrum levels of marine construction were measured during and after the building phases. Noise spectrum levels (1 Hz analysis bandwidth; Fs: 48 kHz, NFFT: 512, time constant: 0.01 s, filter: Hamming window) were generated in *Matlab* (Mathworks, Natick, MA, USA) for acoustic sites and specific events such as drilling activity, in-air explosions, and the underwater explosion. Received levels (RLs) at the bottlenose dolphin were obtained for 20 frequencies spaced arithmetically between 0.25 to 20 kHz (at 0.25, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 7, 8, 10, 12, 14, 16, and 20 kHz). RLs were extracted from the noise spectra in *Matlab*. For accuracy of RL calculations, distances from the source (bridge) to the monitoring sites were calculated in *ArcGIS*. Then, GPS waypoints were used to locate these sites for boat-based recordings. Source-level estimates were calculated using a conservative spherical spreading ($20*\log_{10}[r]$, where r = radius to the source) transmission loss model (Urick, 1983). For source-level estimations, distances from the source (bridge) to the focal bottlenose dolphins were obtained by marking a GPS waypoint at time of the explosions, plotting them in an *ArcGIS* map, and using a distance tool to measure to the center of the bridge.

Focal Follow Analyses—Respiration data collected throughout the follows were calculated as IBIs. Changes in group size, nearest neighbor distance, and IBIs were evaluated before and after the underwater explosion using *t*-tests or non-parametric Wilcoxon matched pairs test. Time series beginning 30 min prior to the explosion and ending 30 min after the explosion were created to illustrate trends in the data. All statistical tests were performed using *Statistica 6.0* (Statsoft, Tulsa, OK, USA), and the level of significance was set at $\alpha = 0.05$, with the exception of the Wilcoxon matched pairs tests where the level of significance was set at $\alpha = 0.01$.

Results

Dolphin Distribution and Density

Bottlenose dolphin distribution, by distance from the construction site, was not significantly different between the three phases (Kruskal-Wallis ANOVA, $H_{(2,172)} = 5.75$, $p = 0.0565$). Mean distances from the bridge were as follows: pre-construction, 2.23 km (SD = 0.98, n = 54); construction, 2.41 km (SD = 0.81, n = 46); and post-construction, 2.00 km (SD = 1.09, n = 72); however, there was a significant difference in mean bottlenose dolphin density in the vicinity of the bridge between the three stages (Kruskal-Wallis ANOVA, $H_{(2,147)} = 9.66$, $p = 0.008$; Figure 2). Furthermore, a Dunn's post-hoc test revealed that there was a higher density of bottlenose dolphins/km^2 in the study area after construction than before or during construction activities (Const/Post stages Q = 10.28; Pre/Post stages Q = 12.74). Mean densities within the bridge study area were

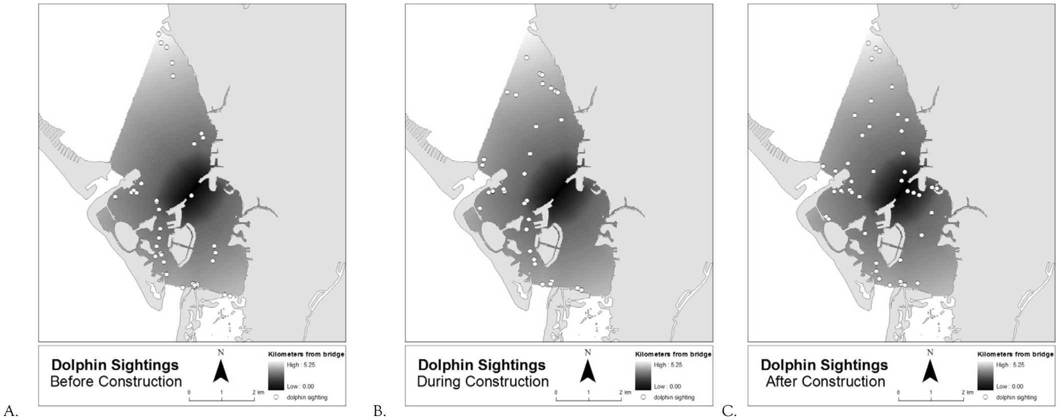

Figure 2. Dolphin group sightings during synoptic surveys conducted (A) before the onset of bridge construction, (B) during the bridge construction phase, and (C) after the completion of bridge construction; sightings overlay a cost/distance grid that was used to extract sighting distances from the bridge for each construction phase.

as follows: pre-construction, 0.58 dolphins/km^2 (SD = 1.50, n = 54); construction, 0.64 dolphins/km^2 (SD = 1.12, n = 45), and post-construction, 0.76 dolphins/km^2 (SD = 0.92, n = 48).

Chronic Demolition: Acoustic Monitoring Sites

Received levels (RLs) were recorded at six sites between August and November 2003, during the construction/demolition phase and compared to underwater ambient levels collected post-demolition. RLs during construction/demolition ranged between 34 dB re 1 µPa$_{rms}$ (at 20 kHz) and 75 dB re 1 µPa$_{rms}$ (at 0.5 kHz), and post-demolition ambient levels at the same sites ranged between 38 dB re 1 µPa$_{rms}$ (at 20 kHz) and 73 dB re 1 µPa$_{rms}$ (at 0.25 kHz). Drilling was recorded on six of 21 monitoring days and probably occurred on more occasions as the monitoring effort only occurred twice weekly. Peak amplitude and frequency of peak amplitude for each documented event are reported (Table 2). Results of RLs spanning 0.25 kHz to 20 kHz are also reported for drilling activity and ambient levels (Table 3).

Acute Demolition: Explosions

In-Air Detonations—Two in-air detonations occurred on 30 September and 21 October to remove the counterweights and bascule sections of the pre-existing bridge. For both detonations, mats, screening, and debris netting were used to catch falling debris. Counterweights and bascule piers were detonated using Emulex™ (a dynamite equivalent that uses emulsion in lieu of nitroglycerine). Blasting occurred simultaneously

Table 2. Characteristics of drilling and explosions recorded during the Ringling Bridge demolition project; analysis specifications are described in the "Methods" section. Table 3 provides ambient noise levels for the frequencies listed here.

Source type	Date	Distance from source (km)	Peak amplitude (dB re 1 µPa$_{rms}$)	Frequency of peak amplitude (kHz)
Drilling	27 Aug 03	0.6	69	5.6
Drilling	27 Aug 03	0.6	71	0.6
Drilling	17 Sept 03	0.6	61	2.9
Drilling	26 Sept 03	1.0	68	0.9
Drilling	2 Oct 03	0.6	68	0.9
Drilling	24 Oct 03	0.6	68	1.1
Drilling	12 Nov 03	0.6	70	1.3
Drilling	12 Nov 03	0.3	70	1.4
In-air explosion	30 Sept 03	0.6	105	1.3
In-air explosion	21 Oct 03	0.6	119	0.7
Underwater explosion	17 Nov 03	0.73	90	9.3
Underwater explosion	17 Nov 03	0.80	69	2.0
Underwater explosion	17 Nov 03	0.95	119	1.6
Underwater explosion	17 Nov 03	1.83	73	0.25

Table 3. Received noise levels for four construction activities (drilling, in-air [2], and underwater [1] explosions) compared to ambient noise levels recorded post-construction; analysis specifications are described in the "Methods" section. All noise level values are presented in dB re 1 µPa $_{rms}$. Only ten frequencies are presented here of the 20 frequencies that were measured. One instance of drilling activity is reported here. These data were collected on 12 November 2003. Ambient noise levels were recorded post-construction on 11 February 2004. Numbers in bold represent the frequency at which the greatest received level difference of the activity vs ambient occurred.

		Frequency (kHz)									
Activity type	Distance (km)	0.25	0.5	1	2	4	6	8	10	16	20
Drilling	0.6	66	64	66	65	56	58	53	52	**50**	46
In-Air #1	0.6	83	95	**102**	95	84	81	76	73	66	63
In-Air #2	0.6	112	109	111	**109**	97	93	89	85	81	77
Under water	0.7	87	52	57	72	71	76	85	87	85	**84**
Ambient	0.6	71	67	64	59	56	52	49	47	42	40

with a 25 ms delay between charges placed in boreholes, for a total duration of approximately 1.5 s for the 21 September explosion and 2.5 s for the 21 October explosion. Information on the weight of the charges used was not available, but the underwater RLs indicated that a heavier charge was used for the second detonation, or that it was less contained. Detonations were approximately 2 and 4.5 m above the water level for the counterweights and bascule piers, respectively. Underwater RLs for the in-air explosions were recorded at the safety radius of 0.6 km designated for the underwater detonation. Recordings were made at a depth of 1 m. For the first in-air explosion, the greatest change in noise level occurred at 1 kHz where the noise exceeded ambient levels by 38 dB (Table 3). For the second in-air explosion, in which larger charges were possibly used, the maximum noise level was 50 dB greater than ambient levels at 2 kHz (Table 3). Peak amplitudes measured *under water* for the in-air explosions were 105 dB re 1 µPa $_{rms}$ and 119 dB re 1 µPa $_{rms}$ both at a distance of 0.6 km from the bridge (Table 2). During the first in-air explosion, there were three bottlenose dolphins sighted 1.6 km from the bridge 18 min after detonation. This group consisted of a mother-yearling pair and another female bottlenose dolphin. No bottlenose dolphins were sighted within 6 h after the detonation of the second in-air explosion.

Underwater Detonation—On 17 November 2003, the remaining bascule piers of the Ringling drawbridge below water level were removed using Emulex™ explosives. The two bascule piers were demolished simultaneously by 18 kg charges with 25 ms delays between charges placed in boreholes, for a total blast duration of approximately 1 s (refer to the section below "Underwater Detonation: Received Levels" for noise level results). The depth of the charges was -5.1 m, 0.6 m below the required removal elevation of -4.7 m, in a water depth of 4.5 m. A steel coffercell was placed around the area to be detonated to contain debris and aid in sound abatement. The addition of the coffercell and the use of smaller charges than originally planned allowed the safety radius around the detonation area of 0.6 km to be reduced to 0.3 km, as granted by a Florida Fish and Wildlife Conservation Commission (FFWCC) permit. The building contractors did not operate under a National Marine Fisheries Service (NMFS) permit such as an Incidental Harassment Authorization (IHA) or Incidental Take Authorization (ITA).

Underwater Detonation: Focal Dolphin Behavioral Follows

Almost 2 h prior to the underwater explosion, one research vessel began a focal follow with a group of four bottlenose dolphins. The bottlenose dolphin with the most distinctive fin was chosen to be the focal animal (hereafter referred to as Dolphin A). One of the other three animals in the group appeared to be an older calf and was seen in a calf position with Dolphin A occasionally, most notably immediately after the explosion. We presumed then that Dolphin A was the mother of this calf. The group was heading north away from the bridge site for the duration of the follow. A few seconds after the detonation, other bottlenose dolphins joined Dolphin A, increasing the group size to eight animals with the tightest group spread (as measured by nearest neighbor distance) that had been observed since the beginning of the follow (Figure 3). All eight animals coalesced and decreased their swim speed, continuing to travel north, away from the bridge. Nearest neighbor distance and group size were not significantly different before and after the underwater explosion for Dolphin A (*t*-test for dependent samples; NN: $t = 2.313$, df = 6, $p = 0.199$; group size: $t = 0.102$, df = 9, $p = 0.921$). The average nearest neighbor

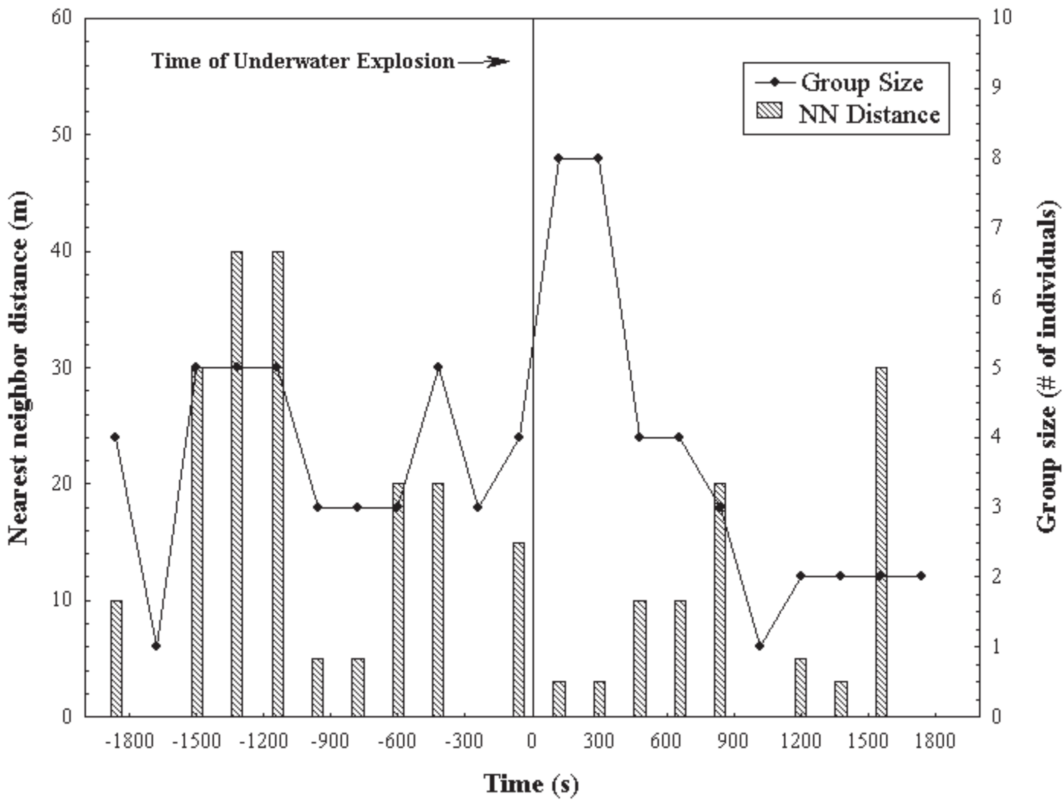

Figure 3. Nearest neighbor distance (bars) and group size (–◆–) for focal Dolphin A before, during, and after an underwater detonation; Dolphin A was 1.83 km from the bridge at the time of detonation.

distance before the explosion was 21.89 m (SD = 13.87, n = 8); and after the explosion, the average distance between associates was 13.0 m (SD = 10.2, n = 6). Mean group size before the explosion was 4 (SD = 1.07, n = 9), and afterwards it was 2.5 (SD = 1.07, n = 8). Additionally, IBI was not significantly different before and after the explosion (Wilcoxon matched pairs test: T = 698, p = 0.546). The mean IBI before the explosion was 24 s (SD = 20.98, n = 56), and after the explosion it was 25 s (SD = 18.48, n = 62). Time series are suggestive of a trend in increased group size and decreased nearest neighbor distance at the time of the explosion and for a brief period of time thereafter; however, they are not conclusive (Figure 3). This was likely due in part to the small sample size and the short duration of the explosion event, which made it only possible to record a data point for each variable at the instant of detonation. The analysis windows were narrowed before and after the event to test whether using longer time windows diluted an acute response; the results remained unchanged and are, therefore, not reported.

Another follow by a second research vessel also started approximately 2 h before the underwater explosion. The focal bottlenose dolphin (hereafter referred to as Dolphin B) was traveling and milling by itself closer to the bridge. Just before the detonation, Dolphin B was heading toward the bridge, and then at the time of detonation and at a distance of 0.73 km from the bridge, it made a 180° heading change, orienting away from the bridge. Although heading change was observed at the time of the detonation, IBI was not significantly different before and after the explosion (Wilcoxon matched pairs test: T = 1,102, p = 0.235). Mean IBI before the detonation was 18 s (SD = 8.49, n = 102), and afterwards was 21 s (SD = 14.36, n = 75). Based on the location and distance between surfacings after the detonation, it is evident that Dolphin B increased its swimming speed while moving away from these shallow waters (< 2 m depth). The animal remained in deeper water until the end of the observation period (30-min post-explosion).

Underwater Detonation: Received Levels

Received underwater spectrum levels at 0.6 km from the underwater detonation were not recorded due to delay of detonation beyond the recording time of the recording device deployed at this site.

The underwater explosion was recorded at four observation vessels. Two vessels were conducting focal bottlenose dolphin follows with Dolphin A at 1.83 km and Dolphin B at 0.73 km from the bridge, while two additional vessels made recordings at their positions at the time of the explosion (0.80 and 0.95 km from the bridge, respectively). Underwater received levels (RLs) were compared to underwater ambient noise levels recorded on 11 February 2004, after the removal of all equipment from the bridge site (Figure 4). RLs at distances of 1.83 and 0.73 km with Dolphin A and Dolphin B, respectively, were much higher in amplitude than ambient levels. Power spectra reveal that the underwater ambient noise distributions were fairly consistent among sites; the spectrum levels ranged between 41 to 65 dB re 1 μPa $_{rms}$ across 20 frequencies spanning 0.25 to 20.0 kHz. RL varied between sites for the underwater detonation, however. At a distance of 0.73 km, the vessel observing Dolphin B recorded a peak amplitude of 90 dB re 1μPa $_{rms}$ at 9.3 kHz (Table 2). The underwater explosion was 44 dB greater than ambient levels at 20 kHz (Table 3 & Figure 4A). At only 0.07 km farther from the blast site, the RLs for ambient and detonation noise overlapped across the entire frequency range (Figure 4B). At this site, the peak amplitude was 69 dB re 1 μPa $_{rms}$ at 1.9 kHz (Table 2). The vessel at the time of the recording was located in seagrass meadows, which are known to greatly attenuate sound (Urick, 1983; D. P. Nowacek et al., 2001), and this could explain the RL difference between these recording sites. Another recording vessel was located adjacent to a seawall at a distance of 0.95 km from the detonation. The vessel's close proximity to a concrete structure allowed the sound to be amplified as it reflected off of the seawall. The underwater explosion in this case had the greatest RL difference of 58 dB at 1 kHz (Figure 4C). Peak amplitude at this distance was 119 dB re 1 μPa $_{rms}$ at 1.6 kHz (Table 2). At the farthest distance of 1.83 km and the location of Dolphin A, the greatest RL difference for the explosion was 20 dB greater than ambient noise at 16 kHz (Figure 4D). The peak

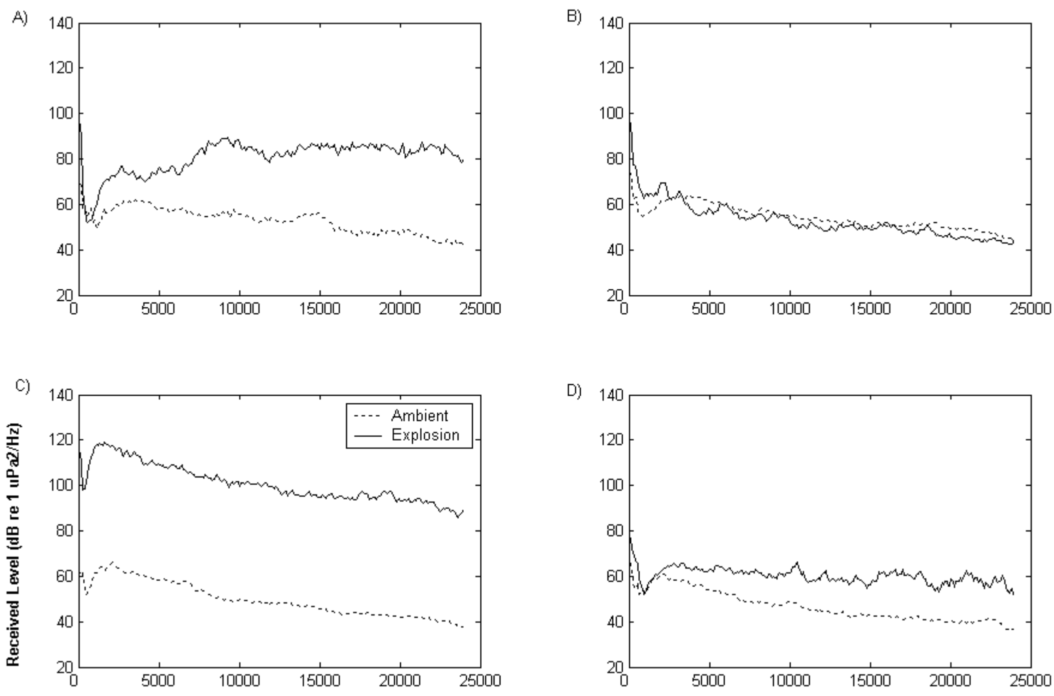

Figure 4. Sound pressure density spectra for ambient sound levels and the underwater explosion recorded at four locations; noise spectrum levels (in 1 Hz bandwidths) were calculated across the duration of each signal, with the duration of the underwater explosion at 1 s. Calibrated, underwater ambient and explosion received levels (RLs) are presented as spectrum level (i.e., dB re 1 μPa^2/Hz) at the following distances from the source: (A) 0.73 km at Dolphin B, (B) 0.80 km in a seagrass meadow, (C) 0.95 km at a seawall, and (D) 1.83 km at Dolphin A.

amplitude was 73 dB re 1 μPa $_{rms}$ at 0.25 kHz (Table 2). It is important to note that although there was the least amount of RL difference between the explosion and ambient noise at this location, there was an observable (while not significant) change in the bottlenose dolphin's behavior at the surface, including an increase in group size and decrease in nearest neighbor distance after the detonation occurred. Representative waveforms for an in-air and the underwater explosion recorded at the closest distance are given (Figure 5).

Discussion

There was a significant increase in mean density of bottlenose dolphins in the post-construction phase compared to during the construction phase. The increase of mean bottlenose dolphin density after the cessation of activities is suggestive of a response to marine construction and demolition. Fewer bottlenose dolphins were also seen during the pre-construction period when compared to the post-construction phase. Other factors, such as possible differences in prey abundance during the 2001-2002 phase vs the 2003-2004 phase, could have had just as important an influence on bottlenose dolphin density in this study area. Additionally, bottlenose dolphins that remained in the area during the construction period, albeit in lower numbers, were not found farther from the bridge. This suggests that the bridge area remained an important corridor between the north and south portions of Sarasota Bay and that some bottlenose dolphins may have still preferred habitats around the Ringling Bridge, despite construction and demolition noise.

Observations made during the underwater detonation at distances of 1.83 and 0.73 km from the explosion site indicated that bottlenose dolphins exhibited short-term behavioral responses to such explosions. While it was not possible to quantify their reactions, observable changes in at-the-surface behaviors (e.g., Dolphin A: increased group size, decreased nearest neighbor distance; Dolphin B: increased swim speed, heading change) were evident.

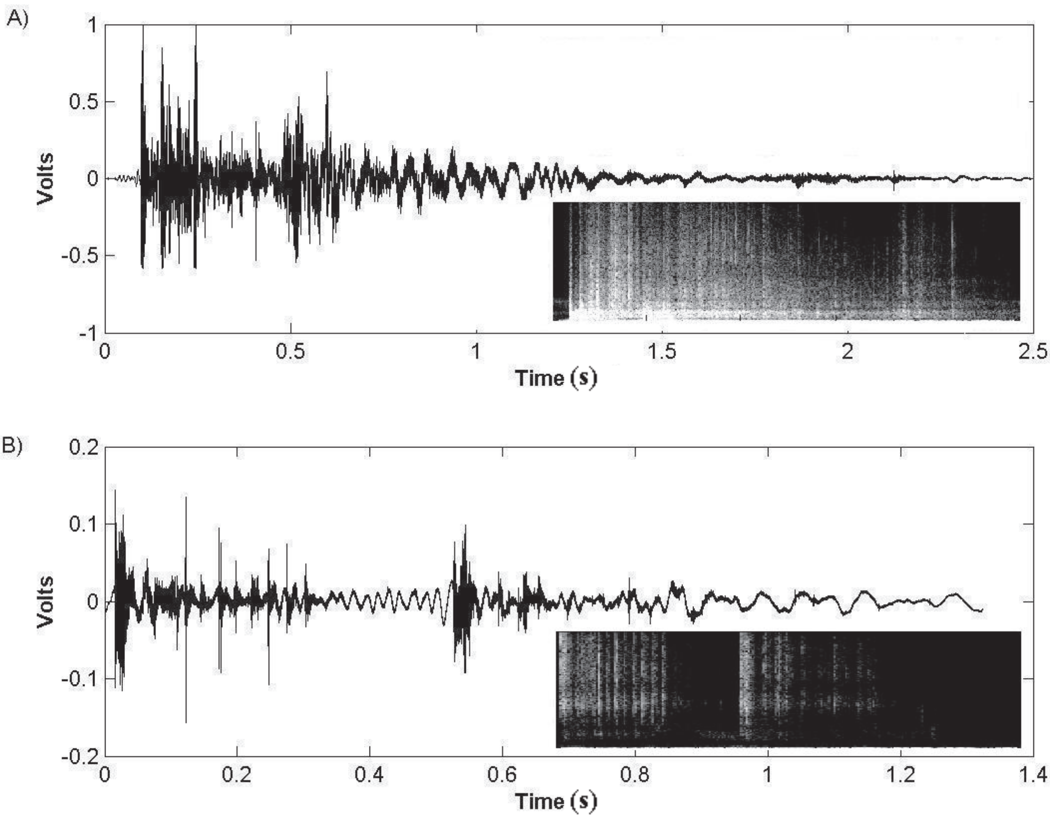

Figure 5. Waveforms (uncalibrated) for the second in-air explosion (A) and the underwater explosion (B); the in-air explosion was recorded under water at 0.6 km from the source, and the underwater explosion was recorded at 0.73 km from the source. The spectrograms and waveforms of the explosions are on the same time scale and frequency range of 0 to 24 kHz.

This study expands the limited available information on the effects of explosions on cetacean behavior. Richardson & Würsig (1997) stated that peak levels of pressure pulses from the detonation of ≥ 1 kg of high explosives at close range exceed levels from any other human-made source. Few data were previously available on behavioral reactions of cetaceans at farther distances from explosions. Finneran et al. (2000) reported that there was a disruption in behaviors of trained dolphins when they were exposed to impulsive sounds corresponding to 5 kg at 9.3 km and 5 kg at 1.5 km. The Ringling Bridge was demolished using 18 kg charges, and behavioral responses were seen at a distance as close as 0.73 km and as distant as 1.83 km where the signal was only 20 dB above ambient spectrum levels recorded at that location.

Underwater explosions are impulsive signals characterized by rapid rise times and high amplitude levels (Ketten, 1995). They are different from other sources of continuous anthropogenic noise in that they produce both an acoustic and a shockwave component (Green & Moore, 1995). These sounds, irrespective of distance to the source, as long as they are audible may cause a startle response because they have different signatures than a naturally occurring sound. Peak amplitude levels, while not very loud at these distances, are still markedly greater than ambient levels, and signals with rapid rise times have been shown to elicit true startle responses in marine mammals (Gotz & Janik, 2011). *Tursiops* have relatively poor hearing sensitivity at frequencies below 1 kHz, but the broadband nature of explosions coupled with the higher frequency of maximum levels of the underwater explosion measured at both distances are still within the lower limits of the hearing range of best sensitivity for the bottlenose dolphin (best sensitivity between 10 to 70 kHz; Richardson, 1995).

The significance of observed short-term behavioral changes relative to the long-term survival and reproduction of the impacted animals remains to be determined, although long-term effects should not be assumed (Bejder, 2005). Before and after measurements of bottlenose dolphin hearing abilities would have been useful but were beyond the scope of this project. A sound exposure level > 198 dB re 1 uPa^2-s has been indicated by Southall et al. (2007) to be high enough to cause the onset of temporary threshold shift (TTS) from single pulse sources. While this study focused on a single marine mammal species, the acoustic data reported can readily be applied to other species and/or situations.

Because of unknown propagation loss factors, it is difficult to calculate accurate source levels for these explosions. Therefore, most assumptions made for the transmission loss model were not held in this instance, but using a spherical spreading ($20*\log_{10}[r]$, where r = radius to the source) model (Urick, 1983), broadband source-level estimates of 160 dB re 1 μPa·m and 176 dB re 1 μPa·m were calculated for the in-air explosions and 147 dB re 1 μPa·m was calculated for the underwater explosion; peak pressures could not be measured. It should be noted that the use of the spherical spreading attenuation model presents a conservative transmission loss model in shallow habitats, and, thus, the resulting source-level calculations of the explosion most likely yielded values that are below actual levels. Sound transmission experiments conducted by Quintana-Rizzo et al. (2006) indicated that most frequencies either followed the spherical spreading attenuation model or had transmission loss values that were intermediate between the predicted values of the spherical and cylindrical spreading attenuation models for shallow water and channel habitats in Sarasota Bay. Both in-air explosions were louder underwater than the underwater explosion that was contained by a steel coffercell. Furthermore, NMFS (2000) has defined a broadband SPL of 160 dB re 1 μPa—criterion for the threshold of responsiveness. This is the area around a source in which an observable behavioral response to the noise occurs and is considered the onset of Level B harassment for impulsive sounds. The in-air explosion met or exceeded this threshold level. Based on these findings, in-air explosions occurring close to water level (< 5 m) should be considered for the potential to adversely affect marine life.

An FFWCC permit that required a Marine Species Watch Program for manatees (as the blasting occurred in a manatee zone) within a designated danger zone (or safety radius) of 0.3 km was implemented for the underwater explosion (no manatees [*Trichechus manatus*] were found in the study area during the underwater explosion). The safety radius required for the in-air explosions was also decreased to 0.3 km. Furthermore, the U.S. Marine Mammal Protection Act of 1972 (MMPA) prohibits the "take" of (simply, adverse impacts to) marine mammals with several specific exceptions. For entities conducting activities that may unintentionally take marine mammals, an ITA (Incidental Take Authorization) may be obtained upon request to the NMFS, provided that the NMFS is able to make certain findings and prescribes appropriate mitigation and monitoring measures. NMFS has responded to many applications for coastal construction and demolition activities and, as appropriate, issued ITAs, which authorize the take but not the activity itself. However, given the level of these types of activities occurring vs the number of ITAs issued, it seems likely that some coastal construction activities impacting marine mammals may not have associated MMPA ITAs (J. Harrison, pers. comm., 29 March 2013). As previously mentioned, the building contractors did not obtain a NMFS permit, such as an IHA (Incidental Harassment Authorization) or ITA. However, unexpectedly louder underwater sound levels for in-air explosions compared to the underwater explosion suggest that permitting practices should be re-evaluated to improve marine mammal protection.

Efforts to reduce potential impacts on the Sarasota Bay dolphins were undertaken by the contractor even in the absence of specific federal regulations. The eventual implementation of the underwater explosion differed from the original design (PCL Civil Constructors, Inc., 2003). Original plans called for larger explosive charges and no coffercells. In fact, the constructors introduced changes to these plans after meeting with the research team and learning that the demolition would be subject to scrutiny through the authors' research efforts. Thus, the acute conditions were not as extreme as initially planned. In the Sado estuary in Portugal, an uncontained underwater explosion was measured 2 km from the demolition site: the acoustic pressure levels exceeded 170 dB re 1 µPa $_{rms}$ (dos Santos et al., 2010). The effects of changes on the Sarasota Bay study in terms of benefits accrued to the marine mammals from being subjected to smaller, contained explosions and the potential reduction in observed responses cannot be quantified but are consistent with the precautionary principle. Future construction events should be used as opportunities to further elucidate the potential sensitivities of marine mammals to common coastal construction and demolition activities.

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