Responses of Bottlenose Dolphins to Construction and Demolition of Underwater Structures

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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, for example, thousands of oil production platforms have been constructed since the mid 1900’s, 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 these older structures. These activities occur within the ranges of a variety of marine mammals, but little work has been done to evaluate their impacts on the animals. Though the precautionary principle would dictate otherwise, marine mammals are given little regulatory protection from potential adverse impacts from construction/demolition activities. There are currently no provisions under the federal Marine Mammal Protection Act of 1972 requiring review and permitting of coastal construction or demolition projects.

Evidence indicates that construction and similar activities, such as drilling, impact marine mammals in several ways. Early work with bowhead whales (*Balaena mysticetus*) indicates that they avoid areas of heavy industrial activity. Richardson et al. (1985) examined distribution patterns of 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 and 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 did not change significantly (Würsig et al. 2000). 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 acoustically enhanced fishing nets 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 dolphins and a beluga whale to simulated underwater explosions. None of the animals showed threshold shifts to even the loudest stimulus (500 kg explosive at 1.7 km range), but all showed behavioral responses during the experiment (Finneran et al. 2000).

In Sarasota Bay, Florida, the construction of a large fixed-span bridge and subsequent demolition of the existing drawbridge allowed us the opportunity to investigate the potential effects of marine building on coastal bottlenose dolphins (*Tursiops truncatus*). In the absence of data clearly indicating no jeopardy, or data clearly showing 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. One approach would be to follow the model of Richardson et al. (1985), taking advantage of opportunistic “experiments” to examine the distribution and behavior of dolphins before, during, and after construction or demolition activities. Extensive long-term databases exist that can quantitatively define dolphins’ patterns of habitat usage in Sarasota Bay before construction (Scott et al. 1990; Wells 1991, 2003), and can be used for comparisons with similar data collected during and after demolition. Photographic identification surveys for dolphins have been conducted for two weeks each month through these waters for the last decade. We continued these surveys and intensified
data collection efforts relative to the bridge project schedule, and related behavior and
distribution patterns to the noise generated by the construction and demolition activities.

Research Objectives

To develop a better understanding of the potential effects of bridge construction and demolition
on bottlenose dolphins, in order to aid regulatory agencies in protecting these animals by:

1) documenting distributions of dolphins relative to an area of marine
construction or demolition and comparing distributions to historical distributions;

2) describing sound levels of construction/demolition;

3) during the acute (explosive) phase, relating dolphin behavior to the
explosion and associated sound levels at the animals.

Materials and 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 4-lane drawbridge in place for several decades was replaced with a 6-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 regularly by five generations of a long-term resident community of
Boat-Based Dolphin Surveys

Dolphin surveys were conducted using standardized techniques. A minimum of two observers (up to 6) on a 6 m outboard-powered center console vessel scanned the waters while moving at a speed of approximately 33 km/hr. Dolphins were approached for identification photographs and collection of environmental and biological data. Surveys were conducted at least 6 times/month by Mote Marine Laboratory (Mote) and Chicago Zoological Society (CZS) staff, often using Earthwatch Institute research assistants. All Earthwatch and synoptic surveys that passed near the original Ringling drawbridge were used. The course of this project can be divided into three phases: 1) pre-construction, (April 2001-July 2002, for which archived summary data were used), 2) construction, including the demolition of the old bridge, further stratified into both chronic activities and acute (explosion) periods (September 2002 – November 2003), and 3) post-construction, after all construction and demolition was completed (December 2003 – May 2004). To remove the confounding variable of seasonal fluctuation in distribution that has been documented in Sarasota Bay (Irvine et al., 1981) we used a subset of data comparing only the months December – May for 2001-02 vs. 2002-03 vs. 2003-04 for the 3 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 we obtained recordings during the construction and post-construction phases of the project. Underwater sound levels were recorded at 6 listening stations within a small study area to the north and south of the Ringling drawbridge. Sites ranged from 0.6 km to 2.5 km from the bridge.
and over seagrass meadows and in channels (Figure 1). Acoustic surveys were conducted on 21 days during the construction and demolition phase. At each site a hydrophone (High Tech Inc., model HTI-96-MIN, sensitivity: −170 dB re 1 V/μPa, frequency response: 2 Hz-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-20 kHz ± 0.5 dB, sampling rate: 48 kHz) to record sound levels for 5 minutes. Ambient levels were recorded at all sites during the post-demolition period as well. Opportunistically, recordings of two in-air explosions were obtained at 2000 ft (0.6 km) from the bridge on 30 September and 21 October 2003.

Focal Animal Follows

Focal dolphin behavioral follows were conducted on 17 November 2003, the day of the underwater explosion. Four vessels were deployed to survey the study area and locate dolphins, two to the north and two to the south side of the bridge. Dolphins were sighted in the area and two survey boats began focal follows. Respiration data were collected continuously throughout the follows. Geographical location, activity state, group size, nearest neighbor distance (measured in meters), and group membership were recorded at 3-min intervals. Both focal follows ended 30 min after the underwater detonation. A hydrophone was deployed from each boat (including the two boats without 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 dolphin), 0.95 km, 0.80 km, and 0.73 km (with a focal dolphin) from the bridge.
Data Analyses

The sighting data were stratified into three phases as follows: 1) pre-construction: December 2001- May 2002, 2) construction/demolition: December 2002- May 2003, and 3) post-construction/demolition: December 2003 – May 2004. The acoustic data were stratified into three modified phases as follows: 1) demolition- chronic: September 2003- November 2003, 2) demolition- acute: 30 September, 21 October, 17 November 2003, and 3) post-construction/demolition: December 2003 – May 2004. It was not possible to categorize the sighting and acoustic data into the same phases because we did not have acoustic data preceding the construction phase as we did for the sighting data from our long-term, ongoing survey efforts. Additionally, sighting data needed to be controlled for seasonal variability in distribution so some periods, such as the “demolition- chronic” for the acoustic phase, did not overlap with the months that we were able to use for sighting analysis. One of our original objectives was to perform data analyses to obtain indications of the animals' behavior relative to the construction/demolition noise, both chronic and acute. Furthermore, we wanted to identify potential responses in terms of distance from the bridge however, this was not possible as the sighting and acoustic phases analyzed were not of the same time periods, with the exception of the third phase, “post-construction/demolition” (refer to Table 1). We were still able to characterize and relate the acoustic environment during and after the building and removal of underwater structures while 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. We used sighting data from all synoptic bridge surveys conducted twice a week
and monthly Earthwatch Institute photographic identification surveys that passed through the construction area. These surveys represent a substantial amount of effort during all stages of the study (refer to Table 1). Data were collected in the field using a Geographic Coordinate System (GCS North America, 1983). In order to measure distance and area for analyses, we re-projected the data into NAD 83 UTM 17N coordinate system. A costdistance grid was created for the study area. This grid measures the distance from each grid cell to the bridge. Grid cell size was 400 m². An ArcScript VBA extension, “Gridspot”, was then used to extract the distance (in meters) of each sighting point from the bridge, using the costdistance grid. A non-parametric Kruskal-Wallis ANOVA was performed to test the null hypothesis that there would be no significant difference in the distance of sightings to the bridge among the three construction phases (pre, during, and post).

To determine if density within the study area changed over the course of bridge construction, calculated dolphins per unit effort (in this case km² surveyed) for each period of the study were compared using a Kruskal-Wallis ANOVA. We used an effective strip width of 280 m, calculated using DISTANCE (Thomas et al., 2003) to buffer the survey tracks recorded by GPS. We then calculated (using VBA script) the total area surveyed for each construction phase. Sighting density, in dolphins sighted per km², was then determined by dividing the number of dolphins seen in each zone by the area surveyed within that zone.

**Acoustic Analyses:** Sound levels of marine construction were measured during and after the building phases. Power spectra were generated in MATLAB (Mathworks, Natick, MA) for acoustic sites and specific events such as drilling activity, in-air explosions, and the underwater explosion. Received level values were obtained for 20 frequencies within the spectrum between
250 Hz – 20,000 Hz. Using mean received level from the power spectra, t-tests were performed to compare received noise levels at acoustic monitoring sites during the construction/demolition phase to ambient levels during the post-demolition phase. Mann-Whitney U tests were performed for those sites in which the data were non-normally distributed. T-tests were also used to compare drilling activity, in-air explosions, and the underwater explosion to ambient levels at the same locations post-demolition.

**Focal Follow Analyses:** Respiration data collected throughout the follow were calculated as interbreath intervals (IBI). Changes in group size, nearest neighbor distance, and IBI 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) and the level of significance was set at $p = 0.05$, with the exception of the Wilcoxon Matched Pairs tests where the level of significance was set at $p = 0.01$.

**Results**

**Dolphin Distribution and Density**

Dolphin distribution, as 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), construction- 2.41 km (SD = 0.81), and post-construction- 2.00 km (SD = 1.09). However, there was a significant difference in dolphin density 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 dolphins/km² in the study area sighted after construction than there were 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 as follows: pre-construction- 0.58 dolphins/km² (SD = 1.50), construction- 0.64 dolphins/km² (SD = 1.12), post-construction- 0.76 dolphins/km² (SD = 0.92).

**Chronic Demolition: Acoustic Monitoring Sites**

Received levels were monitored at 6 sites between August – November 2003, during the construction/demolition phase and compared to ambient levels collected post-demolition. Received levels at the 6 sites during construction/demolition ranged between 52 dB – 58 dB re 1 μPa-m and post-demolition ambient levels at the same sites ranged between 52 dB – 56 dB re 1 μPa-m. T-tests were used to compare the noise levels during the construction/demolition to post-demolition noise levels at each site. There were no significant differences in noise levels at any site between these two phases. During some of the acoustic monitoring sessions in-air drilling activity was recorded up to 1 km from the bridge. T-tests were also performed to determine if these events were significantly louder than ambient levels. Drilling was recorded on 6 of 21 monitoring days and probably occurred on more occasions as our monitoring effort only occurred twice weekly. The drilling events that we recorded were not significantly above ambient levels recorded at the same sites after the construction/demolition had ceased. Mean received level (RL), peak amplitude, and frequency of peak amplitude for each documented event are reported in Table 2.
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 which uses emulsion in lieu of nitro-glycerine). Blasting occurred simultaneously with a 25 msec delay between charges placed in boreholes, for a total duration of approximately 1.5 sec for the 21 September explosion and 2.5 sec for the 21 October explosion. Information on the weight of the charges used was not available, but the underwater received levels indicate that a heavier charge was used for the second detonation, or that it was less contained. Detonations were approximately 6 ft. (2 m) and 15 ft. (4.5 m) above the water level for the counterweights and bascule piers, respectively.

Underwater received levels for the in-air explosions were recorded at the safety radius of 2000 ft. (0.6 km) designated for the underwater detonation. Recordings were made at a depth of 1 m. Both explosions were significantly louder than post-demolition ambient levels (30 September: $t = 8.997$, df = 38, $p = < 0.0001$; 21 October: $t = 13.655$, df = 38, $p = < 0.0001$). The mean RLs, averaged across a spectrum of 250 – 20,000 Hz, were 83 dB for the 30 September explosion and 96 dB for the 21 October explosion. Peak amplitudes for the in-air explosions were 105 dB re 1 μPa-m and 119 dB re 1 μPa-m both at a distance of 0.6 km from the bridge. During the first in-air explosion there were 3 dolphins sighted 1.6 km from the bridge 18 min after detonation. This group consisted of a mom-yearling pair, and another female dolphin. There were dolphins sighted near the bridge on the day of the second in-air explosion, but these dolphins were in proximity to the bridge area 6 hr prior to detonation. No dolphins were sighted around the time of detonation.
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 40 lb (18 kg) charges with 25 msec delays between charges placed in boreholes, for a total blast duration of approximately 1 second. The depth of the charges was –17 ft (-5.1 m), two feet below the required removal elevation of –15.30 ft (-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. This addition and the use of smaller charges than originally planned allowed the safety radius around the detonation area of 2000 ft to be reduced to 1000 ft (as granted by an FFWCC permit).

Focal Dolphin Behavioral Follows: Almost two hours prior to the underwater explosion, one research vessel began a focal follow with a group of 4 dolphins. We chose the individual with the most distinctive fin 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 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 the group size increased to 8 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 8 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: $t = 0.102$, $p = 0.920$).
df = 9, \( p = 0.921 \)). The average nearest neighbor distance before the explosion was 21.89 m (SD = 13.87), and after the explosion the average distance between associates was 13.0 m (SD = 10.2). Mean group size before the explosion was 4 (SD = 1.07) and afterwards, 2.5 (SD = 1.07).

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 sec (SD = 20.98) and after the explosion it was 25 sec (SD = 18.48). Time series are suggestive of a trend in increased group size and decreased nearest neighbor at the time of the explosion and for a brief period of time thereafter, however they are not conclusive (Figure 3). This was most likely due in part to 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 the detonation.

Another follow by a second research vessel also started approximately two hours before the underwater explosion. The focal dolphin (hereafter referred to as Dolphin B) was traveling and milling by itself closer to the bridge site. 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 was observed making 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, \( T = 1102, \ p = 0.235 \)). Mean IBI before the detonation was 18 sec (SD = 8.49) and afterwards, it was 21 sec (SD = 14.36). Based on the location and distance between surfacings after the detonation it is evident that the dolphin increased its swimming speed while moving off of the shallows (< 2 m depth). The animal remained in deeper water until the end of the observation period (30 min post-explosion).
**Received Sound Levels:** Sound levels at 2000 ft. (0.6 km) from the underwater detonation were not recorded due to delay of detonation beyond the recording time of the recording device at this site. Sound levels at 0.73 km from the source had a peak of 90 dB re 1 μPa-m at 9300 Hz.

The underwater explosion was recorded at 4 observation vessels, two were conducting focal 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 km and 0.95 km from the bridge). Comparisons of received sound levels were made to ambient noise levels recorded on 11 February 2004 after the removal of all equipment from the bridge site (Figure 4). Statistical analyses indicate that received levels at distances of 1.83 km and 0.73 km with Dolphin A and Dolphin B, respectively, were significantly louder than ambient levels (Dolphin A: U = 39, p < 0.0001; Dolphin B: U = 26, p < 0.0001). Mean received levels were 62 dB and 76 dB at 1.83 km and 0.73 km, compared to a mean ambient level of 54 dB at both locations. Power spectra reveal that the ambient noise levels were fairly consistent between each site; the mean noise levels ranged between 53 – 59 dB re 1 μPa-m between 250-20,000 Hz. RL varied between sites for the underwater detonation, however. The peak amplitude at this distance was 90 dB re 1μPa-m at 9300 Hz (Table 2). At a distance of 0.73 km, the vessel observing Dolphin B recorded the underwater explosion to be 20 dB greater than ambient levels averaged over frequencies between 250-20,000 Hz (Fig. 4, A). At only 0.07 km farther from the blast site, the RLs for ambient and detonation noise overlap across the entire frequency range (mean RL = 60 dB for ambient and explosion; Fig. 4, B). At this site, the peak amplitude was 69 dB re 1 μPa-m at 1990 Hz (Table 2). The vessel at the time of the recording was located in seagrass meadows which are known to greatly attenuate sound (Nowacek, Buckstaff, Johnson, & Wells, 2001; Urick 1983) and this can explain the RL difference between these recording sites.
Another recording vessel was located adjacent to a seawall at a distance of 0.95 km. 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 was recorded as 50 dB greater over frequencies between 250-20,000 Hz (Fig. 4, C). Peak amplitude at this distance was 119 dB re 1 \( \mu \text{Pa-m} \) at 1600 Hz (Table 2). At the farthest distance of 1.83 km and the location of Dolphin A, the mean RL for the explosion was 9 dB greater than ambient noise (Fig 4, D). The peak amplitudes was 66 dB re 1 \( \mu \text{Pa-m} \) at 19,500 Hz (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, we did observe a dramatic change in at-the-surface behavior, specifically, an increase in group size and a 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 in Figure 5.

**Discussion**

We found a significant increase in density of bottlenose dolphins in the post-construction phase compared to during the construction phase. The increase of dolphin density after the cessation of activities is evidence of a response to marine construction and demolition. Fewer dolphins were also seen during the pre-construction period when compared to the post-construction phase. Other factors, such as differences in prey abundance during the 2001-2002 phase versus the 2003-2004 phase, could have had just as important an influence on dolphin density in this study area. Additionally, dolphins that remained in the area, albeit in lower numbers, during the construction period 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 dolphins may have still preferred habitat areas, although noisier, around the Ringling Bridge.

Our study expands the limited available information on the effects of explosions on cetacean behavior. Richardson and 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 man-made source. Few data were previously available on behavioral reactions of cetaceans at farther distances from explosions. In our study, observations made during the underwater detonation at distances of 1.83 km and 0.73 km from the explosion site indicated that dolphins do exhibit short-term behavioral responses to such explosions. While it was not possible to quantify their reactions, observable changes in at-the-surface behaviors were evident. Finneran et al. (2000) reported that there was a disruption in trained dolphins’ behaviors at exposures 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 9 dB above ambient 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 shock-wave component (Green and Moore 1995). These sounds, irrespective of distance to the source, as long as they are audible may cause a startle response as 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. *Tursiops* have relatively poor hearing sensitivity at frequencies below 1 kHz, but the broadband nature of explosions (refer to spectrograms in Figure 5) coupled with the higher frequency of peak 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 10-70 kHz; Richardson 1995, refer to Table 2). The significance of observed short-term behavioral changes relative to the long-term survival and reproduction of the impacted animals remains to be determined. Before and after measurements of hearing ability through evoked auditory potentials would have been useful, but were beyond the scope of this project.

Recorded differences in sound levels for in-air and underwater explosions suggest that permitting practices should be re-evaluated to improve marine mammal protection. A permit that required a Marine Species Watch Program for manatees (as the blasting occurred in a manatee zone) within a designated danger zone of 1000 ft was implemented for the underwater explosion (no manatees were found in the study area during the underwater explosion). The safety radius required for the in-air explosions was decreased to 300 ft. Recordings of the in-air explosions were recorded 0.13 km closer to the source than the underwater explosion, and exposure levels should decrease with increasing distance from the source. Because of unknown propagation loss factors, it is difficult to calculate 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 ($20 \log R$, where $R$ = radius to the source) model (Urick 1983) 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. Both in-air explosions were louder underwater than the underwater explosion that was contained by a steel coffercell. Based on these findings, in-air explosions occurring close to water level (< 15 ft) should be considered for the potential to adversely affect marine life as well.
The implementation of the experiment differed from the original design (PCL, 2003) in terms of the strength of the underwater explosion. Original plans called for larger explosive charges and no cofferdams. Changes to these plans were introduced by the constructors after meeting with our research team and learning that the demolition would be subject to scrutiny through our research efforts. Thus, the acute conditions were not as extreme as initially planned. The effects of these changes on the experiment, in terms of benefits accrued to the marine mammals from being subjected to smaller explosions, and potential reduction in observed responses, cannot be evaluated. It would be useful to take advantage of future construction events to perform experiments to further elucidate the potential responses of marine mammals to common coastal construction and demolition activities.
Acknowledgements

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References


Table 1. Dolphin survey and acoustic monitoring efforts during the three phases of the project.

<table>
<thead>
<tr>
<th>Data Recording</th>
<th>Phase</th>
<th>Dates</th>
<th>Surveys</th>
<th>Total distance (km)</th>
<th>Dolphins Sighted</th>
<th>Acoustic Recordings</th>
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<td>Dec. 2002-May 2003</td>
<td>45</td>
<td>147.96</td>
<td>102</td>
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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.
Figure 2. Dolphin 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 costdistance grid that was used to extract sighting distances from the bridge for each construction phase.
Table 2. Characteristics of drilling and explosions recorded during the Ringling Bridge demolition project. ( ) denotes standard deviation.

<table>
<thead>
<tr>
<th>Source type</th>
<th>Date</th>
<th>Distance from source (km)</th>
<th>Peak amplitude (dB re 1 μPa-m)</th>
<th>Frequency of peak amplitude (Hz)</th>
<th>Mean Received Level (dB)</th>
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<tr>
<td>Drilling</td>
<td>12-Nov-03</td>
<td>0.3</td>
<td>70</td>
<td>1350</td>
<td>62 (4.89)</td>
</tr>
<tr>
<td>In-air explosion</td>
<td>30-Sep-03</td>
<td>0.6</td>
<td>105</td>
<td>1254</td>
<td>83 (11.26)</td>
</tr>
<tr>
<td>In-air explosion</td>
<td>21-Oct-03</td>
<td>0.6</td>
<td>119</td>
<td>651</td>
<td>96 (10.58)</td>
</tr>
<tr>
<td>Underwater explosion</td>
<td>17-Nov-03</td>
<td>0.73</td>
<td>90</td>
<td>9291</td>
<td>76 (9.32)</td>
</tr>
<tr>
<td>Underwater explosion</td>
<td>17-Nov-03</td>
<td>0.80</td>
<td>69</td>
<td>1985</td>
<td>60 (4.39)</td>
</tr>
<tr>
<td>Underwater explosion</td>
<td>17-Nov-03</td>
<td>0.95</td>
<td>119</td>
<td>1604</td>
<td>107 (7.88)</td>
</tr>
<tr>
<td>Underwater explosion</td>
<td>17-Nov-03</td>
<td>1.83</td>
<td>66</td>
<td>10498</td>
<td>62 (4.03)</td>
</tr>
</tbody>
</table>
Figure 3. Nearest neighbor distance 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.
Figure 4. Sound pressure density spectra for ambient noise levels and the underwater explosion recorded at 4 locations. Power levels (in 1 Hz bandwidths) were calculated across the duration of each signal. Underwater ambient and explosion received levels, calibrated and referenced to 1 μPa at 1 m for 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, D) 1.83 km, at Dolphin A.
Figure 5. Waveforms (uncalibrated) for the second in-air explosion (A) and the underwater explosion (B). The in-air explosion was recorded underwater at 0.60 km from the source and the underwater explosion was recorded at 0.73 km from the source. The spectrograms of the explosions have the same duration as the waveforms and a frequency range of 0 – 24,000 Hz.