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Characterization of Underwater Sounds Produced by a Hydraulic Cutterhead Dredge Fracturing Limestone Rock

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PURPOSE: The purpose of this study was to record and analyze underwater sounds generated by large hydraulic cutterhead dredge fracturing rock while engaged in the New York/New Jersey Harbor Deepening Project. Of particular interest was determining: 1) the sound frequency characteristics of the rock fracturing process, 2) the received sound pressure levels at various distances from the source, 3) the predicted source level, and 4) ambient and other anthropogenic sound sources in the study area. These data will fill an important knowledge gap and inform future dredging project management decisions.

BACKGROUND/INTRODUCTION: In recent years, the potential impact of underwater sounds associated with dredging operations has come under increasing scrutiny by regulatory agencies. Underwater noise has previously been identified as a concern, but has primarily been linked to petroleum industry seismic surveys and construction activities such as pile-driving (Richardson et al. 1995). In fact, the scant scientific literature pertaining to effects of underwater sound on fishes and other aquatic organisms has largely resulted from monitoring of pile driving operations (e.g., Caltrans 2001, Nedwell et al. 2003, Abbot et al. 2005, Ruggerone et al. 2008). Multiple USACE Districts and other Federal Agencies (e.g., NASA) have had formal or informal consultations with resource agencies concerning underwater sounds and their potential impacts on fishes or species with threatened or endangered status. A concern cited by NOAA-Fisheries and the New Jersey Department of Environmental Protection involves potential blockage or delay in the migration of anadromous fishes such as American shad (*Alosa sapidissima)*, blueback herring (*Alosa aestivalis)*, and Alewife (*Alosa pseudoharengus*) through navigable waterways. Their concern focuses on American shad, which is currently experiencing stock declines and is presumed to be sensitive to dredge sounds. In a 2010 Memorandum for Record to the USACE New York District, NOAA-Fisheries expressed concern that fishes encountering an active dredge would stop or delay further upstream movement, thereby impeding their pre-productive migration. On the Pacific coast, the USACE San Francisco District has experienced restrictions regarding potential impacts to fishes from underwater noise related to pile driving and other construction activities, but until recently the issue of underwater sound had not been linked to dredging projects. However, concerns for negative impacts of underwater sounds on aquatic species (e.g., salmon and smelt) were raised during interagency coordination of the Sacramento River Deep-Water Ship Channel Deepening Project. Concerns ranged from sounds associated with the use of two or more dredges working concurrently to sounds generated from the use of booster pumps.

Concerns about underwater noise have not been limited to impacts on fish species. The USACE New England District recently performed advanced maintenance dredging with a small hopper dredge to remove sand waves in the lower reaches of the Kennebec River, Maine. Comments citing potential underwater sound impacts on harbor seals (*Phoca vitulina*) led to consultation with the National Marine Fisheries Service (NMFS). The NMFS stated that underwater noise levels exceeding 160 dB could harass marine mammals. Currently the NMFS does not provide Incidental Harassment Authorization (IHA) with regard to dredging projects, but it is an issue being considered for application to future dredging operations. Currently IHAs are only required for underwater noise associated with pile-driving operations. The authorization requires that a 500-m safety zone must be established in all areas where underwater sound pressure levels (SPL) were anticipated to exceed 190 dB re 1 µPa. The National Aeronautics and Space Administration (NASA), Goddard Space Flight Center was required to enter into a consultation with NOAA under Section 7(a) (2) of the Endangered Species Act (ESA) for permits for a proposed Wallops Island Shoreline Restoration and Infrastructure Protection Program for threatened and endangered species. The NMFS concluded in a 2010 Biological Opinion that the proposed dredging operation may produce sounds that affect listed species of sea turtles and whales.

NMFS is developing a comprehensive acoustic policy that will provide guidance on assessing the impacts of anthropogenically produced sound on marine mammals. In the interim, NMFS' current thresholds for determining impacts to marine mammals typically center around root-mean-square (rms) received levels of 180 dB re 1 µPa (cetaceans) and 190 dB re 1 µPa (pinnipeds) for potential injury and 160 dB re 1 µPa for behavioral disturbance or harassment from an impulse sound (e.g., seismic survey), and 120 dB re 1 µPa for behavioral disturbance or harassment from a continuous noise source (e.g., certain dredging sounds). Underwater sounds generated by hydraulic dredging operations are generally considered to be continuous and consist of low frequencies (< 1000 Hz) (Clarke et al. 2002) and as such are within the audible range of listed species of both whales (7Hz - 22 kHz) and sea turtles (100-1000 Hz).

Dredge type and potential sources of sound: Hydraulic pipeline cutterhead dredges are commonly used throughout the United States for both new work and maintenance projects. They are capable of excavating most types of material and pumping the resultant sediment-water slurry through pipelines for distances of several miles or longer with the use of booster pumps. During excavation the cutterhead rotates in contact with the sediment bed while swinging laterally into the sediment face. Large, powerful cutterhead dredges are capable of dredging rock-like formations such as coral and the softer types of basalt and limestone without the need for blasting. The dredge advances by alternately swiveling on posts called "spuds" while anchored cables on each side of the dredge control lateral movement. Winch and generator sounds transmitted through the hull of the dredge are a typical sound source associated with this type of dredging operation. During hydraulic dredging, it is very difficult to separate the individual processes involved by their temporal location in the acoustic record (Clarke et al. 2002). The major processes contributing to hydraulic dredging sounds include: 1) dredged material collection sounds originating from the rotating cutterhead in contact with the bed and intake of the sediment-water slurry, 2) sounds generated by pumps and impellers driving the suction of material through the pipes, 3) transport sounds involving the movement of sediment through the pipes, and 4) ship and machinery sounds, including those associated with the lowering and lifting of spuds and moving of anchors by dredge tenders.

The hydraulic dredge *Florida* owned and operated by the Great Lakes Dredge and Dock Company was monitored in the present study. The *Florida* has an overall length of 524 ft (159.4 m), a width of 60 ft (18.3 m), and a draft of 14 ft (4.3 m). Dredging depth ranges from 25 to 95 ft (7.6 to 29 m). Suction and discharge diameters are 37 in. (940 mm) and 36 in. (914 mm), respectively. The *Florida* uses a 3,000-hp Esco 54D cutter with an 11-ft (3.3-m) diameter, rotating at 26 rpm (Figure 1). Total installed power is 25,400 hp, of which 10,000 hp operates the main pump.

Figure 1. The dredge *Florida* with attached HP Esco 54D cutterhead.

METHODS

Study site: The study location within New York/New Jersey Harbor lies at the confluence of the Kill van Kull (KVK) waterway and the Upper Bay area of the Hudson River Estuary. The Port of New York and New Jersey is the largest port on the Atlantic coast of the United States. Underwater acoustic monitoring occurred in the lower portion of the Anchorage Channel in June 2011. The study site is located on NOAA chart 12327 at approximately $74^{o}04.28$N and $40^{o}39.11$W (Figure 2).

Sound equipment and software: Sound data were collected using a Sound Technologies ST1400ENV mobile audio data recorder and a Cetacean Research C55 hydrophone. The ST1400ENV consists of a sound DAQ (Data Acquisition Board), data processor (Panasonic Toughbook Computer), Global Positioning System (GPS), auxiliary data storage hard drive (500GB), and an internal battery power supply integrated into a self-contained unit (Pelican case). External components consisted of the GPS antennae and the hydrophone. The C55 hydrophone was calibrated by the manufacturer and the calibration information was stored in the ST1400ENV. The system's calibration is certified using a standard developed by the National Institute of Standards and Technology (NIST). The system is designed specifically to record underwater sounds while simultaneously monitoring and logging sound pressure levels (SPL in dB) and other sound level parameters. The pre-amplified C55 hydrophone is fully capable of measuring quieter sources such as ambient conditions as well as louder sources. The ST1400ENV records digital WAV format audio files, which can be post-processed using the hydrophone and ST1400ENV system calibration information to produce calibrated sound spectra analyses.

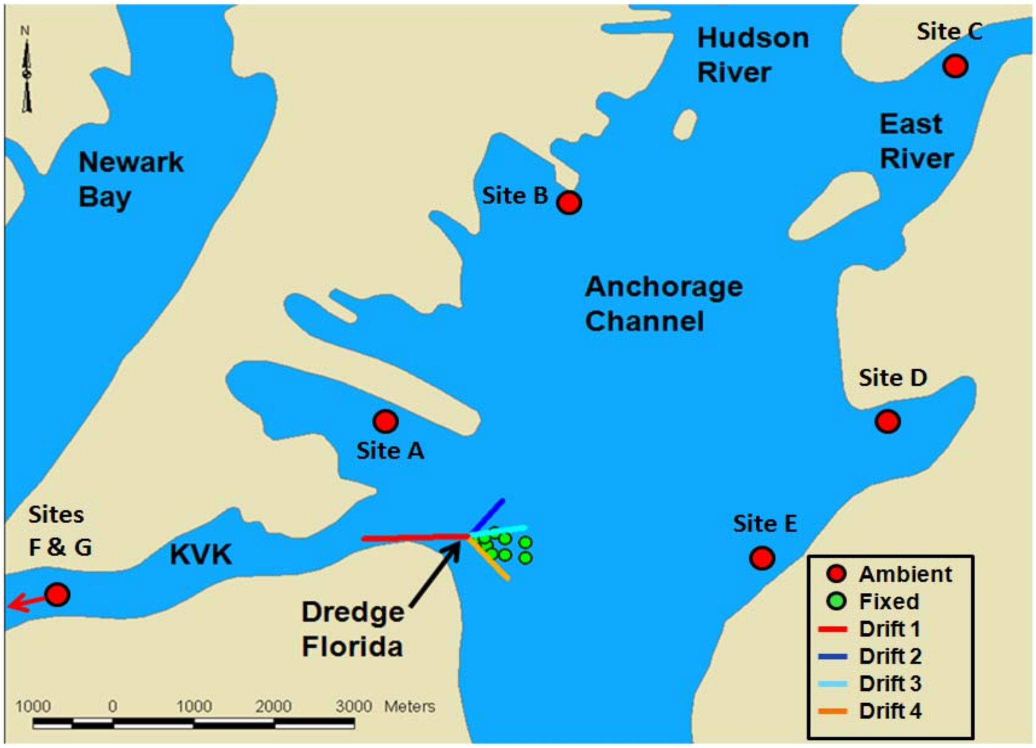

Figure 2. Study site.

Sound data were collected with MDR_SLM software provided by Sound Technology Inc., which allows input parameters to control data collection settings such as gain, filtering, and file collection sizes, as well as real-time monitoring of sound pressure levels (SPL in dB re 1 µPA rms). The primary MDR_SLM data collection parameters used in this study were: 1) gain = 0dB, 2) filtering = Off (none), 3) file sample rate = 48000 Hz, and 4) file bit density = 24 bit.

Data acquisition. Recordings were made from the M/V *Hudson* provided by the U.S. Army Engineer District, New York. After selecting an appropriate recording location, the hydrophone cable was attached to a lift line above a 5-lb weight and lowered into the water. A similar deployment configuration was used by Robinson et al. (2011). During recording sessions, the hydrophone was successively deployed at depths of 10 ft (3 m) and 30 ft (9.1 m) below the water surface. At each monitoring site, a depth reading was taken with the recording vessel's depth sounder to determine if an adequate depth was present to collect sound recordings at both preselected depths.

During recording sessions, the survey vessel was either anchored at a known distance from the dredge or was allowed to drift freely in the down-current direction. Recordings were made at 10 fixed stations (green circles in Figure 2) located 90 m to 700 m from the dredge *Florida*. Four drift transects were occupied at distances from 89 m to 1,050 m from the dredge. Distance from the survey vessel to the sound source was measured using a laser range finder manufactured by Bushnell (Elite Model 1500), with a maximum range of 1,500 m. These distances were confirmed during data post-processing by plotting positioning information of the dredge and each anchored monitoring station. When employing the "drift transect" method, distances to the sound source were taken approximately every 15 sec by laser range finder. GPS coordinates were logged automatically through the STV1400ENV, which had an attached external GPS antenna mounted on the roof of the survey vessel. Wind speed and sea state observations were taken throughout the recording sessions. Sound measurements were taken at two depths (3 m and 9.1 m) unless otherwise noted. Results were compared with ambient SPLs measured at five sites in the Anchorage Channel area and two sites in the Arthur Kill waterway, as identified in Figure 2. For the file to be considered representative of ambient conditions, no vessel traffic could be transiting the area during the recording segment.

The recording system was powered by a deep-cycle marine battery connected to a StatPower pure sine-wave inverter, which provided a 120V AC power source to an APC Smart-UPS 1000 uninterruptible power supply. By using a marine battery as the only power source, the entire system could be operated with the survey vessel completely shut down to a "quiet" mode. This eliminated any noise artifacts that would be introduced by the engine or generator aboard the survey vessel.

Data analysis. All detected sounds were logged by time stamp and clipped into 30-sec files (n = 400) from the original calibrated WAV file recorded by the ST1400ENV. Software used to clip the segments of interest included a combination of Sony Sound Forge Audio Studio and Syntrillium Cool Edit 2000. The newly created subsections of the original WAV files were saved using the same input parameters, thereby preserving the original file calibration integrity. The files produced in the previous step were sorted and organized into a directory file structure and cataloged in a spreadsheet. Individual sound files were analyzed using Sound Technologies SpectraLab 4.32 sound spectrum analysis software. SpectraLab uses Fast Fourier Transform (FFT) to convert the time-domain (amplitude vs. time) WAV files into the frequency domain (amplitude vs. frequency). Files were processed to generate an average sound spectrum and SPL across the entire file from the time series values, and using 1/3 octave analysis averaged across the whole sound clip. Each of these spectral analyses was saved in a separate text file to create graphic displays of the results. Also noted during analysis of each sound clip file were the peak frequency (in Hz) and peak amplitude (dB re 1µPA rms) for both the collection of peaks and the 1/3 octave analysis. The 1/3 octave analysis computes SPL frequency "bands" of equal length. The lower frequency bands are narrower than the higher frequency bands. The frequency bands follow a logarithmic progression. The 1/3 octave analysis sums the dB values for each frequency in the individual frequency bands and produces a dB value of the collective frequencies in each band. Each band is defined by a center frequency. The 1/3 octave analysis-Infinite average-Peak frequency is the center frequency of the 1/3 octave band with the highest calculated dB band. Note that in most cases, single peak values are not very meaningful, as they simply measure the peak amplitude of the strongest single frequency observed throughout the given sound clip. This is particularly true for sounds that are not of an impulse nature, such as the rotation of the cutterhead. In these cases, the total power is calculated from all of the collective peaks and would exaggerate any real sound levels at any single instant during the clip. The 1/3 octave analysis across the sound clip is a more meaningful value for comparing one clip to another. Conversely, if the sounds are of a more instantaneous impulse type (e.g., pile driver), an analysis of peak amplitudes and frequencies might be more appropriate. Results from the 1/3 octave were also portioned into two subcategories: 50-1000 Hz, the general frequency range audible to most fishes, and the 100- to 400-Hz frequency range audible to fish species with greater hearing sensitivity. Dredge sounds were compared to background data selected from files collected throughout the study area either prior to dredging or when the dredge was shut down. Additional ambient files were collected throughout New York/New Jersey Harbor.

Data analysis was performed with SpectrLab 4.32 using the following settings: a) Decimation Ratio = 1, which resulted in a upper frequency analysis limit of 24000 Hz due to the Nyquist sampling theorem and the original file recording parameter of 48000 Hz, b) FFT Size (samples) = 32768, which resulted in a Spectral Line Resolution of 1.465 Hz, c) FFT Overlap = 50%, which allowed a time resolution of 341.33 msec, d) Smoothing Window = Hanning, e) Peak analysis = Peak hold checked (on) and average of 1, f) 1/3 octave analysis = peak hold unchecked (off) and average all samples in the file (Infinite), and g) Frequency Weighting = None (Flat).

RESULTS

Ambient sound: In the process of compiling this technical note, 146 ambient file segments (each 1 minute in length) were selected and analyzed. Figure 3 is a spectrum plot of representative ambient sound measurements recorded at each. Table 1 is a data summary of 1/3 Octave SPLs. Ambient noise ranged from 97 to 131 dB re 1µ Pa rms (mean = 117±6.9 dB re 1µ Pa). Upper and lower 95% confidence intervals ranged from 116 to 118.3 dB re 1µ Pa. Ambient SPLs were calculated for the frequency ranges of 50-1000 Hz (mean SPL = 113.6 dB re 1µ Pa) and 100-400 Hz (mean = 107.2 dB re 1µ Pa) so that interpretations could be based on target species of known hearing sensitivities.

Lowest background sound levels (SPL in dB, 1/3 octave) were recorded in the upper water column (3 m) at Site B, located near Liberty State Park, Pier 7, averaging 107.4 dB re 1µPa, followed by Site A (mean = 110.4 dB re 1 µPa), located north of Constable Hook near the Global Marine Terminal. Other sites where SPL averaged less than 120 dB re 1 µPa included Gowanus Bay (Site D, mean = 111.9 dB re 1 µPa) at a depth of 7.5 m, and in the upper water column (3 m) at Site E, located east of the Bay Ridge Flats (averaging 117 dB re 1 µPa), and Site F (119.8 dB re 1 µPa), located in the Arthur Kill. Highest SPL occurred in the lower water column (6 m) at Site F, located in the Arthur Kill (averaging 126.5 dB re 1µPa), followed by Site C (averaging 125.3 dB re 1 µPa at a depth of 9 m), located at the entrance to the East River. Ambient data collection sites are plotted in Figure 2. Table 2 is a summary of SPL by site.

Hydraulic cutterhead dredge sounds. Sounds produced by hydraulic cutterhead dredges are essentially continuous in nature. The rotation of the cutterhead assembly embedded in the substrate occurs while the dredge is in production mode with pumps activated. Occasionally the cutterrhead is raised off the bottom to entrain water to flush the system, or while the dredge is repositioned by spud or tender vessel maneuvers. The system is flushed periodically to clear the pipeline pathway or to prime pumps. The duration of production "cuts" depends on a number of factors, including depth of insertion of the cutterhead, type of sediment being excavated, and width of the navigation channel. While these operations are occurring, continuous sounds are being produced by the pumps and dredge power plant. In the present study the dredge was not actively pumping, but using the mechanical forces of the rotating cutterhead to fracture limestone rock. The fractured material was later removed by the backhoe dredge *New York* (as described in a separate technical note). Thus the present study examined a "worst case scenario" in terms of sound generation in that the cutterhead was used aggressively to apply mechanical force to a hard substrate. However, pump sounds were minimized and sounds associated with material movement within pipes were absent.

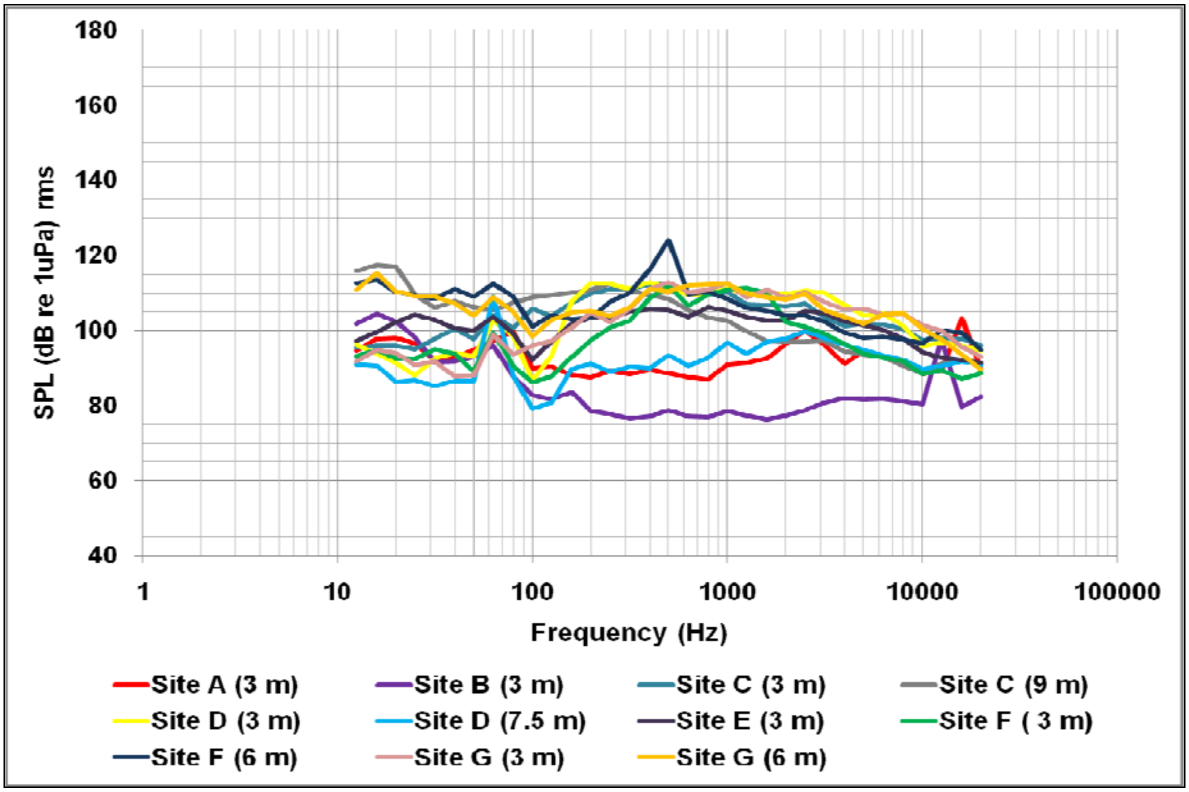

Figure 3. Representative examples of SPL (dB re 1 µPa) results from 1/3 octave analysis at monitoring sites throughout New York Harbor.

Table 1. Summary of 1/3 octave ambient SPL (dB re 1µPa).

SPL	All Frequencies	50-1000 Hz	100-400 Hz
Minimum	97.5	95.1	81.8
Maximum	131.2	125.9	123.3
Average	117.1	113.6	107.2
SE	0.574	0.631	0.83
Upper 95% CI	118.3	114.8	108.8
Lower 95% CI	116.0	112.3	105.6

Table 2. Results of 1/3 octave ambient SPL (dB re 1µPa) by site.

Location	Water Depth, (m)	Minimum, SPL	Maximum, SPL	Average, SPL
Site A	3	108.6	112.5	110.4
Site B	3	97.5	116.8	107.4
Site C	3	121.7	122.2	121.9
Site C	9	122.2	130.9	125.3
Site D	3	116.7	123.3	120.2
Site D	7.5	116.7	123.3	120.2
Site E	3	115.3	119.3	117.2
Site F	3	118.2	123.6	119.8
Site F	6	124.1	131.2	126.5
Site G	3	120.3	124.7	121.3
Site G	6	120.9	123.3	121.9

Multiple sound recordings were collected while the cutterhead assembly was operating in contact with the bottom by anchoring the recording vessel platform at known distances from the dredge plant, and by positioning the survey vessel as close to the source as possible at the start of the recording session and allowing the vessel to slowly drift away from the source. An example sound pressure waveform for a 30-second time interval (Figure 4) clearly indicates the continuous nature of sounds measured immediately in front of the operating cutterhead). These sounds could not be partitioned into discrete components attributable to individually identifiable sound sources. Within the sound record, sound intensity varied depending on the amount or hardness of the material to be removed during the cut as noted by the less intense peaks towards the right side of the example sound pressure waveform. Thus, characterizing the cutterhead sounds collected in this study was constrained to analyses of cumulative sources.

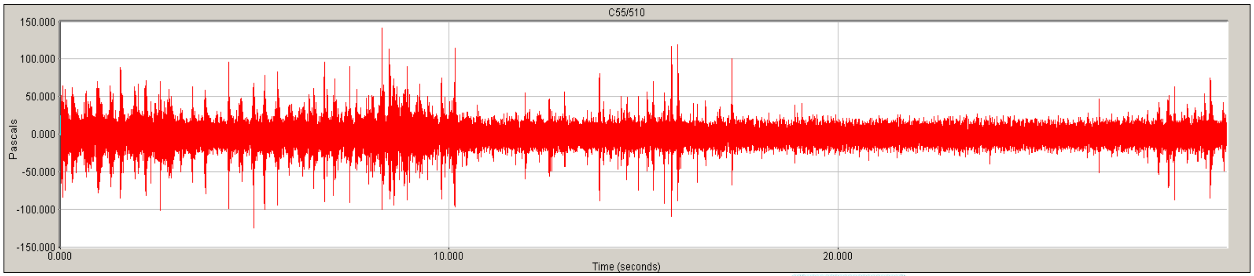

Figure 4. Pressure waveform for hydraulic cutterhead sounds.

Sound File

Tables 3 and 4 summarize the 1/3 octave analysis SPL (dB re 1µPa) rms versus range for the 3-m and 9-m deep hydrophones. Most of the sound energy produced fell within 1/3 octave center peak frequency bins ranging from 12.5 to 2500 Hz. The three most common peak center bin frequencies were 800 Hz, 1000 Hz, and 2500 Hz, accounting for nearly 60% of all files analyzed. Maximum received SPL at a distance of 89 m (hydrophone depth = 3 m) from the source was 149.3 dB re 1µPa, or slightly more than 32 dB above background (mean ambient = 117.1dB re 1µPa). When applying minimum (97.5 dB re 1µPa) and maximum (131.2 dB re 1µPa) ambient values, SPLs at this distance from the source ranged from as low as 18.2 to as high as 51.8 dB re 1µPa above background. Note that all distances are from the listening vessel to the wheelhouse of the dredge plant. Therefore, 40 m was subtracted to estimate the distance to the cutterhead when the cutterhead was positioned directly in front of the wheelhouse. Actual distance varied based on the orientation of the cutterhead as the dredge swept across its cutting arc. Slightly higher SPLs were received at the 9-m hydrophone depth, 100 m from the source at 151 dB re 1µPa, averaging 33.9 dB re 1µPa above background. SPL differed by less than 2 dB between the shallow and deep listening stations. SPL remained above 140 dB re 1µPa, (23 dB above ambient) at the deep listening depth as far as 200 m from the source (Table 4), exceeding maximum ambient SPL by as much as 9 dB. At the 3-m listening depth, received SPLs exceeding 140 dB re 1µPa were common as far as 172 m from the source, and intermittently detected to a distance of 425 m from the source. SPLs greater than135 dB re 1µPa but less than 140 dB re 1µPa were commonly detected out to 500 m from the source at the 3-m listening depth, and to 740 m at the 9-m listening depth. An SPL of 135 dB re 1µPa would exceed average background SPL by 17.9 dB. Over the next 200 m, or out to 700 m from the sound source, SPLs at the shallow listening depth were as low as 130 dB re 1µPa. This value exceeded average background SPL by 13 dB, or slightly below maximum ambient SPL (131.15 dB re 1µPa). The lowest recorded SPL was 123.5 dB re 1µPa, which exceeded ambient by only 6.4 dB. Figure 5 depicts SPL versus distance from the cutterhead operation. This graph illustrates the variation in SPL at distance and depth. For example, SPL differed by as much as 10 to 15 dB at distances of less than 200 m among the analyzed 30-second file segments. This variation typically decreased to less than a 4-dB difference with increasing distance from the sound source. Assuming a transmission loss of 15LogR (practical spreading), source levels (SL) would reach 175 dB re 1 µPA @1m.

Table 3. Summary of 1/3 octave analysis SPL (dB re 1 µPa) rms versus range (m). (Hydrophone depth = 3 m)

Range	SPL (ALL FREQ)	SPL (All Freq. > Avg. Ambient	SPL (50-1000 Hz)	SPL 50-1000 Hz > Avg. Ambient	SPL 100-400 Hz	SPL 100-400 Hz > Avg. Ambient
89	149.3	32.2	148.0	34.4	144.3	37.1
96	147.1	30.0	145.4	31.8	140.7	33.5
102	142.6	25.5	140.6	27.0	136.0	28.8
111	137.4	20.3	134.9	21.3	130.2	23.0
121	145.1	28.0	142.9	29.3	137.8	30.6
125	145.1	28.0	142.7	29.1	138.1	30.9
126	142.2	25.1	140.4	26.8	136.5	29.3
130	141.0	23.9	139.3	25.7	135.5	28.3
133	142.2	25.1	140.4	26.8	137.0	29.8
138	147.9	30.8	145.3	31.7	138.6	31.4
140	143.1	26.0	141.2	27.6	137.4	30.2
147	143.0	25.9	141.0	27.4	136.8	29.6
149	142.7	25.6	139.4	25.8	133.7	26.5
151	137.1	20.0	134.2	20.6	131.0	23.8
152	143.9	26.8	140.5	26.9	135.3	28.1
153	139.8	22.7	136.9	23.3	132.8	25.6
154	138.1	21.0	134.5	20.9	130.7	23.5
155	136.6	19.5	132.6	19.0	129.0	21.8
157	137.2	20.1	133.8	20.2	130.2	23.0
158	137.4	20.3	134.9	21.3	130.9	23.7
160	142.5	25.4	140.7	27.1	134.8	27.6
163	143.1	26.0	141.6	28.0	138.3	31.1
166	142.1	25.0	140.5	26.9	138.2	31.0
167	142.0	24.9	138.9	25.3	133.7	26.5
168	137.6	20.5	133.9	20.3	129.4	22.2
169	142.2	25.1	140.2	26.6	137.3	30.1
172	140.5	23.4	138.1	24.5	135.0	27.8
173	134.9	17.8	132.0	18.4	128.9	21.7
180	138.1	21.0	135.2	21.6	131.5	24.3
182	149.2	32.1	146.2	32.6	138.5	31.3
187	139.3	22.2	136.4	22.8	132.4	25.2
203	146.8	29.7	144.0	30.4	134.8	27.6
204	138.6	21.5	135.7	22.1	132.4	25.2
209	137.4	20.3	133.9	20.3	130.3	23.1
212	141.7	24.6	139.4	25.8	131.8	24.6
214	136.5	19.4	133.6	20.0	130.0	22.8
220	139.7	22.6	136.2	22.6	131.9	24.7
224	138.5	21.4	136.2	22.6	129.2	22.0
229	140.0	22.9	136.9	23.3	133.2	26.0

Range	SPL (ALL FREQ)	SPL (All Freq. > Avg. Ambient	SPL (50-1000 Hz)	SPL 50-1000 Hz > Avg. Ambient	SPL 100-400 Hz	SPL 100-400 Hz > Avg. Ambient
240	138.4	21.3	135.8	22.2	130.7	23.5
250	138.4	21.3	135.9	22.3	132.0	24.8
253	136.8	19.7	133.7	20.1	127.3	20.1
264	138.6	21.5	136.4	22.8	131.9	24.7
265	135.9	18.8	133.3	19.7	129.5	22.3
266	137.5	20.4	134.4	20.8	129.9	22.7
268	139.1	22.0	136.6	23.0	132.9	25.7
270	136.7	19.6	134.3	20.7	131.9	24.7
272	138.0	20.9	135.9	22.3	132.9	25.7
273	135.8	18.7	131.9	18.3	127.5	20.3
274	135.9	18.8	132.8	19.2	130.2	23.0
275	138.1	21.0	136.1	22.5	133.3	26.1
279	139.0	21.9	137.9	24.3	136.0	28.8
281	138.8	21.7	136.4	22.8	132.1	24.9
282	138.5	21.4	137.2	23.6	135.5	28.3
287	136.8	19.7	134.9	21.3	132.8	25.6
292	135.4	18.3	133.7	20.1	131.6	24.4
296	137.3	20.2	135.3	21.7	133.3	26.1
300	137.5	20.4	134.9	21.3	132.2	25.0
302	135.8	18.7	133.0	19.4	129.7	22.5
303	140.2	23.1	138.1	24.5	131.3	24.1
305	135.2	18.1	132.5	18.9	129.0	21.8
308	135.5	18.4	132.9	19.3	129.4	22.2
310	136.1	19.0	134.0	20.4	129.5	22.3
316	140.9	23.8	138.8	25.2	133.1	25.9
329	142.3	25.2	140.1	26.5	134.4	27.2
347	140.2	23.1	137.5	23.9	129.3	22.1
351	136.6	19.5	134.8	21.2	130.8	23.6
353	135.3	18.2	132.7	19.1	127.8	20.6
355	136.4	19.3	132.5	19.8	128.1	20.9
356	135.6	18.5	132.1	18.5	128.2	21.0
358	137.2	20.1	135.5	21.9	130.6	23.4
359	136.4	19.3	133.0	19.4	128.1	20.9
362	134.5	17.4	130.7	17.1	126.5	19.3
364	136.6	19.5	134.7	21.1	130.2	23.0
365	134.7	17.6	131.3	17.7	129.1	19.9
368	140.1	23.0	136.9	23.3	130.6	23.4
369	133.5	16.4	130.5	16.9	127.0	19.8
370	132.6	15.5	129.4	15.8	124.8	17.6
373	133.3	16.2	130.6	17.0	126.8	19.6
375	132.3	15.2	129.5	15.9	124.7	17.5
376	132.0	14.9	128.2	14.6	123.1	15.9
377	142.6	25.5	139.4	25.8	132.6	25.4
378	133.6	16.5	131.0	17.4	127.1	19.9
381	131.4	14.3	129.0	15.4	125.9	18.7
382	132.8	15.7	129.6	16.0	124.8	17.6
383	135.2	18.1	132.7	19.1	128.9	21.7
387	142.3	25.2	139.0	25.4	132.1	24.9
388	133.5	16.4	130.6	17.0	126.8	19.6
389	133.8	16.7	130.0	16.4	124.3	17.1

Range	SPL (ALL FREQ)	SPL (All Freq. > Avg. Ambient	SPL (50-1000 Hz)	SPL 50-1000 Hz > Avg. Ambient	SPL 100-400 Hz	SPL 100-400 Hz > Avg. Ambient
395	144.5	27.4	140.8	27.2	134.0	26.8
400	134.2	17.1	130.4	16.8	124.9	17.7
407	143.9	26.8	139.4	25.8	131.4	24.2
410	133.3	16.2	129.8	16.2	124.7	17.5
417	132.5	15.4	129.0	15.4	124.1	16.9
419	142.6	25.5	139.5	25.9	132.7	25.5
425	140.1	23.0	137.2	23.6	132.5	25.3
426	132.5	15.4	129.3	15.7	124.4	17.2
433	138.3	21.2	135.7	22.1	131.6	24.4
440	134.4	17.3	130.9	17.3	126.8	19.6
450	134.9	17.8	133.3	19.7	129.3	22.1
453	133.0	15.9	129.0	15.4	125.0	17.8
466	134.3	17.2	132.1	18.5	128.3	21.1
474	134.7	17.6	130.5	16.9	126.6	19.4
480	129.3	12.2	125.4	11.8	122.0	14.8

Table 4. Summary of 1/3 octave analysis SPL (dB re 1 µPa) rms versus range (m). (Hydrophone depth = 9 m)

Range	SPL (ALL FREQ)	SPL > Avg. Ambient	SPL (50-1000 Hz)	SPL > Avg. Ambient	SPL 100-400 Hz	SPL > Avg. Ambient
100	151.0	33.9	148.9	35.3	146.3	39.1
111	148.9	31.8	146.9	33.3	144.1	36.9
126	146.6	29.5	144.4	30.8	141.0	33.8
130	143.5	26.4	141.8	28.2	139.0	31.8
145	143.7	26.6	141.6	28.0	138.8	31.6
149	143.1	26	140.9	27.3	137.5	30.3
157	142.1	25	140.3	26.7	138.5	31.3
168	143.3	26.2	141.6	28.0	139.6	32.4
185	143.1	26	141.2	27.6	139.0	31.8
200	140.7	23.6	139.4	25.8	137.5	30.3
215	139.9	22.8	138.7	25.1	137.0	29.8
220	139.3	22.2	137.0	23.4	133.5	26.4
230	139.5	22.4	138.0	24.4	136.0	28.8
240	140.2	23.1	138.2	24.6	135.9	28.7
265	139.8	22.7	136.8	23.2	134.3	27.1
301	140.4	23.3	137.8	24.2	135.0	27.8
318	140.1	23	137.4	23.8	134.6	27.4
338	139.0	21.9	136.0	22.4	133.6	26.4
350	138.8	21.7	135.6	22.0	133.1	25.9
355	138.3	21.2	134.9	21.3	130.7	23.5
360	137.0	19.9	134.4	20.8	131.9	24.7
370	137.1	20	134.8	21.2	132.5	25.3
385	136.4	19.3	133.4	19.8	131.1	23.9
400	137.1	20	134.4	20.8	132.3	25.1
500	137.5	20.4	132.7	19.1	129.3	22.1
520	136.5	19.4	132.3	18.7	129.0	21.8
520	132.1	15	126.0	12.4	122.7	15.5
540	136.6	19.5	131.0	17.4	127.6	20.4

Range	SPL (ALL FREQ)	SPL > Avg. Ambient	SPL (50-1000 Hz)	SPL > Avg. Ambient	SPL 100-400 Hz	SPL > Avg. Ambient
550	136.1	19	129.0	15.4	125.7	18.5
560	135.9	18.8	128.4	14.8	124.9	17.7
570	136.7	19.6	128.4	14.8	125.0	17.8
580	136.3	19.2	129.4	15.8	125.6	18.4
595	135.3	18.2	130.0	16.4	126.7	19.5
610	136.6	19.5	129.6	16.0	126.8	19.6
630	136.2	19.1	128.9	15.3	126.4	19.2
650	136.2	19.1	128.4	14.8	125.6	18.4
670	135.2	18.1	128.3	14.7	125.1	17.9
680	132.9	15.8	128.7	15.1	125.8	18.6
700	132.6	15.5	127.6	14.0	124.4	17.2
720	136.2	19.1	129.9	16.3	125.5	18.3
740	136.0	18.9	129.1	15.5	125.4	18.2

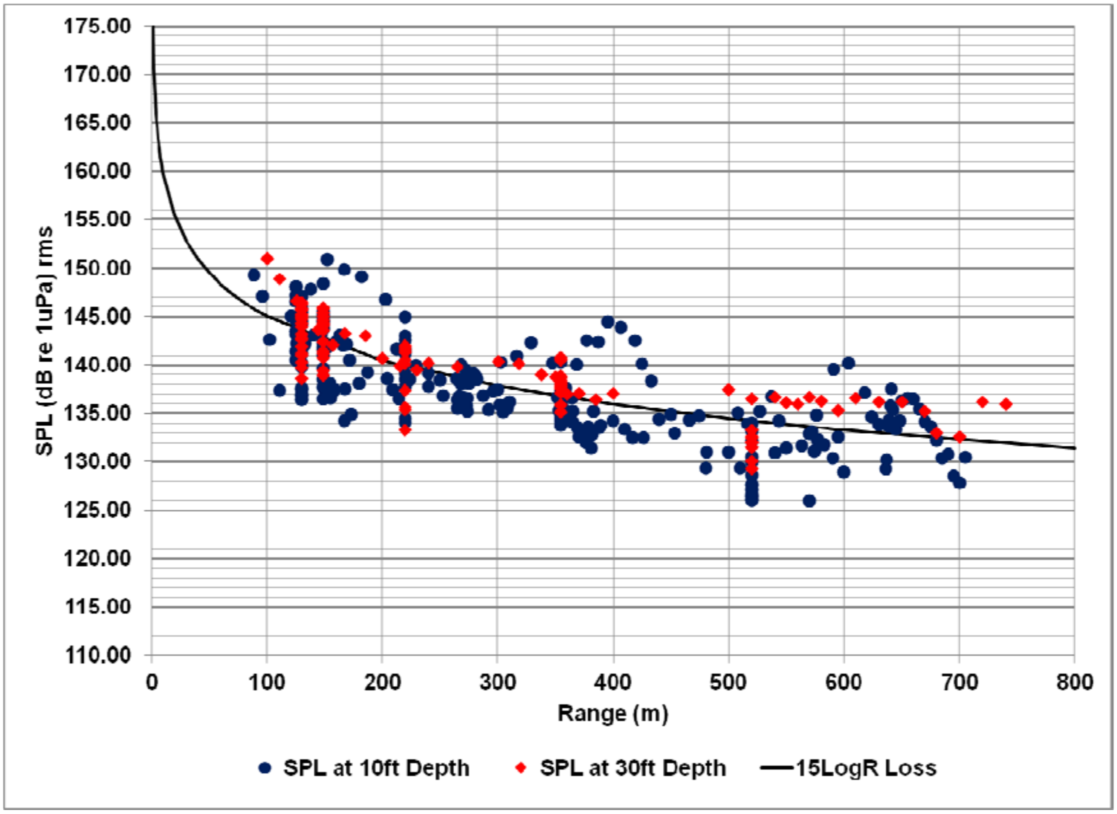

Figure 5. Analysis results for 1/3 octave (SPL in dB re 1µPa) rms versus range (m).

The study also determined 1/3 octave SPLs for the 50- to 1000-Hz frequency range, which is audible to the majority of fish species, and the 100- to 400-Hz range, which covers the audible range of the most sensitive fish species (Tables 3 and 4). Results indicated that background SPLs were 3.5 dB (50-1000 Hz) to 9.9 dB (100-400 Hz) lower than the total energy contained across all frequencies. Background 1/3 octave SPLs averaged 113.6 dB re 1µPa (range = 95.1 to 125.9 dB) in the 50- to 1000-Hz frequency range and 107.2 dB re 1µPa (range = 81.8 to 123.3 dB) in the narrower 100- to 400-Hz frequency range. At the upper shallow 3-m listening depth, 1/3 octave SPLs typically differed by less than 5 dB (range = 1.3-7 dB) when compared to results from the 50- to 1000-Hz range, and by less than 11.7 dB (range = 3-11.7 db) for the 100- to 400-Hz frequency range when compared to results across all analyzed frequencies.

At the deeper 9-m listening depth, 1/3 octave SPLs within the 50- to 1000-Hz frequency range were 1.7 to 6.9 dB lower in comparison to all frequencies analyzed (12.5 Hz- 20 kHz). Variation in SPL tended to be greater with increasing distance from the source. A similar pattern occurred in the 100- to 400-Hz frequency range with 1/3 octave SPLs 3.6 to 11.7 dB lower than the results across all frequencies. Differences in SPL were not as pronounced with increasing distance from the source as at the upper listening depth.

Although there was typically a decrease in SPL when comparing subsets of frequencies (50-1000 Hz and 100-400 Hz) to all frequencies within the range, there was generally an increase in SPL relative to background. For example, at 89 m from the source (hydrophone depth = 3 m), the received 1/3 octave SPL was 149.3 dB re 1µPa for “all frequencies” analyzed, 148.0 dB re 1µPa in the 50- to 1000-Hz frequency range, and 144.3 dB re 1µPa in the 100- to 400-Hz frequency range. When factoring in background SPL for each frequency range, SPL exceeded ambient by 32.2 dB for all frequencies, 34.4 dB for the 50- to 1000-Hz (mean ambient = 113.6 dB) frequency range, and 37.1 dB for the 100- to 400-Hz (mean ambient = 107.2 dB) frequency range. For all analyzed file segments, SPLs exceeding ambient within the 50- to 1000-Hz frequency range were as much as 2.4 dB higher at distances less than 400 m from the source. In contrast, SPLs were 3.8 dB lower at distances exceeding 400 m in comparison with the results for the entire frequency spectrum analyzed. In the 100- to 400-Hz frequency range, almost all file segments analyzed had SPL increases of at least 0.5 dB to as high as 5 dB when comparing SPL for all frequencies combined.

A similar pattern was observed at the deeper 9-m listening depth. For example, at 100 m from the source, the received 1/3 octave SPLs were 151 dB re 1µPa for all frequencies analyzed, 148.9 dB re 1µPa in the 50- to 1000-Hz frequency range, and 146.3 dB re 1µPa in the 100- to 400-Hz range. Adjusting for background SPL within each frequency range, SPL exceeded ambient by 33.9 dB (all frequencies) to 35.3 dB for the 50- to 1000-Hz range and by 39.1 dB for the 100- to 400-Hz range. At distances less than 400 m from the sound source, 1/3 octave SPLs exceeded ambient in the 50- to 1000-Hz range by 0.1 to 2.3 dB when compared to the SPL exceeding ambient for all frequencies combined. At distances greater than 500 m from the source, SPLs decreased by 0.7 to 4.8 dB when compared to SPLs exceeding ambient for all frequencies. In the 100- to 400-Hz frequency range, 1/3 octave SPLs relative to ambient increased by 0.5 to 7 dB at distances as far as 550 m from the source when compared to SPL exceeding ambient for all frequencies. At distances greater than 550 m, results were mixed with approximately half of the files analyzed showing increases (0.5 to 1.8 dB) while the other half had decreases (0.1 to 2.8 dB) in SPL relative to SPL exceeding ambient for all frequencies.

DISCUSSION: Ambient noise can be described as sounds present in the environment without distinguishable sources. Ambient noise is continuous, but with considerable variation on time scales ranging from several seconds to over the course of an entire year. To understand ambient underwater noise, repeated measurements must be taken on appropriate temporal and spatial scales under varying environmental conditions, such as varying tidal and storm-associated hydrodynamic conditions. Knowledge of average ambient sound levels and the variability surrounding these levels is fundamental to interpretation of sounds produced by anthropogenic sources and assessment of responses of organisms to those sounds. Under ideal research conditions, a comprehensive characterization of ambient noise would require long-term deployment of acoustic data-logging sensor arrays. Long-term records would be collected either continuously or at predetermined intervals. This approach, however, is extremely labor-intensive and costly. For the purposes of the present study, the adopted approach used site- and time-specific measurements. Although the obtained ambient noise levels do not represent the acoustic sound field for the entire harbor over an extended period of time, site-specific measurements provide an accurate baseline for comparison to sounds emitted by dredges during this study. Several sources of ambient noise are present in New York Harbor. Tidal currents produce hydrodynamic sounds, which are most significant at very low frequencies (< 100 Hz), but increase in strength with increasing water depth. Ship traffic, including ships passing through the immediate study area, generate sounds that can travel considerable distances, especially in frequencies ranging from 10 to 1000 Hz. Sea state, as influenced by wind speed, produces ambient sounds above 500 Hz. Transient sounds comprise a general category consisting of a variety of sources, particularly of industrial origin in this coastal setting. Biological sounds are associated with a host of mammals, fishes, and invertebrates, which can generate broadband noise in the frequency range of 1 to 10 kHz with intensities as high as 60 to 90 dB. In certain cases, sounds generated by whales and dolphins for echolocation and communication can reach 180 to 200 dB in the 50- to 200-kHz frequency range.

Blackwell and Greene (2002) reported ambient SPLs at six locations isolated from industrial activities in Anchorage Harbor and the Knik Arm of Cook Inlet, Alaska. The authors reported that ambient sound levels ranged from 95 dB in the Knik Arm to 124 dB near Point Possession on an incoming tide. Sound pressure levels in Anchorage Harbor averaged 113 dB. These ambient SPLs are comparable to those recorded in the Canadian Beaufort Sea, averaging 99 dB, by Greene (1987) and off Barrow Alaska (1/3 octave range 50 to 115 dB) by Richardson et al. (1995). In the present study, the average background noise measurement ranged from 97.5 to 131.2 dB re 1 µPa (mean = 117.1 dB re 1µPa). Maximum ambient SPLs reported in this study exceeded those reported by Blackwell and Greene (2002) and Richardson et al. (1995). This may simply reflect the fact that the previous studies were conducted in open-water environments away from major industrial activities.

The majority of underwater sounds produced by hydraulic cutterhead dredging operations monitored in this study were of relatively low frequency, generally less than 1000 Hz, and occurred most frequently in three 1/3-octave bands (800 Hz, 1000 Hz, and 2500 Hz). There was considerable variation in SPL measured at specific distances. Variation tended to be greater at listening stations located nearer the sound source. Some degree of variation in SPL results from the orientation of the listening to the dredge plant, to the position of the cutterhead as it swings laterally, and to the non-uniform, intermittent sediment removal process. An example of the latter involves the type and density of the sediment to be removed. In the sound pressure wave given in Figure 4, the cutterhead is fully engaged in rock fracturing at the start of the file segment, whereas toward the end of the file the sediment became less dense and led to generation of lower SPLs.

The cutterhead rock fracturing source level (SL) was estimated to be between 170 and 175 dB re 1 µPa@1-m. Sound levels decreased with increasing distance from the source. In the upper water column, SPL diminished by 21 dB re 1 µPa as distance increased from 89 m to 700 m from the source. At the deep 9-m listening depth, SPL decreased by 15 dB across a comparable distance (100 m to 740 m). Maximum detection distances in this study were approximately 800 m. Using 15LogR as loss attributable to practical spreading and 175 dB as a source level, SPL generated in this study would diminish to 131.5 dB at a distance of 800 m from the source. This value would be nearly equivalent to the maximum (131.2 dB) ambient value derived in the present study; however, it would still exceed average background SPL by 14 dB. Data collected at two additional anchored listening stations located 900 m and 1040 m from the source were corrupted by hydrodynamic noise as current velocities approached maximum flow conditions. Sounds produced by the dredge may have been detectable at these ranges, had ambient conditions within the harbor been closer to average rather than maximum values. The apparent maximum detection distance of 800 m in this study was influenced by a number of factors. Importantly, one must consider that New York Harbor is an expansive sound field and that drifting away from one sound source typically means moving into the zone of influence of one or more other sources. The geomorphology of the study site also affects the propagation of sound throughout the study area. The presence of a broad navigation channel with depths near 60 ft (18.3 m), bordered to the north and south by shoals with water depths around 22 ft (6.7 m), and adjacent shoals grading from 11 ft (3.3 m) to as shallow as 5 ft (1.5 m) creates a complex physical setting in which sounds can reflect off side slopes. In addition, comparatively high suspended sediment loads in estuaries can shorten sound attenuation distances in comparison to offshore "blue" water settings. Richards et al. (1996) reported that suspended sediment concentrations as low as 20 mg/l could cause an attenuation of 3 dB over a distance of 100 m at 100 kHz. Although no water samples were taken for gravimetric analysis in this study, many samples have been collected during suspended sediment plume characterizations in the harbor. Ambient suspended sediment concentrations in New York/New Jersey Harbor occasionally surpass 20 mg/l.

Few prior studies have described dredging sounds. Studies by Greene (1985, 1987), Miles et al. (1986, 1987), Department for Environment, Food, and Rural Affairs (DEFRA) (2003), Parvin et al. (2008), and Robinson et al. (2011) are among the very few relevant references that exist. Greene (1985, 1987) measured broadband noise emitted by two hydraulic cutterhead-pipeline dredges at ranges extending to 25 km in the Beaufort Sea. For the Dredge *Beaver Mackenzie,* peak spectral levels were 122 dB at 190 m with a peak frequency of 120 Hz. Received levels in the 20- to 1000-Hz band were 133 dB (rms) re 1 µPa at 190 m from the sound source. Source level (rms) was calculated to be 168 dB re 1 µPA@1m. Measurements were obtained from a second cutterhead dredge (*Acquarius*) at distances ranging from 0.2 to 14.8 km. At the closest distance, the 20-to 1000-Hz band had received levels of 140 dB at two hydrophone depths (3 and 18 m). Peak spectral levels were 122 dB at 200 m at a peak frequency of 120 Hz. Source level (rms) was calculated to be 178 db re 1µPa@1m. Greene (1987) also reported underwater sound levels for three hopper dredges. The authors reported that hopper dredges produced the loudest noises but with fluctuating levels. Hopper dredges produced the most noise during the loading or unloading process, and are quieter while underway. For the 8000-m^3 capacity *Geopotes X,* SPL were 139 dB re 1µPA@430 m in the 20- to 2000-Hz band. The 9000-m^3 hopper dredge *Cornella Zanen* recorded peak spectral levels of 125 dB @ 200 m with a peak frequency of 175 Hz. Received SPL at 930 m was 142 dB re 1 µPa. Received SPLs for a smaller capacity (6000-m^3) hopper dredge, *W. D. Gateway,* were

131 dB µPA at 1500 m. Estimated source levels for these three hopper dredges ranged from 179 to 187 dB re 1 µPa.

Miles et al. (1986, 1987) recorded sounds produced by a bucket dredge, noting that the most intense sounds were in the 1/3 octave at 250 Hz ranging from 150 to 162 dB re 1 µPa. The authors reported that the loudest sounds measured in their study were produced during winching of the loaded bucket up through the water column.

The Center for Environment, Fisheries, and Aquaculture Science measured the sounds from a 2,890-m^3 trailing suction hopper dredge (*Acra Adur*) operating at two different locations in the southern North Sea. Produced sounds were predominantly of low frequency (< 500 Hz) with peak spectral levels of 122 dB re 1 µPa at a range of 56 m, and a peak frequency of 320 Hz (DEFRA 2003).

Parvin et al. (2008) measured the source levels of a 2,700-m^3 hopper dredge (*The City of Westminster*) operating on the Hasting Shingle Bank and calculated the broadband source levels of 186 dB re 1 µPa@1-m (20 Hz to 80 kHz) consistent with SPLs reported by Greene (1987) for hopper dredging operations during the removal of gravelly sand. No 1/3 octave band source level data were provided. Detection ranges in the Beaufort Sea extended out to 25 km. Parvin et al. (2008) reported levels below background at 6 km, attributable to relatively high ambient background noise in the English Channel.

Robinson et al. (2011) reported source levels (1/3 octave range = 155 to 185 dB re 1 µPa@1-m) for six hopper dredges (capacity range 1,418-4,832 m^3) during marine aggregate dredging. The authors reported that noise radiated at frequencies less than 500 Hz and was similar to that of a merchant vessel traveling at a modest speed. During aggregate mining, however, dredging generated higher sound levels at frequencies above 1 kHz than a typical merchant vessel. These sounds were associated with the impact/abrasion of the aggregate material passing through the draghead, suction pipe, and pump. The authors concluded that the elevated broadband noise was dependent on the aggregate type being extracted and that gravel produced higher noise levels than sand.

Reine et al. (in preparation) characterize sounds produced by the 3,434-hp excavator dredge *New York*, which used a 25-yd^3 bucket to remove limestone rock previously fractured by the cutterhead dredge *Florida*. Six distinct “events” were identified, including four events associated with a single cycle of bucket deployment and retrieval, one event (spud walking) associated with movement of the dredge plant, and one event (spud anchoring) associated with barge anchoring. One additional short-lived event was identified as a “popping” sound apparently associated with a mechanical issue with the hydraulic boom, which was quickly corrected. SPL and source levels for each event were: bottom grab (SPL range = 132-148 dB, Source Level = 179.4 dB); spud walking (SPL range = 136-147 dB, Source Level = 175.5 dB); barge loading (SPL range = 130-139 dB, Source Level 166.2 dB); hydraulic ram noise (SPL range = 129-137 dB, Source Level = 164.2 dB); anchoring spuds (SPL = 133-137 dB, Source Level 172.7 dB); engine/generator noise (SPL = 123-135 dB, Source Level = 171.8 dB), and popping noises (SPL range = 135-140 dB, Source Level 167.1 dB). The range of SPLs is given for the 1/3 octave analysis for each sound type. Source levels were back-calculated based on transmission loss due to practical spreading (15LogR). Peak frequencies ranged from 140 to 1250 Hz. With the exception of engine/

generator noise, which was detected to just under 700 m from the source, all other noise types were not detected beyond 300 m.

CONCLUSION: The present study represents the first characterization of sounds produced by a hydraulic cutterhead dredge during rock fracturing within a major U.S. harbor. Based on the type of substrate alone, this mode of cutterhead dredging might be assumed to be a "worst case scenario" with respect to sound production. This assumption was generally incorrect. Although source levels were calculated to approach 175 dB re 1 µPa@1-m rms, the area of influence was limited to less than 100 m from the source. At 100 m, received levels were less than 150 dB re 1µPa rms. The NMFS is currently developing guidelines for determining sound pressure level thresholds for fishes and marine mammals. Based on a few existing studies, the NMFS current thresholds for determining impacts to marine mammals is centered around root-mean-square (RMS) received levels between 180 and 190 dB re 1 µPa for potential injury to cetaceans and pinnipeds, respectively, and 160 dB re 1 µPa for behavioral disturbance/harassment from an impulsive noise source (e.g., seismic survey) and 120 dB re 1µPa for behavioral disturbance/ harassment from a continuous noise source (e.g., dredging). In the present study, the zone of influence in which 1/3 octave SPL reached 160 dB re 1 µPa, was less than 20 m from the source. At no time during the study did received or calculated SPLs exceed the 180- and 190-dB criteria for potential injury for cetaceans and pinnipeds. The 120 dB re 1µPa proposed threshold for behavioral disturbance/harassment from a continuous noise source such as dredging was reached and frequently exceeded by ambient conditions in the absence of dredging activities.

The NMFS' interim criterion for physical injury to fish is a 206 dB peak, regardless of fish size. For cumulative sound exposure levels (SEL), criteria are 187 dB re 1 µPa per unit of time for fish weighing greater than 2 grams and 183 dB re 1 µPa per unit of time for fish less than 2 grams. Few studies have documented the effects of anthropogenic sounds on the behavior of fishes. However, based on the present state of knowledge, SPLs in the 1/3 octave analysis for all frequencies were well below levels that would cause physical injury to any fish species in the harbor. The same was true for SPLs for the 50- to 1000-Hz, and 100- to 400-Hz frequency ranges, which are commonly considered to be audible by fishes in general and by fishes with high sound sensitivity. Herring and shad species of the family Clupeidae are capable of hearing well outside these ranges into the ultrasonic range from 0.2 to 180 kHz (Mann et al. 1998). Highest sensitivity of the American shad ranged from 200 to 800 Hz in the sonic range and from 25 to 130 kHz in the ultrasonic range. Because most sounds produced by dredges are at frequencies less than 1 kHz, American shad could potentially be affected by dredge sounds in the sonic range. A behavioral response to sound in the ultrasonic range has been observed for some clupeids and has been used to prevent fish entrainment by repelling them from power plant intakes (Dunning et al. (1992). Behavioral responses to low-frequency sounds generated by dredging operations are not well documented, although the concern is frequently cited by resource agencies as having potentially negative impacts on anadromous fish migrations. Mann et al. (2001) demonstrated that Gulf menhaden (*Brevoortia patronus*) can detect sounds in the ultrasonic range. Bay anchovies (*Anchoa mitchilli*), scaled sardines (*Harengula jaguana*), and Spanish sardine (*Sardinella aurita*) may be able to detect sounds to 4 kHz. A critical issue in assessing dredging-induced sound effects on fish behavior is not only whether the sound is within the hearing frequency range of a fish species, but whether the sound is loud enough to be detectable above ambient thresholds. Hearing data exist for about 100 of the 29,000 known fish species. Based on reviews by Popper et al. (2006) and Southall et al. (2007), it is unlikely that underwater sound from conventional dredging operations can cause physical injury to fish species. Some temporary hearing loss could occur if fishes remain in the immediate vicinity of the dredge for lengthy durations, although the risk of this outcome is low (Central Dredging Association (CEDA) 2011).

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