Developing a Low Impact Sea Scallop Dredge

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Final Report

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II. Executive Summary

The sea floor habitat impact of “New Bedford”-style dredges fishing for sea scallops *Placopecten magellanicus* is generally presumed to be high, especially in sand and gravel substrates. At the same time, sea scallops are highly prized as food, providing ex-vessel income that typically exceeds $70 million per year to the Commonwealth of Massachusetts alone. We sought to develop a dredge with lower impact to habitat that maintains current catch rates.

Bay scallops *Argopecten irradians* were observed swimming up into the water column following the passage of a boat with an outboard engine. Bay scallops and sea scallops were exposed to frequencies selected from engine noise recordings, recordings of engines, and the original engine. This testing resulted in less reaction than historically viewed; subsequent efforts with DC electric pulses showed some indication of a possible future research direction.

III. Purpose of the Project

New Bedford-style dredges are the primary means used to harvest sea scallops *Placopecten magellanicus* from Georges Bank and in the Mid-Atlantic region (NREFHSC 2002). The value of this fishery to the Commonwealth of Massachusetts typically exceeds $70 million (pers. comm., National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, MD). Dredges are constructed of heavy-gauge steel tubing, welded into a triangular shape, with a bag hung from one side made of steel rings with twine mesh on the upper side. The dredge is towed from the apex of the triangle, and rides along the sea floor on “shoes”: steel plates welded to the dredge at the corners of the triangle where the bag is attached.

The actual capture mechanism for sea scallops is theorized to be initiated when scallops swim up vertically in reaction to, or are lifted vertically by, the hydrodynamic effect of the “cutting bar”. The 15 ft long (usually) cutting bar rides at or just above the sea floor perpendicular to the direction of the dredge, and connects two corners of the triangle. The leading edge of the ring bag passes beneath the scallops when they rise, and thus the scallops fall into the bag and are captured, unless they are smaller than the inside diameter of the rings (currently mandated at 3.5 in) that comprise the bag and pass through.

The shoes and the bottom half of the bag are the primary contacts of the dredge with the sea floor. The turbulence behind the cutting bar also results in suspension of sediment and some smoothing of irregularities. Other physical impacts relating to setting out and hauling of the dredge occur but are minor in comparison to the shoes, bag and cutting bar.

The overall weight of a New Bedford-style scallop dredge can exceed 1 MT in air (R. Smolowitz, pers. comm.). This weight, amongst other considerations, led to a suspicion that the use of scallop dredges may impact the sea bottom (Dorsey and Pederson 1998). While the severity and consequences of this impact are unknown, it is suspected that some impact occurrs (Collie et al. 1997; Kendall 1998). Underwater observations using side-scan sonar (pers. obs.) show that the passage of a dredge left notable marks on the sea floor. A recent synthesis of fishing gear effects on marine habitats in the Northwest Atlantic concluded that scallop dredges can frequently and strongly impact sand and gravel dominated sea floors (NREFHSC 2002). National Research Council (2002) cited four generalities describing dredge impact including reduction of habitat complexity, changes to benthic communities, reduction of benthic productivity, and increased vulnerability of some fauna. While the questions of the effects of fishing are not likely to be quantified or fully answered in the near future (National Research Council 2002), it is clear that investigation of possible alternative dredge designs or harvest methods should be undertaken in advance of definitive determination of dredge impact.

While developing potential dredge alternatives, field observations were recalled where bay scallops *Argopecten irradians* responded to the passing of an outboard engine by swimming up vertically (A. Carr, unpub. data). The exhaust noise appeared to irritate the scallops. On four separate occasions in four separate embayments, this behavior was observed by a diver swimming behind a boat. These observations were made in shallow water and the response by the bay scallops seemed to be limited to an arc just behind the moving engine. Bivalves do not have a sensory organ for hearing, but it was surmised that mechanoreceptors could be sensitive to the pressure caused by different sound frequencies (Charles 1966).

It was further theorized that these observations could be repeated further offshore, with sea scallops *Placopecten magellanicus*. The motility of the sea scallop has long been recognized, and they have been considered one of the ablest swimmers among lamellibranchs (Drew 1906). Drew (1906) considered the whole structure of the animal as modified for this purpose. Belding (1931) observed that swimming is frequently a diversion of the scallop, which, after lying quietly on the bottom, suddenly takes a slant shooting through the water. We theorized that if *P. magellanicus* reacted the same way as *A. irradians*, the response might be exploited to catch scallops with a re-engineered lighter sea scallop dredge.

The use of sound in finding and enumerating fish is common (Urick 1983). The reaction of fish to sound is a primary component in some commercial fishing methods (Cetinic 2002) and is thought to initiate the capture process for trawl nets (Fridman 1973; Wardle 1993). The use of sound to capture shellfish is not known.

Our initial objectives were:
a) To determine what frequencies stimulate a response in bay scallops and sea scallops.
b) To then apply this knowledge *in situ* using a sea scalloper and underwater observation systems.
c) And to construct or modify a sea scallop dredge that would use acoustics in the capture process to determine effectiveness in the targeted catch and reduction of finfish bycatch.

Following initial efforts, the assessment of the effectiveness of an acoustic dredge was repeated using DC electricity. Electricity is known to induce responses in fish (Fridman 1973), and is widely used to sample fish in freshwater research (Reynolds 1983). In salt water, electricity has also been used for benthic sampling (Phillips and Scolaro 1980) and commercial fishing. For example, an ongoing study in Europe funded by the Dutch government and fishing groups is developing an electrified beam trawl for use in a sole fishery (pers. comm., B. Van Marlen).

IV. Methods

Acoustics

Determination of Frequencies

We attempted to determine if specific predominant frequencies within the range of outboard motor output could be identified and reproduced over bay scallop beds. To uncover these frequencies, outboard engine sound output was recorded underwater in three ways. Initially, an interference frequency analyzer with a hydrophone was used to identify dominant frequencies directly by visiting marinas and boat launching sites. In some cases, recordings were made opportunistically with cooperation of private boat owners; some recordings were made of Division of Marine Fisheries (DMF) engines. Essentially, this equipment allowed the user to step through the sound spectrum and record the intensity at each wavelength.

The second and third methods took a slightly different approach: engine sound was recorded and later analyzed for peak intensities. The second method used a digital minidisk recorder with a stereo microphone inside a waterproof dive housing. This arrangement allowed the collection of sound onto a high quality medium simply and inexpensively. Following concerns over the muting effect of the dive housing, further sound was collected using a transducer/hydrophone system that was initially purchased for the production of sound. This system allowed the recording of engine noise without the use of a housing, and therefore avoided the potential muting or elimination of portions of the sound spectrum.

In all cases, the manufacturer, model and age of engines were recorded to identify specific frequency ranges produced by each engine, including the engine which produced the original phenomenon, a one-cylinder British Seagull outboard boat engine. Where possible, engines were recorded at a range of RPMs.

Sound Analysis

Peak frequencies were either identified with the frequency analyzer, or through graphical analysis using a computer program (Horne 2000). The program produced sonograms (frequency (Hz/100) v. intensity (dB) plots). Dominant frequencies were selected by examining peaks in the decibel output of the engines. Peak frequencies were compared across engine types to select candidate frequencies for broadcast to scallops.

Sound Broadcast

Sounds were broadcast to both bay and sea scallops in both laboratory and field settings. Two laboratory facilities were used: the Marine Resource Center (MRC) at the Marine Biological Laboratory in Woods Hole, MA and DMF's Lobster Hatchery on Martha's Vineyard, MA. Both facilities maintain flow-through systems and have experience culturing scallops. Field observations were conducted in several places in the general vicinity of Pocasset, MA.

Sounds were broadcast using two different speaker systems: a University Sound UW-30 and a DRS-8 speaker from Ocean Engineering Enterprises. In addition, sound was broadcast to scallops in the field using the original sound source that produced the upward movement, the British Seagull outboard engine.

Two different types of sound were broadcast. Recorded engine noise was played to bay and sea scallops; also, pure tones of frequencies selected from sound analysis were broadcast using sound generators. Recorded sounds were initially played back from the minidisk recorder via a 60-watt amplifier; later, a public address system was added to increase sound output.

Electricity

Reaction Testing

Pulsed DC voltage supplied by a fish barrier pulsator was acquired based on advice from engineers familiar with the use of electricity to attract fish. The pulsator inverts 110 V AC current from a portable 2.5 KW gasoline generator to various DC voltages and waveforms. The pulses of DC voltage are attenuated in a spherical energy wave between a positive current anode and negative current cathode. To test scallop response, two electrodes were constructed out of steel threaded rod and placed on a frame made of PVC pipe that was placed on the sea floor at a depth of approx. 5 ft. A diver observed the reaction of the scallops to the stimuli.

Tests were conducted with this apparatus on bay and sea scallops in the field and at the Lobster Hatchery and MRC. A bed of bay scallops was found and subjected to electricity. Some of these scallops were collected for subsequent testing in the Lobster Hatchery. Sea scallops were acquired from a commercial scallop dredge vessel and tested in the MRC. A subset of these scallops were transferred for field testing. Field and laboratory testing methods were similar.

Distance between the electrodes was varied between 12 inches and three feet. Variables in the composition of the electric field were wavelength, voltage, amperage and frequency. Pulses were released between electrodes placed directly on and slightly above (6 in) the sea or aquarium bottom. Frequencies of 1 to 30 Hertz and wavelengths of 2 to 10 milliseconds (ms) were tested between 28 and 150 V at amperages of between 24 and 148 A.

Field Trials

An 8-ft New Bedford-type scallop dredge was fitted with electrodes and connected to 400 ft of six-gauge submersible stranded 2-conductor supply line. This length allowed us to dredge to a maximum depth of 70 feet. Connections between the supply cable and the electrodes were made watertight to prevent leakage of electricity. Electrodes were constructed from 3/8 inch diameter steel tow wire and connected to the dredge with conventional shackles, isolated from the dredge using rings cut from tires. Three electrodes were used. One acted as the anode and two as cathodes, producing an area of exposure equal to approximately 6 feet in width extending from the trailing edge of the cutting bar to the chain sweep. Rock and tickler chains were left in place. The dredge was tested by lowering it into the water and placing a lobster between the electrodes.

The dredge was then towed over sandy bottom during a two-day period. Paired tows were carried out by applying current during the first or second tow of the pair and leaving it off for the corresponding tow over the same grounds. Electrodes remained on the dredge for all tows. Tows were conducted on an inshore commercial scallop vessel, the F/V *Bantry Bay*, 300 HP, < 40 ft, homeported in Gloucester, MA.

Underwater Filming

Underwater footage of a scallop dredge was collected for several purposes: to capture the behavior of sea scallops and other species during pursuit by the dredge; to establish some understanding of the bottom impact of a standard dredge for comparison to experimental dredges; to investigate the attitude of the dredge during fishing. Footage was collected from an inshore 42-ft commercial scallop vessel, the F/V *Petrel*, homeported in Sandwich, MA.

V. Results and Discussion

Acoustics

Determination of Frequencies

Underwater engine noise was recorded on several dates between 27 January 2000 and 1 August 2001. A variety of manufacturers was sampled, including Evinrude, Honda, Johnson, Mariner, Mercury, Mercruiser, Seagull and Yamaha. Engine horsepowers ranged from < 10 to 225.

Attempts to identify common frequencies among engines were unsuccessful. Sonograms varied widely between manufacturers and changed based on engine RPM (Figure 1). Table 2 lists identified peak frequencies for thirteen different sound samples. These peaks ranged from 100 to 3700 Hz.

Sound Broadcasts

Bay and sea scallops were exposed to sound on ten different occasions, from 25 April 2000 to May 2001. Bay scallops and sea scallops were variously exposed to engine noise, recorded engine noise, and specific frequencies chosen from recorded samples. (Table 3). Reactions of scallops of both species never matched the intensity or frequency of the original reported reaction. Some scallops swam after being exposed to sound, but scallops were also observed swimming during periods of no exposure. Shell closings were frequently observed in apparent reaction to sound; some observations indicated that the frequency of shell closings was related to the broadcast volume. These observations are consistent with the hypothesis that mechanoreceptors in the scallops would be sensitive to a pressure wave produced by high volume.

Equipment was upgraded several times in order to increase the accuracy of sound reproduction. Also, the original outboard engine was used in areas of high bay scallop concentration. These attempts resulted in the same approximate level of reaction by scallops. None of the levels of reaction to any of the acoustic stimuli was sufficient to suggest that scallop dredges should be altered to exploit them.

The failure of bay scallops to react in the way that was previously viewed was puzzling. We duplicated the circumstances as much as possible, even using the same engine. It is possible that ambient sound levels are higher now than with the initial phenomenon was observed, and that bay scallops have developed less sensitivity to this type of disturbance. Long-term effects of exposure to noise have not been thoroughly investigated for fish, much less shellfish (Scholik and Yan 2001) although long-term exposure to sound can result in reduced sensitivity thresholds in fathead minnows *Pimephales promelas* (Scholik and Yan 2002).

Electricity

Reaction Testing

Height of the electrodes above bottom did not appear to cause any clear differences in scallop response (Table 4). An apparent difference was observed in the response time and type at different combinations of the four variables (wavelength, voltage, amperage and frequency). A combination of higher voltage and higher amperage resulted in more scallops (of both species) exhibiting a response. Administering of shocks held in the laboratories frequently resulted in clapping reactions from approximately 40% of scallops present. “Clapping” was defined as repeated opening of the scallop to full extension and closing. Testing in the field with previously unshocked scallops yielded similar results with both species.

Field Trials

The test lobster responded on all attempts. We interpreted this reaction as evidence of satisfactory function by the electrode array.

Four pairs of alternate tows were conducted on 4-5 April 2002 near Gloucester MA. Voltage was set at 88 VDC at 112 A in 0.2 MS intervals at 30 Hz. No difference was observed in the mean catch rates (electricity off: 232 lb/hr; on: 240 lb/hr). While these data do not show any improvement in dredge efficiency, the results should be viewed as inconclusive. These sample sizes were small due to the limitations of funding, and tows were conducted over identical grounds. A fully developed plan of testing would require more tows and could include the requirement that tows be conducted each time over new grounds. The tows that were conducted show an effect based on the order of tows. Of the four pairs of tows, all four of the first tows had higher catch rates.

Underwater Filming

Underwater footage of a New Bedford-style sea scallop dredge was recorded on 7 September 2000. Analysis of four hours of video indicates that sea scallops are not readily seen passing over the cutting bar; other species can be seen contacting the bar. Also, dredges appeared to ride heavily over sandy bottom, flattening humps and reworking sand into small ridges, and suspending sediment. The attitude of the bail of the dredge was angled off the bottom, so that the cutting bar and shoes provided the initial contact. However, the attitude of the bail was sensitive to engine speed, and could easily be altered.

Summary

Select frequencies, recorded engine noise and actual engine noise could not be used to recreate the original phenomenon that motivated this study. Reaction to noise was observed in both species of scallops, but at lower levels of intensity. The cause of the original, strong reaction remains unknown and unrepeated.

Direct electrical current caused reactions in scallops that were stronger than reaction to acoustics.

The technical aspects of rigging the dredge were solved and the use of electricity can be safe and practical. The effect on catch rates or efficiency of the use of electricity remains unresolved.

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Enos of the Marine Biological Laboratory for the use of their facilities. Technical assistance was provided by Smith-Root, Inc. and Ocean Ears, Inc. Funding was provided by the National Marine Fisheries Service Saltonstall-Kennedy Program, Grant # NA96FD0072.

VI. Products

This report is # 12 of the DMF technical report series. A redacted version is planned for publication in the DMF newsletter, distributed to thousands of recipients by mail and Internet. The video footage collected during this study is archived at DMF offices.

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VIII. Key words: sea scallop; bay scallop; acoustics; electricity; impact reduction.

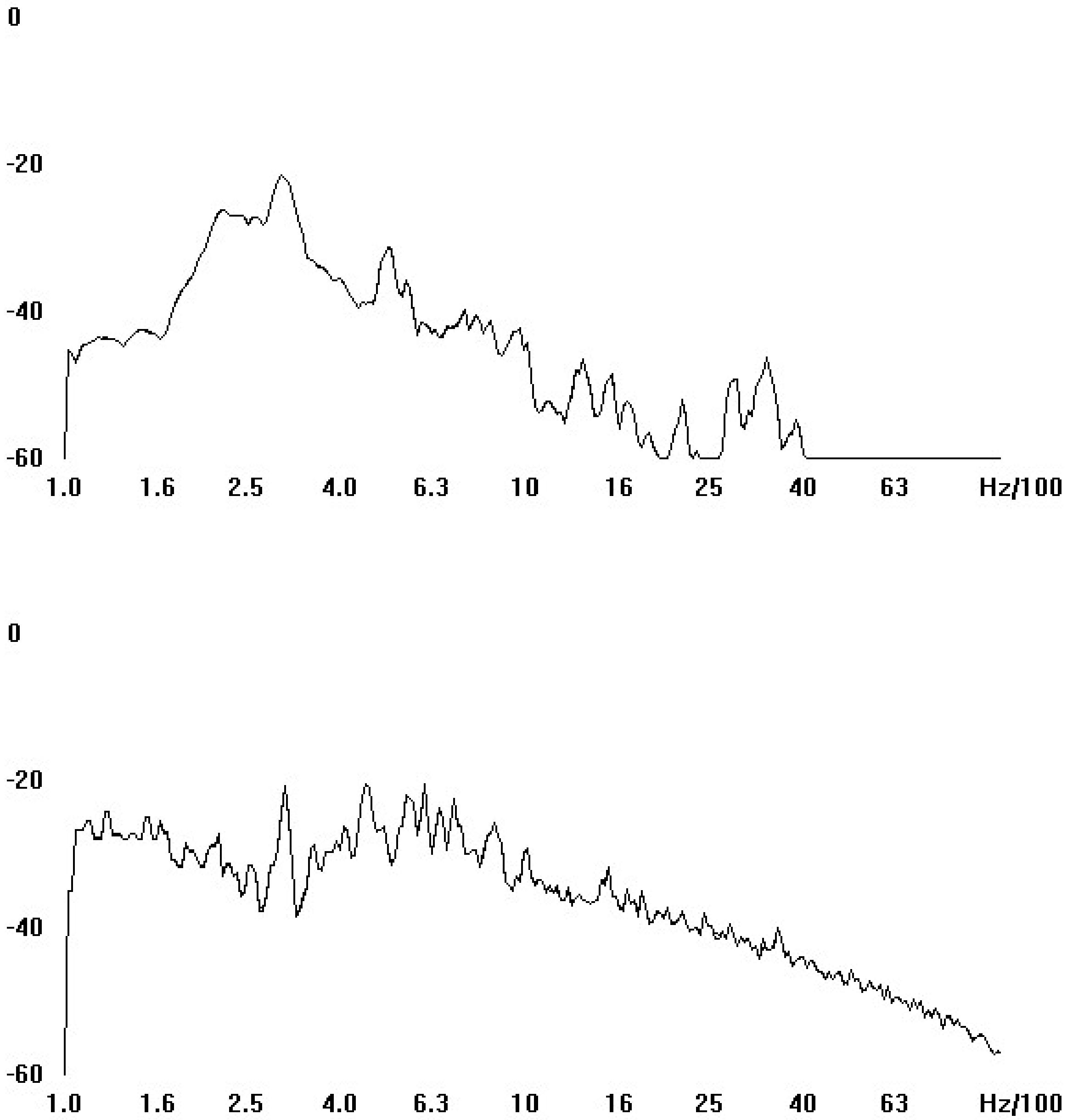

Figure 1: Two sonograms of outboard engine noise: the engine originally observed causing the movement of bay scallops (Seagull, above); and a Mercury outboard recorded opportunistically (below).

Table 2: Peak frequencies identified for thirteen different sound samples. Horsepowers are nominal.

Engine Type	Horsepower	Peak Frequencies (Hz)
Honda (twin)	90	111, 120, 156, 193, 226, 336, 426, 472, 503, 663, 811, 1012, 1238, 2034, 2489, 2937
Johnson (twin)	120	120, 135, 156, 279, 389, 532, 826, 2189
Evinrude	75	128, 171, 385, 434, 512, 811, 1021
Evinrude	75	112, 123, 171, 290, 395, 438, 527, 797, 819, 1021
Yamaha	115	117, 140, 167, 204, 279, 312, 365, 442, 494, 522, 616, 713, 804, 873, 1012
Mercury	90	102, 123, 183, 214, 245, 274, 309, 339, 368, 396, 430, 485, 727, 857, 1692, 3465
Mercury	200	102, 151, 176, 216, 267, 330, 389, 480, 639, 881, 1021, 1296,1602
Mercury (twin)	225	107, 162, 392, 489, 761, 857, 1012, 1308, 1692
Evinrude	225	113, 123, 151, 216, 301, 455, 557, 605, 651, 700, 857, 1012, 1502, 1788, 3529
Evinrude	225	102, 129, 210, 234, 274, 411, 541, 651, 811, 984, 10470, 1602
Mariner	150	106, 123, 216, 290, 336, 512, 811, 1012, 1383, 1631, 2937, 3465
Mariner	150	123, 161, 190, 241, 342, 467, 522, 639, 782, 842, 975, 1273, 1631, 3529
Seagull	?	147, 220, 295, 508, 552, 740, 975, 1333, 1544, 2189, 2857, 3340, 3869
Seagull	?	143, 195, 248, 389, 476, 639, 1408, 1631, 1890, 2356, 2779, 3340, 3798

Table 3: Summary of date, duration, location, species and type of sounds for acoustic exposure experiments.

Date	Days	Location	Species	Type of Sound
Apr-2000	1	Lobster Hatchery	Bay scallops	Rec. engine noise
May-2000	2	Marine Resources Center	Sea scallops	Rec. engine noise
Sep-2000	4	Lobster Hatchery	Bay scallops	Rec. engine noise and frequency generated
Sep-2000	1	Lagoon Pond	Bay scallops	Rec. engine noise, live engine noise, and frequency generated
May-2001	4	Lobster Hatchery	Bay scallops	Rec. engine noise and frequency generated

Table 4: Reactions of bay and sea scallops to electrical stimulation.

TRIAL #	Ht off bottom (in)	Separation (in)	Voltage		Amperage		Freq. (Hz)	Wave-length (ms)	Response	Species
			Begin	End	Begin	End				
November Bay Scallop Lab and Field tests on Martha's Vineyard										
1-2 minute respite between trials**										
1 aquaria	0	34"	56	46	54	44	4	2	30% of scallops clapping during duration of the exposure	bay
2 aquaria	0	34"	56	46	54	44	4	2	30% of scallops clapping during duration of the exposure	bay
3 aquaria	0	21"	56	46	54	44	4	2	same response	bay
4 aquaria	0	21"	56	46	54	44	4	2	80% clapping 5% swimming	bay
5 aquaria	0	21"	82	68	80	66	4	2	80-90% spinning and clapping	bay
6 aquaria	0	10"	82	68	80	66	4	2	80-90% spinning and clapping	bay
7 aquaria	0	10"	82	68	80	66	15	7	decrease in activity to 20% moving, weakly	bay
1 field	6	21"	56	46	54	44	4	2	30% spinning 5% swimming	bay
2 field	6	21"	56	46	54	44	4	2	30% spinning 5% swimming	bay
3 field	6	21"	56	46	54	44	4	2	30-40% spinning	bay
4 field	6	21"	56	46	54	44	4	2	same response	bay
5 field	6	21"	82	68	80	66	4	2	40-50% clapping	bay
6 field	0	21"	82	68	80	66	4	2	80-90% clapping 10%moved slightly vert. And about 8" horiz.	bay
7 field	0	21"	82	68	80	66	15	7	80-90% clapping 10%moved slightly vert. And about 8" horiz.	bay
December Sea Scallop Lab and Field tests in Woods Hole and Pocasset										
3 minute respite between trials**										
1 aquaria	0	21"	128	126	64	62	5	6	40% clapping every 2-3 seconds	both
2 aquaria	0	21"	78	76	44	42	15	4	20% clapping	both
3 aquaria	0	21"	128	126	64	62	15	5	20%clapping	both
4 aquaria	0	21"	78	76	44	42	20	5	same response	both
5 aquaria	0	21"	128	126	64	62	20	4	10% clap in a weaker fashion	both
6 aquaria	0	21"	78	76	44	42	30	5	same response as above	both
7 aquaria	0	21"	128	126	64	62	1	5	weakening	both
8 aquaria	0	21"	128	126	64	62	30	5	overexposure??	both
9 aquaria	0	21"	128	126	64	62	1	10	lazily clap every 10 seconds	both
1 field	0	21"	128	126	64	62	5	6	40% clapping every 2-3 seconds	both
2 field	0	21"	78	76	44	42	15	4	40% clapping every 2-3 seconds	both
3 field	0	21"	128	126	64	62	15	5	40% clapping every 2-3 seconds	both
4 field	0	21"	78	76	44	42	20	5	40% clapping every 2-3 seconds	both
5 field	0	21"	128	126	64	62	20	4	40% clapping every 2-3 seconds	both
6 field	0	21"	78	76	44	42	30	5	40% clapping every 2-3 seconds	both
7 field	0	21"	128	126	64	62	1	5	two individuals swim one meter away and 40% of the others clap	both
8 field	0	21"	128	126	64	62	30	5	slower reponse and 20% respond	both
9 field	0	21"	128	126	64	62	1	10	same as last treatment	both