Supplementary Information for

Categorizing Active Marine Acoustic Sources Based on Their Potential to Affect Marine Animals

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Table S1. Maximum densities of cetacean and sea turtle species reported in available model grids, along with calculations for the threshold radius R_t using equation (4) in main text and assuming probability p=0.01 (1% probability of taking a single animal) and random, uniform distribution of animals at the sea surface. The adjusted SL (SL_{it}) is determined as outlined in the main text, using the appropriate Level B received SPL for cetaceans vs. turtles. 90[th] and 95[th] percentile calculated for species with high reported densities.

	U.S. PACIFIC MARGIN (CA, OR, WA)[a]					NORTHERN GULF OF MEXICO[b]					U.S. ATLANTIC MARGIN[c]				
Common Name	Max density[d] per 100 km^2	R_t (m)[e]	SL_{it} (dB)[f]	90% density[g]	99% density[h]	Max density[d] per 100 km^2	R_t (m)[e]	SL_{it} (dB)[f]	90% density[g]	99% density[h]	Max density[d] per 100 km^2	R_t (m)[e]	SL_{it} (dB)[f]	90% density[g]	99% density[h]
Whales															
Baird's beaked whale	9.32	184.8	205.3												
Beaked whales	Model results not used[a]					4.68	260.8	208.3			56.8	74.9	197.5	3	6
Blue whale	1.17	521.6	214.3								6.84	215.7	206.7		
Bryde's whale						0.578	742.1	217.4			6.84	215.7	206.7		
False killer whale						0.748	652.3	216.3			0.008	6308	236.0		
Fin whale	8.2	197.0	205.9	2.65	4.5	0.001	17841	245.0			7.61	204.5	206.2		
Humpback whale	19.4	128.1	202.2								8.55	192.9	205.7		
Killer whale	Present in area, but not in database					0.101	1775	225.0			0.009	5947	235.5		
Kogia whale						2.56	352.6	210.9			0.094	1840	225.3		
Melon headed whale						4.61	262.8	208.4			0.241	1149	221.2		
Minke whale	0.491	805.2	218.1								3.62	296.5	209.4		
North Pacific Right Whale	Present in area, but not in database														
North Atlantic Right Whale											5.58	238.8	207.6		
Northern bottlenose whale											0.041	2786	228.9		
Pilot whales						6	230.3	207.2			31.2	101.0	200.1		
Pygmy killer whale						0.691	678.7	216.6							
Sei whale											2.39	364.9	211.2		
Sperm whale	Model results not used[a]					2.05	394.0	211.9			5.86	233.1	207.3		
Dolphins and Porpoises															
Atlantic white sided dolphin											62.2	71.5	197.1	12	24
Atlantic spotted dolphin						65.9	69.5	196.8	24	35	75.15	65.1	196.3	18	26
Bottlenose dolphin	154	45.5	193.2	1	2	143	47.2	193.5	55	96	2486	11.3	181.1	15	30
Clymene dolphin						16.3	139.7	202.9			2.53	354.7	211.0		
Dall's porpoise	17.6	134.5	202.6												
Fraser's dolphin						0.389	904.6	219.1			0.104	1750	224.9		
Harbor porpoise											594.7	23.1	187.3	5	13

Long beaked dolphin	476	25.9	188.3	1.4	150										
Northern right whale dolphin	307	32.2	190.2	7.5	60										
Pacific white dolphin	62.2	71.5	197.1	10	20										
Pantropical spotted dolphin						88.5	60.0	195.6	31	35	0.61	722.4	217.2		
Risso's dolphin	22.4	119.2	201.5			10.2	176.7	204.9			57.2	74.6	197.5	3	7
Rough toothed dolphin						1.93	406.2	212.2			0.069	2148	226.6		
Short beaked dolphin	295	32.8	190.3	125	214						298	32.7	190.3	12.5	100
Small beaked dolphin	1.03	555.9	214.9												
Spinner dolphin						146	46.7	193.4	3	34	0.04	2821	229.0		
Striped dolphin	43.5	85.5	198.6	10	16	5.76	235.1	207.4			84.3	61.4	195.8	26	35
White beaked dolphin											0.008	6308	236.0		
Turtles[i]															
Loggerhead						9.7	181.2	211.2			30.1	102.8	206.2		
Leatherback						3.2	315.4	216.0			14.1	150.3	209.5		
Kemp's ridley											204.6	39.4	197.9		
Hardshell (green and hawksbill)						151	45.9	199.2			51.4	78.7	203.9		

[a]Density models from Becker et al. (2020). Sperm whale and beaked whale models are considered not robust (E. Becker, NOAA, written pers. comm., April 12, 2020) and were not used. Southern resident killer whales, North Pacific right whales, and other species are present in the area, but not included in the density models.

[b]Density models from Roberts et al. (2016).

[c]Density models from Roberts et al. (2016).

[d]Maximum density in each regional model grid for each species. Where models for each month were available for the Gulf of Mexico or U.S. Atlantic margin locations, August models were used. Values for the U.S. Pacific margin (Becker et al., 2020) are reported in animals per 1 km^2 and were scaled to densities per 100 km^2. Grid cells having values other than "no data" are 11619 (U.S. Pacific margin), 7015 (Gulf of Mexico), and 12188 (U.S. Atlantic margin).

[e]Threshold radius (R_t) calculated for the maximum density, 1% probability (p=0.01) of an animal being within the circle of radius R_t around a source, and a uniform distribution of the animals at the surface according to equation (4) in the text. Note that any received SPL value can be assigned at R_t.

[f]Source level for incidental take (SL_{it}) at threshold radius R_t corresponding to received SPL of 160 dB re 1 µPa, the current Level B take level for marine mammals used by the U.S. National Marine Fisheries Service. 166 dB re 1 µPa is used in the SL_{it} calculation for sea turtles. The calculation is done with spherical spreading in this table. Spherical spreading is a valid approximation for even shallow water depths when frequencies are hundreds to thousands of Hz. Actual units for SL_{it} dB re 1 µPa @ 1 m. To adjust SL_{it} for p=0.005 (0.5% probability), subtract 3 dB.

[g]90th percentile of animal densities per 100 km^2 for a given species. Only provided when the density exceeds 32 animals per 100 km^2, which corresponds to R_t of 100 m and SL_{it} of 200 dB re 1 µPa @ 1 m.

[h]95th percentile of animal densities per 100 km^2 for a given species. Only provided when the density exceeds 32 animals per 100 km^2, which corresponds to R_t of 100 m and SL_{it} of 200 dB re 1 µPa @ 1 m.

[i]Turtle density models as reported by Geo-Marine Inc. (2007a, b, c). Densities given in animals per 1 km^2 scaled to animals per 100 km^2 for this table. The hardshell category includes green sea turtles and hawksbill turtles.

Table S2. Modeling results for degree of exposure (Factor 5 in main text).

Acoustic Source	Source Level (dB re 1µPa@1m	Sound Power Level (Radiated Power) dB re 10^{-12}W	Pulse repetition rate (s)	Vessel Speed in m/s (approximate speed in knots)	Exposure duration[a] at 100 m depth (s)	Ping exposure[a] at 100 m depth (number of pings above threshold)	Exposure duration[a] at 1000 m depth (s)	Ping exposure[a] at 1000 m depth (number of pings above threshold)
EM122, 0.5˚ (MBES) Single swath[b]	245	168	5	5 (9.7)	15	3	15	3
EM710, 0.5˚ (MBES) Single swath[b]	232	155	5	5 (9.7)	5	1	0	0
EK60/80 (38 KHz, 7˚; SBES)	229	150	5	5 (9.7)	15	3	0	0
Knudsen 3260 4x4 (hull-mounted SBP)	232	161	5	5 (9.7)	85	17	105	21
3-plate boomer	210 (peak)	145	1	2.5 (4.9)	83	83	0	0
Sparker-1 (6 kJ Delta)[c]	226 (peak)	169	4	2 (3.9)	1964	491	1692	423
Sparker-2 (700 J SIG ELC 820)[d]	215 (peak)	158	4	2(3.9)	548	137	0	0
Single Air Gun	234 (peak)	177	15	2 (3.9)	5010	334	4920	328

[a]Exposure duration and ping exposure are defined in the main text and refer to the total time (including silence between pings) for transmission of pings that are received at >160 dB re 1 µPa threshold and the number of received pings above that threshold, respectively.

[b]See main text for more explanation of single and dual swath MBES ping accumulation and the exposure of animals receiving pings on adjacent tracklines.

[c]Sparker-1 refers to a 6 kJ Delta sparker, which is normally deployed at this power level only in deeper (> 500 m) waters.

[d]Sparker-2 represents a more widely deployed configuration of the SIG ELC 820 sparker run at ~700 J, as is common at shallow (< 200 m) water depths.

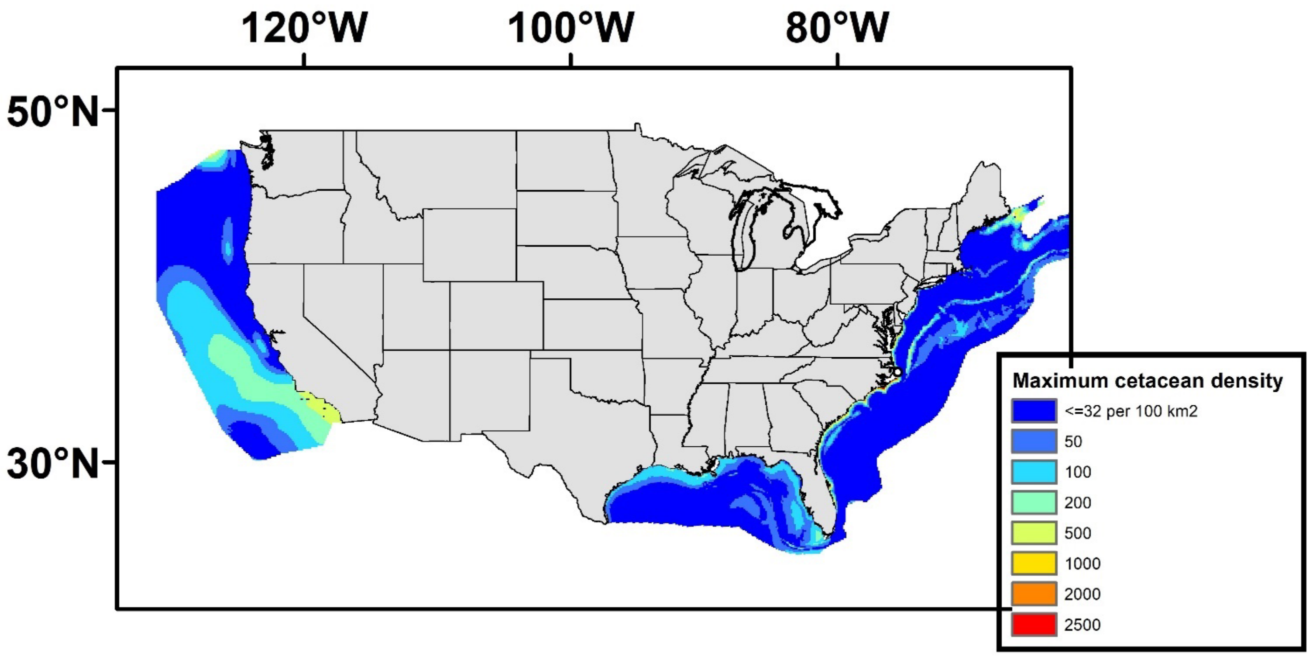


Figure S1. Maximum density of any cetacean species in each grid cell for all modeled species (Table S1) for the U.S. Pacific margin (Becker et al., 2020) and for the northern Gulf of Mexico and U.S. Atlantic margin (Roberts et al., 2016). When monthly density grids were available, the calculations were done for August.

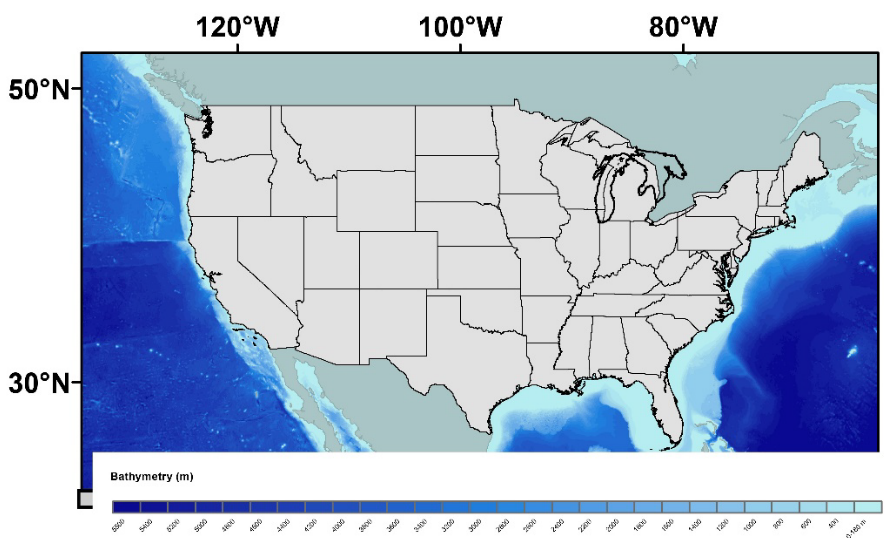


Figure S2. Bathymetry used for calculations for Factors 2 and 4, taken from 1 arc second ETOPO grid (NOAA National Geophysical Data Center, 2009).

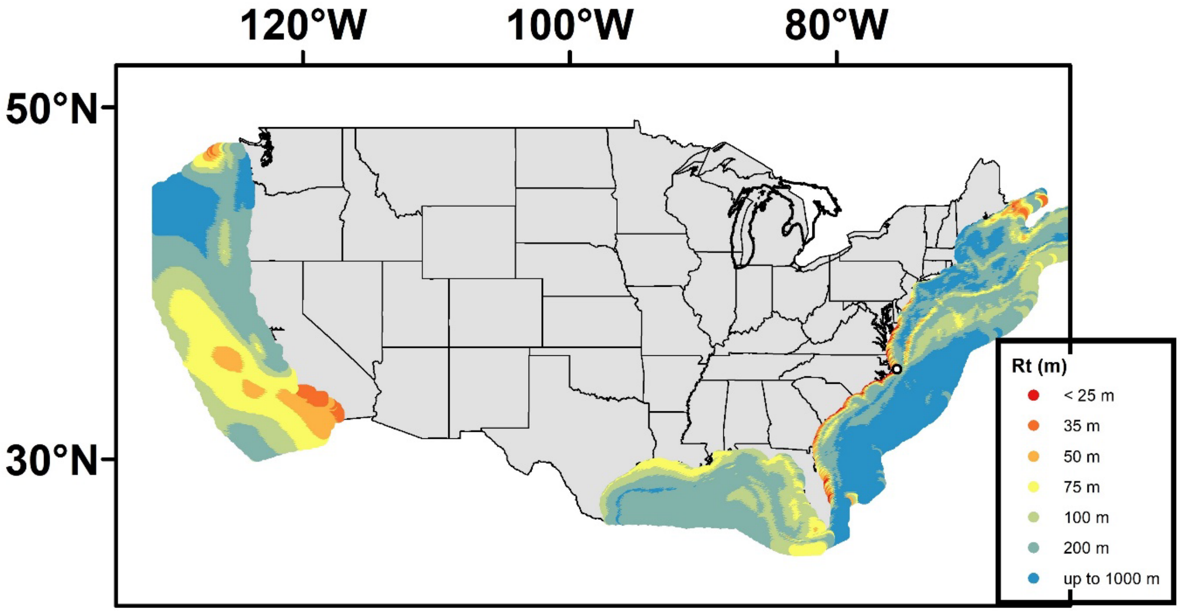


Figure S3. R_t calculated for 1% probability (p=0.01) of a single animal being within R_t of the source, using the maximum density of any cetacean species in each grid cell and assuming a uniform distribution of animals at the surface. An arbitrary radius of 25 m around a source is currently used by NMFS, but this yields a 1% probability (p=0.01) of an animal being within that distance of the source only immediately adjacent to the coast from Delaware to Florida on the U.S. Atlantic margin and offshore southern California on the U.S. Pacific margin. 40 m may be a more appropriate arbitrary value, but 100 m is reasonable along much of the U.S. Atlantic and Gulf of Mexico margins, including on much of the continental shelf. The corresponding SL_{it} calculated from these values is shown in Figure 7a of the main text.

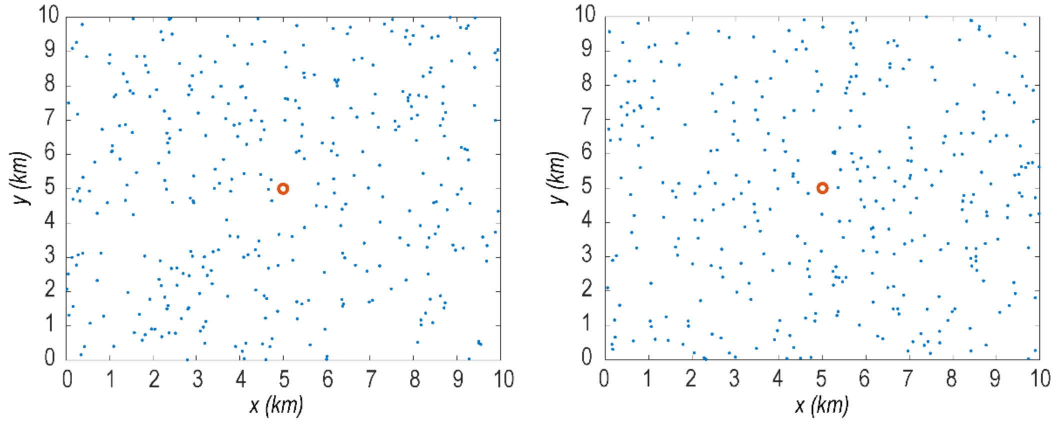


Figure S4. Two realizations of 350 random, uniformly distributed animals (blue dots) distributed in a 10 km x 10 km block at the ocean's surface. *x* and *y* coordinates are randomly chosen from a uniform distribution for 10^5 simulations. The red circle has ~100 m (R_t = 100 m) radius around the hypothetical source located at (5 km, 5 km). No animal is within the circle in either of these realizations. The *p* value for this combination of density and R_t is 0.099, meaning that there is nearly a 10% possibility that one animal would be within the red circle for any given realization. The large R_t value used here for this relatively high marine animal density is for illustrative purposes only. The calculations in the main text and in this supplement generally use p=0.01 (1% probability). For a user-defined distribution of animals, even one including clustering of animals in pods, the Monte Carlo approach could be used to determine R_t empirically for a given *p* value.

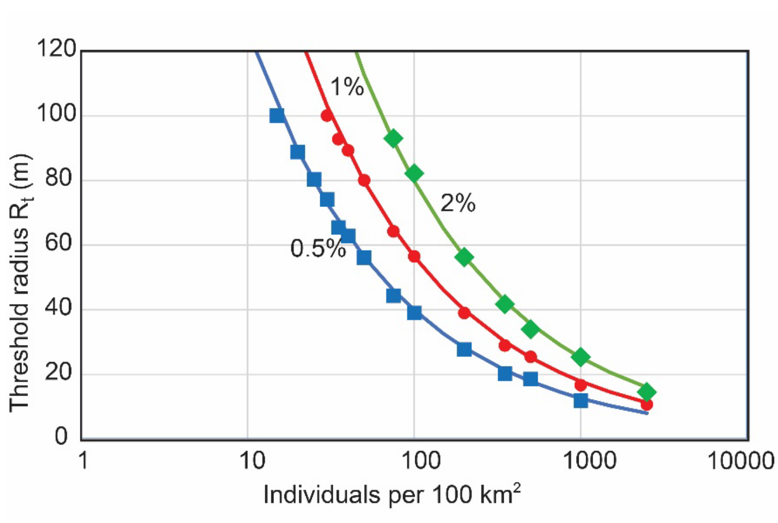
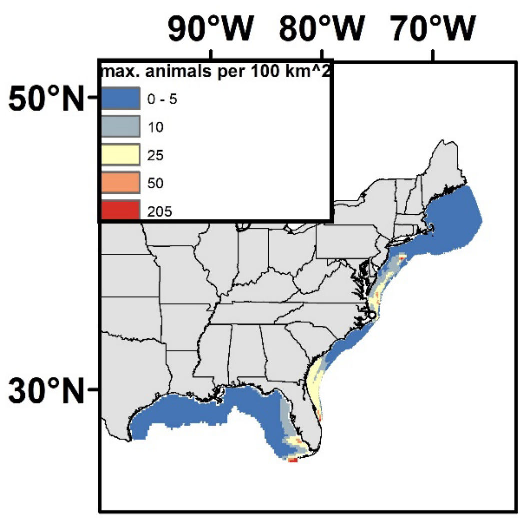


Figure S5. Comparison between empirically determined R_t values (points) using a Monte Carlo approach with the given *p* values and 10^5 realizations for each animal density, with the individual animal locations randomly and uniformly distributed on the surface of an 100 km^2 block. The solid analytical curves are calculated using Equation 4 in the main text. That equation only applies when the density distribution meets the uniform criterion.



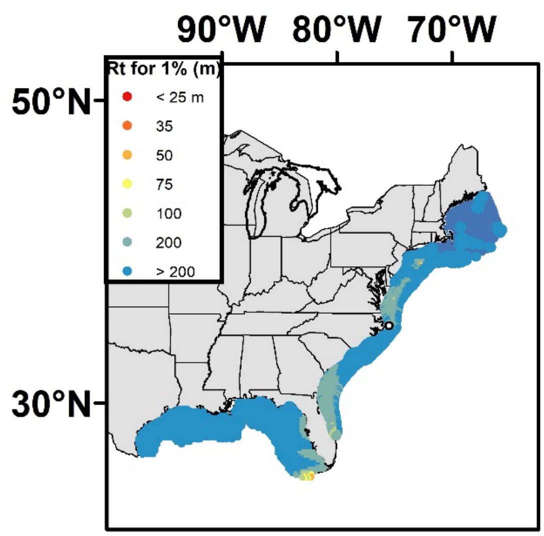


Figure S6. (Left) Maximum turtle densities scaled to animals per 100 km^2 for the U.S. Atlantic and northern Gulf of Mexico areas [Geo-marine, Inc., 2007a, b, c]. Note that the coverage for these models is not as extensive as for cetaceans (Figure S1). (Right) R_t calculated using the turtle maximum density distribution for p=0.01 (1% probability of a single animal being within R_t of the source).

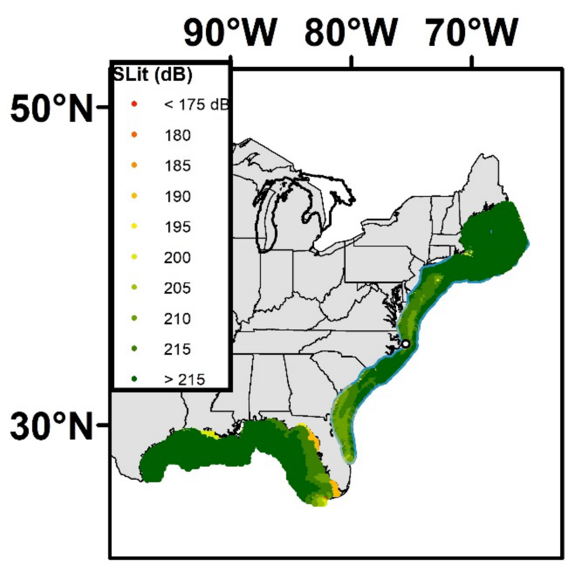


Figure S7. SL_{it} for the maximum densities of turtles, using 166 dB re 1 μPa as the Level B received SPL_B threshold applied at R_t. Spherical spreading assumed for water depths exceeding 10 m, and cylindrical spreading at shallower water depths. Note that SL_{it} for turtles exceeds 200 dB re 1 μPa @ 1 m almost everywhere except the west coast of Florida and near the Louisiana coast.

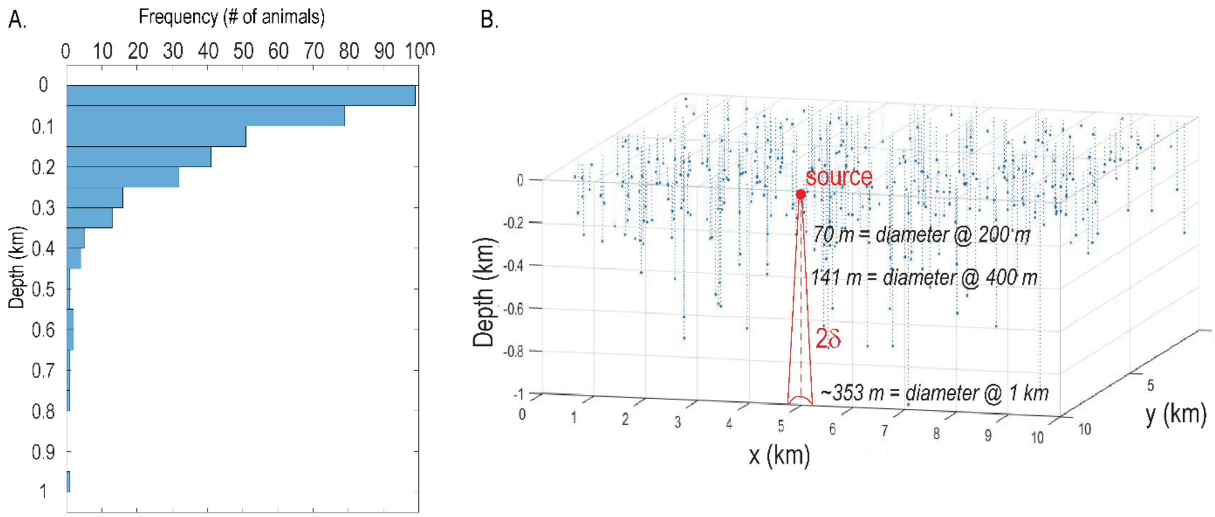


Figure S8. Configuration of animals for beamwidth limit calculations. (a) Histogram of the distribution of 350 animals as a function of depth for one of the 10^5 Monte Carlo realizations. Animal depth is chosen randomly from a gamma distribution. (b) Stem plot showing position of each of the 350 animals (blue dots) within the 10 km (*x*) x 10 km (*y*) x 1 km (*z*) block for this realization. The x-y positions are chosen randomly from a uniform distribution. The red cone shows a schematic ensonification cone for a surface source with $2\delta = 20°$. For the actual Monte Carlo simulations, the source was placed at x-y position (5 km, 5 km) at the surface. The ensonification cone is drawn to scale in the x-direction to highlight how small the diameter is at particularly shallow water depths.

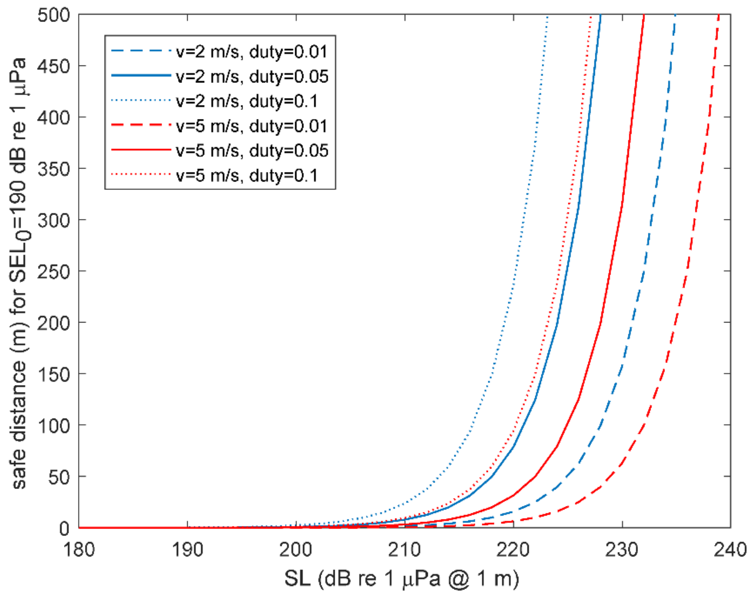


Figure S9. The impact of duty cycle (ratio of pulse length to pulse repeat rate) on safe distance as a function of SL, calculated from Equation (5), adapted from Sivle et a. (2015), with SEL_0 of 190 dB re 1 μPa. While this result describes safe distance as applied to Level A take (NMFS-OPR-59, 2018), it illustrates dependence on pulse length, which is a factor that the degree of exposure *de minimis* criterion (Factor 5) does not include. These results are not significant for incidental take in any absolute sense, but do demonstrate how pulse length can affect metrics associated with protection of marine animals.