Supplemental Material

1. Data: Creating a standardized coordinate system

Translating raster density models into vector density models: The steps below outlines the process of converting monthly right whale density maps by Roberts et al. (2016) to a 20 km² vector grid[1]. Once these steps were complete, all other NOAA data were then assigned to this 20 km² vector grid based on recorded latitude and longitude information.

Steps:

1. Establish a standardized coordinate system for the raster density model in vector format so that it can be understood temporally and with additional spatial data can be clipped to it. The 12 months of North Atlantic right whale data of the Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico (Roberts et al.) were downloaded from http://seamap.env.duke.edu/models/Duke-EC-GOM-2015/results/EC_North_Atlantic_right_whale.zip. The specific raster files chosen from this download had the *_abundance.img suffix (i.e. EC_North_Atlantic_right_whale_month01_abundance.img).
2. The raster files were converted to vector format so that each 10,000 square kilometer block could be given a unique key so that the density number of any particular month and any additional spatial vector data could be clipped and associated with that particular 10 km² block of right whale density information. This would also allow the data to be

[1] This work was completed by a Dennis Corvi, a contractor for Social Sciences Branch, Northeast Fisheries Science Center, NOAA who was assigned to the right whale project.

converted into tabular format. The unique identifier of each 10 km² block was referred to as a 'Cell_ID'.

3. The vector conversion and key assignment was completed using several dozen system geospatial tools in ArcGIS Desktop 10.5. The tools were organized and documented into repeatable workflows using ArcGIS ModelBuilder and placed into a custom arc Toolbox so they could be executed in sequence by any potential user. The main geospatial tools that were used to create the new vector grid were:
    a. Create Fishnet (no pun intended) to create a standardized blank grid of equal size polygons that are analogous to each raster cell,
    b. Raster to Point to create a set of points located at the center of each raster grid that contains the right whale density number, and,
    c. Feature To Polygon that combined the point data and fishnet polygon data into a single complete vector feature with all of the original raster information.
4. This process was run for all 12 months of the density data. Each month contained the same ubiquitous Cell_ID.
5. Once the geoprocessing was compete, the new 10 km² vector grid with the Cell_ID key could be used in combination with any other vector data such as zones or aerial surveys while simultaneously allowing the vector grid to be converted to a table with a unique key.
6. To produce a 20 km² vector grid, the same process was run with the addition of the Resample tool run at the beginning.[2]

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[2] Note: The maps by Roberts et al. (2016) are currently being updated to include complementary data based on recommendations from a peer-reviewed, independent panel of non-NOAA scientists on November 19-21, 2019 (date accessed August, 6, 2020; https://www.fisheries.noaa.gov/feature-story/decision-support-tool-helpful-those-finding-ways-reduce-whale-entanglement-fishing). The authors here plan to use updated whale density maps going forward.

2. Methods: Fishing effort expansion

Our primary data are NOAA-Fisheries Vessel Trip Reports (VTR) and dealer data.[3] The dealer data are considered a census which reports total catch and revenues, however, information about where vessels fished is not collected. The VTR record fishing location for a subset of the catch. To build a data set of vessel information including length, vessels were tracked across years in the NOAA-Fisheries and Atlantic Coastal Cooperative Statistics Program (ACCSP) databases.[4] The unit of fishing effort is a trip. We estimate fishing effort E_{tpla} by month t, port group p, length class l, right whale management area a for each year.[5]

To allocate dealer landings not recorded in the VTR data, we stratify the data using in-common key variables. The data are stratified by seven port groups based on the spatial distribution of VTR effort: northern Maine, southern Maine, New Hampshire, north of Boston, south of Boston, east of Cape Cod and south of Cape Cod. Vessels are binned into 3 length classes l (less than 40 feet; 40 to less than 60 feet; and 60 feet or greater). VTR trips were binned into area a, outside (i.e. "open") or inside a right whale management area (i.e. dynamic, static or closed) by month t, port group p, and length class l. For simplicity, the fishing area subscript "*a*" is dropped.

Let VQ_{tl} and VE_{tl} be the VTR landed catch (VQ) and fishing effort (VE, i.e. number of fishing trips) in month t and length class l. The catch per trip for month t and length class l is simply

$$q_{tl} = VQ_{tl} / VE_{tl} \qquad (1)$$

where q_{tl} is calculated for each year, 2002 to 2009, and averaged over all years (S. Table 1). We assume the landed catch per trip within a month and vessel length class are constant across all fishing areas, a. Further, the difference in catch rates between length classes in any month (q_{tl}),

[3] For NOAA-Fisheries data requests please contact nmfs.gar.data.requests@noaa.gov,

[4] The development of the vessel database was undertaken by a contractor, funded by the Social Sciences Branch, Northeast Fisheries Science Center, NOAA-Fisheries and completed prior to the start of this research.

[5] In cases where a management area is restricted for less than a month (i.e. 2 weeks), fishing effort for the other 2 weeks of that month for that same area are assigned to the "open" area.

indirectly capture difference in fishing effort at the individual trip level (i.e. number of days fished and traps hauled per day).

To then estimate dealer fishing effort in trips for month t, port group p, and length class l, DT_{tpl}, the total dealer landed catch DQ_{tpl} (less landed catch reported in the VTR) is divided by the estimated catch per trip q_{tl} (Eq. 1).

$$DT_{tpl} = DQ_{tpl}/q_{tl} \qquad (2)$$

Next, dealer trips are assigned to a fishing area a. We assume the dealer trips by vessels with similar vessel characteristics (i.e. same month, port group and length class), DT_{tpl}, will fish in the same area (a) as vessels that did provide VTR location information. For example, trips in the dealer data for a 40-foot vessel are likely to fish in the same areas as a 40-foot vessel in the VTR during the same month and port group, rather than the same area as a 60-foot vessel in the same month and port group. Let PVE_{tpla} be the proportion of VTR trips in port group p, month t, length class l, and fishing in area a. The estimated dealer trips in port group p, month t, length class l for fishing area a, DE_{tpla}, is the product of the proportion of VTR trips in area a and estimated dealer trips (Eq. 2).[6] That is:

$$DT_{tpla} = DT_{tpl} * PVE_{tpla} \qquad (3)$$

The total number of fishing trips, E_{tpla} is then the sum of dealer DT_{tpla} and VTR trips VE_{tpla} in port group p, month t, length class l, fishing in area a. These data are then summed over length classes, and month (S. Table 2). Ignoring 2009 where only 3 months of data are included, total fishing effort in right whale management areas ranged between 0.2% to 1.9%. Finally, for the analysis, fishing effort is summed by port groups to estimate E_{ta}.

[6] Dealer trip records with unknown hull numbers (USCG or state), were aggregated by length, port group and month, and then allocated to areas proportional to the trips that had length class information.

Supplementary Table 1. Average landed catch per trip by month and length class (q_{tl}) with coefficients of variation, CV(q_{tl}), representing the variance across years (2002-2009).

	Length < 40		40 <= Length < 60		Length >=60	
Month	q_{tl}	CV	q_{tl}	CV	q_{tl}	CV
1	223	22.7%	729	31.3%	8758	20.3%
2	168	21.4%	864	46.1%	7645	22.4%
3	125	21.5%	743	45.9%	7258	26.6%
4	134	18.3%	472	22.7%	6540	21.7%
5	143	13.4%	419	11.7%	6920	19.5%
6	147	9.7%	399	16.3%	6887	15.9%
7	210	16.7%	372	10.9%	6761	21.1%
8	250	11.3%	380	12.6%	6832	18.6%
9	284	13.4%	419	15.3%	6605	22.2%
10	343	11.1%	537	13.5%	6148	16.0%
11	359	12.5%	611	11.8%	7516	10.9%
12	306	14.1%	650	24.4%	8089	10.6%
Average	224	15.5%	550	21.9%	7163	18.8%

Supplementary Table 2. Total number of lobster trips estimated by year and port group ($E_{yp} = \sum\sum E_{yta}$) fishing north of 40 degrees' latitude to The Hague line with percentage of total trips in NARW management areas in lower table.

	2002	2003	2004	2005	2006	2007	2008	2009
Total trips								
N. Maine	133,689	122,315	153,607	157,009	174,910	140,221	163,860	4,491
S. Maine	65,956	46,560	70,807	64,231	67,990	61,177	66,569	3,478
New Hampshire	1,974	2,319	2,069	2,561	3,311	3,003	3,142	306
N. Boston	13,467	14,336	13,616	12,087	13,594	11,945	11,506	826
S. Boston	10,143	10,166	10,641	8,320	8,627	9,187	9,946	428
E. Cape Cod	2,023	2,391	2,793	2,328	2,063	2,466	1,845	13
S. Cape Cod	14,814	12,233	12,595	19,634	14,455	11,586	6,613	605
Total	*242,066*	*210,320*	*266,126*	*266,169*	*284,951*	*239,584*	*263,482*	*10,147*
Percent of trips in right whale management areas								
N. Maine	0.000	0.000	0.001	0.000	0.005	0.002	0.001	0.000
S. Maine	0.011	0.004	0.001	0.000	0.026	0.045	0.029	0.085
New Hampshire	0.047	0.015	0.017	0.008	0.063	0.052	0.066	0.142
N. Boston	0.012	0.005	0.006	0.055	0.024	0.062	0.044	0.063
S. Boston	0.013	0.018	0.029	0.055	0.039	0.023	0.025	0.468
E. Cape Cod	0.019	0.003	0.043	0.033	0.003	0.006	0.005	0.000
S. Cape Cod	0.005	0.000	0.005	0.001	0.000	0.001	0.001	0.000
Total[i]	*0.005*	*0.002*	*0.003*	*0.005*	*0.012*	*0.019*	*0.012*	*0.058*

[i] Differences between this table and Table 2 in the manuscript are the result of rounding.