How exactly did you fill Cape Cod Bay with Ganley et al.'s (2019) results?

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What we see is not what there is: estimating North Atlantic right whale *Eubalaena glacialis* local abundance

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ABSTRACT: Aerial surveys can be used to estimate animal abundance, but animals unavailable for detection for portions of the survey can cause biased abundance estimates. Moreover, these biases may be variable owing to changes in behavior. We conducted focal follows to obtain surface and dive times of North Atlantic right whales *Eubalaena glacialis* in Cape Cod Bay (CCB) and measured the aircraft field of view; these metrics were combined to estimate availability and correct monthly abundance estimates from 1998 to 2017 generated via distance sampling methodology. We used a general least squares model to test for trends in abundance. Availability varied with month (0.27–0.85), likely linked to changes in the depth of copepod food resources. Detection probability varied across the years (0.43–0.87). Sightings per unit effort and counts of whales were significant, but downward-biased indicators of abundance and availability caused changes in bias over the season. Estimated abundance in CCB increased during the study period (4.9 whales yr^{-1}), and estimated abundance in peak months increased at a faster rate (10% yr^{-1} for 1998–2017) than for the overall population (2.8% yr^{-1} for 1990–2010). Accurate abundance estimates are necessary to monitor long-term changes in abundance of right whales in CCB, to understand the importance of CCB relative to other areas, and improve management strategies to protect this endangered species from entanglements in fishing gear and ship-strikes. Failing to correct for seasonal variation in availability results in substantial and variable underestimation of abundance.

KEY WORDS: Abundance estimation · Availability bias · Bayesian · Distance sampling · $g(0)$ · Right whales · Transect sampling · Diving

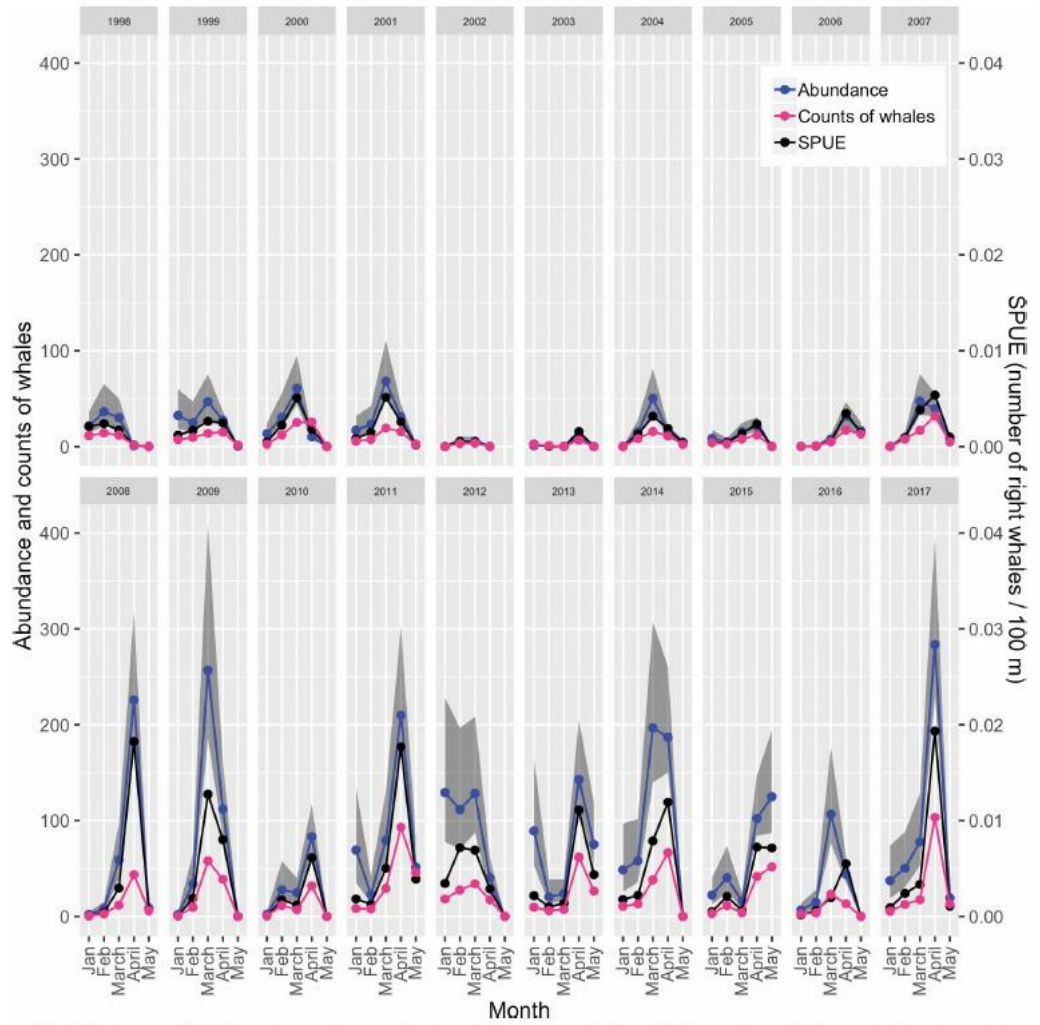

Fig. 6. North Atlantic right whale abundance estimates, sightings per unit effort (SPUE), and counts in Cape Cod Bay by month for each year. Blue points: median of the distribution of bootstrapped abundance; gray shaded regions: 1st and 3rd quartiles of the distribution; black points: SPUE; pink points: counts of right whales divided by the number of surveys in each month. There was no survey effort in May 2002

Cape Cod Bay

- In 2015-2017, we solicited a collaboration with Center for Coastal Studies (CCS), so that their surveys of Cape Cod Bay could be added to our model
- CCS replied positively, but their surveys lacked perpendicular distances to whale sightings, which we needed for our analysis
- They undertook an effort to reconstruct those distances from logged GPS data and then produce abundance and density estimates for CCB
- We left CCB “empty” for Winter and Spring seasons in our v7 model
- Laura Ganley published results in Feb 2019, which we incorporated into v8
  - Rather than incorporate CCS data into our model, we overlaid their results on ours
  - Cape Cod Bay is such a “special place” that it is best modeled separately
    - This may change if robust zooplankton maps become available across the northeast

Incorporation of Ganley et al. (2019) CCB results

Step 1: For our model, Laura Ganley provided:

- Climatological mean abundance and standard error estimates for the 1999-2016 seasons, the period spanned by our model, for 5 months (Jan-May)
- The geographical area those estimates applied to: 4105 km^2

Step 2: I derived mean density estimates and standard errors for each month:

Month	Mean abundance (whales)	SE	Area (km2)	Density (whales/100 km2)	SE
1	23.67	8.29	4105	0.58	0.20
2	25.14	6.16	4105	0.61	0.15
3	66.33	16.18	4105	1.62	0.39
4	71.78	16.73	4105	1.75	0.41
5	16.52	8.20	4105	0.40	0.20

From Laura

I derived

Incorporation of Ganley et al. (2019) CCB results

Step 3: I also needed estimates for December and June:

- For December, I used Ganley's January estimate. Ganley indicated that right whales occasionally showed up in CCB in December. She'll try to include December in her next update.
- For June, I used the density model's prediction.

Month	Mean abundance (whales)	SE	Area (km2)	Density (whales/100 km2)	SE
12				0.58	0.20
1	23.67	8.29	4105	0.58	0.20
2	25.14	6.16	4105	0.61	0.15
3	66.33	16.18	4105	1.62	0.39
4	71.78	16.73	4105	1.75	0.41
5	16.52	8.20	4105	0.40	0.20
6				0.0035	0.0023

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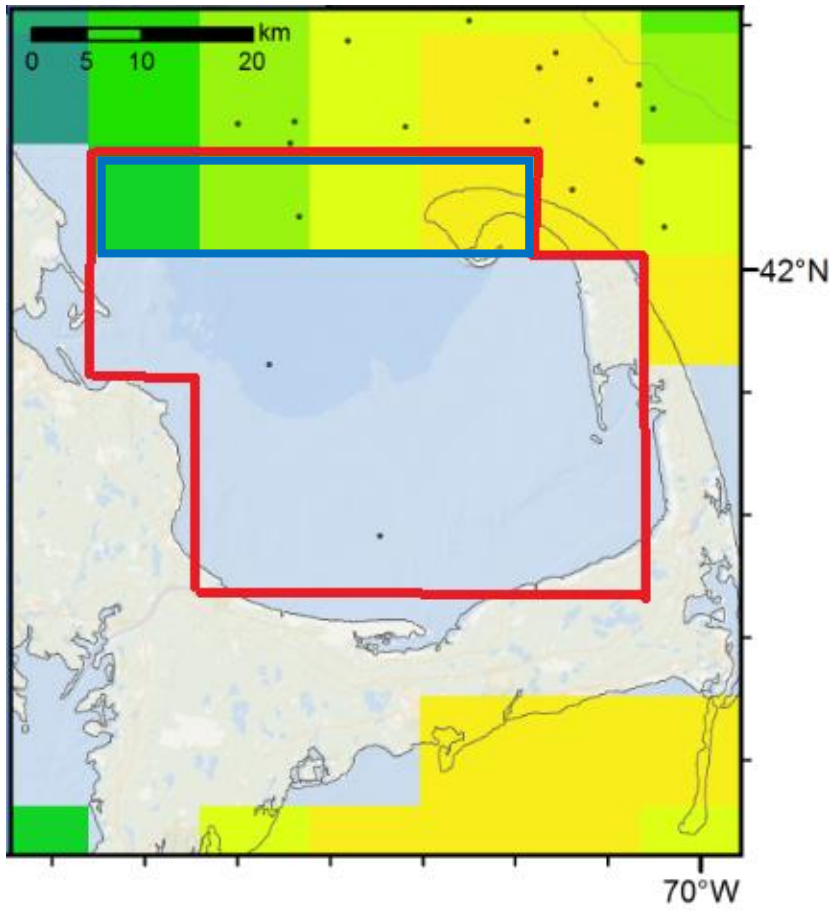
From density model

Incorporation of Ganley et al. (2019) CCB results

Step 4: Together, Ganley and I identified the cells of the density model's grid that best matched the area of CCB surveyed by CCS (red polygon).

For each month, December-June, I set those 17 cells to the monthly density and SE estimates from the previous step. (Each cell received the same value for that month.)

4 cells that were populated with density model predictions in v7 are now populated with Ganley's estimates in v8 (blue polygon).



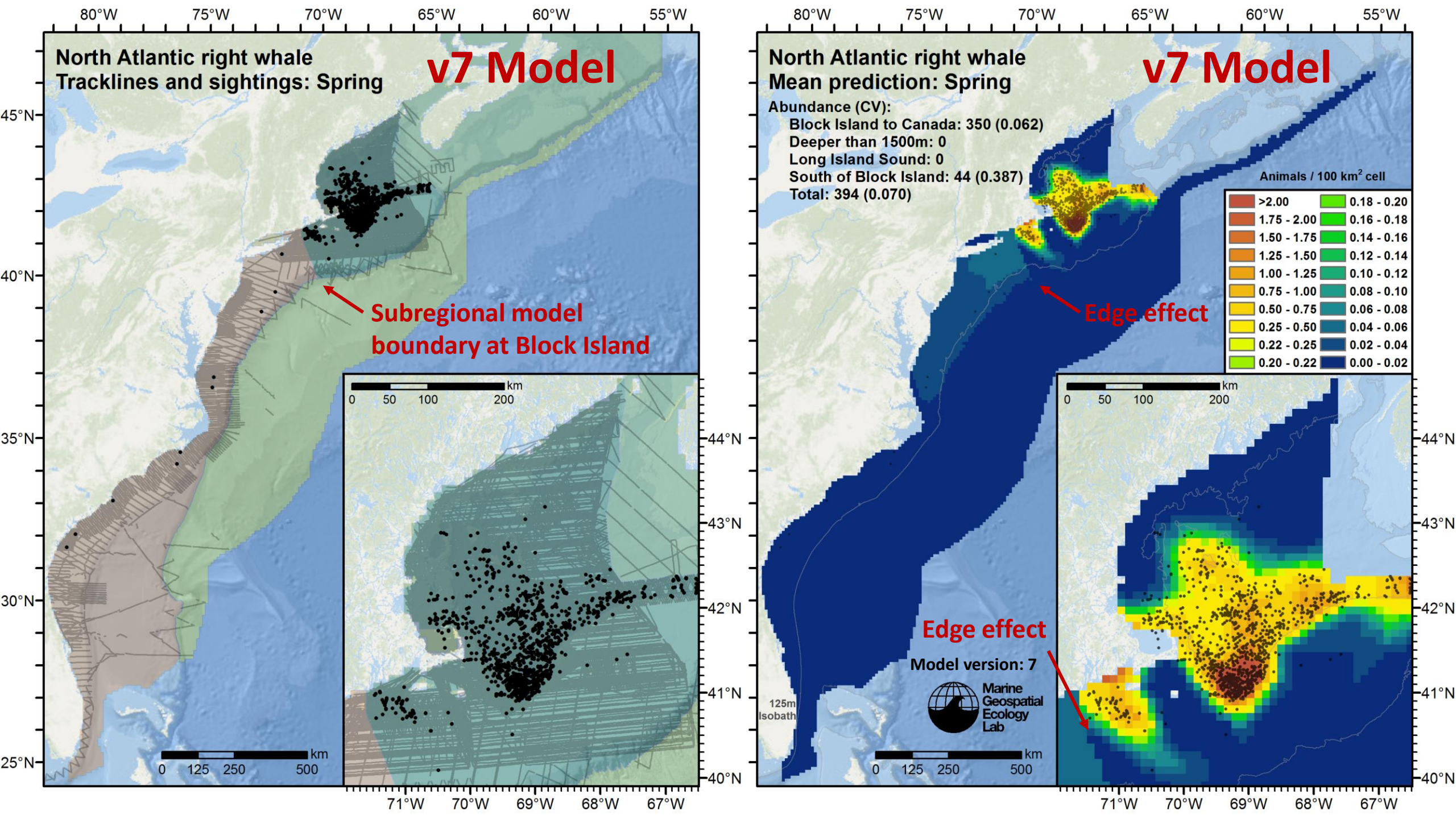
Frequently Asked Question

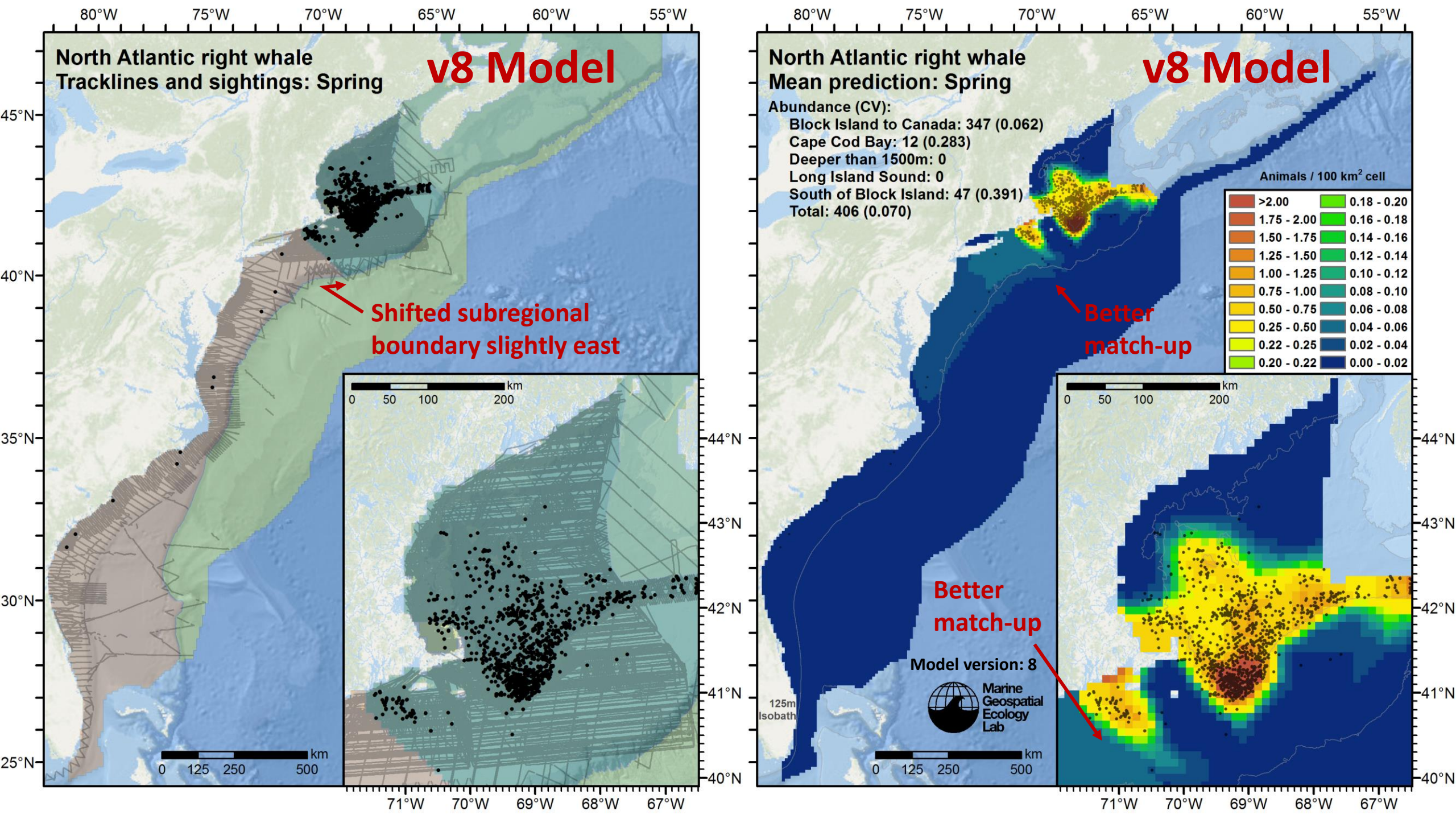
What are the "edge effects" from v7 that were reduced in v8?

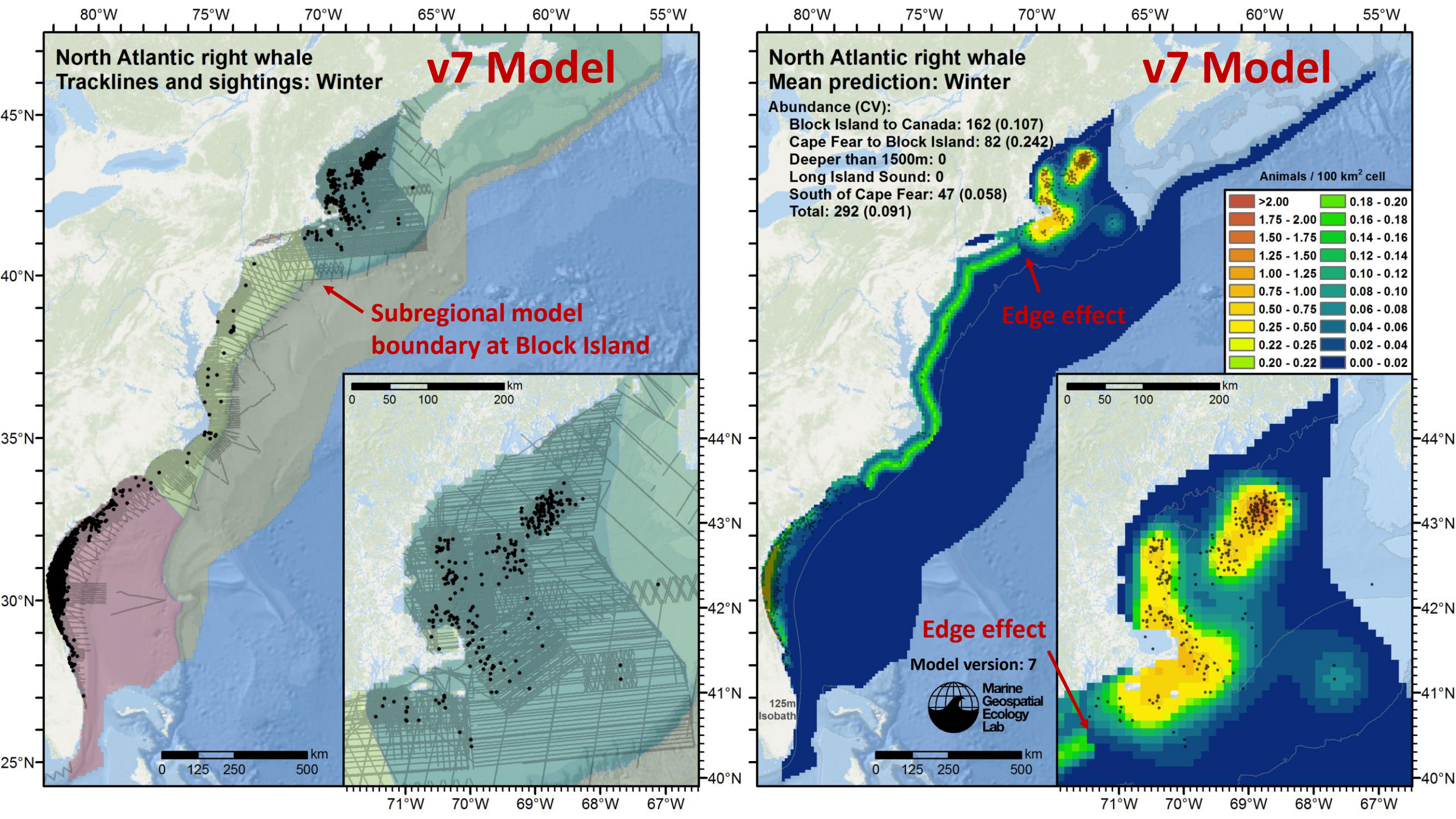
Our modeling approach was to split the study area seasonally and spatially into subregions where we suspect the species exhibits different species-environment relationships, based on the literature and patterns in the data.

We placed one such split at Block Island:

- Aggregations of feeding right whales were observed in multiple years just north of here in Rhode Island Sound
- We were unaware of such regular feeding aggregations south of there
- We split the study area there, to allow models to express different density-to-habitat relationships, in case right whales behaved differently
- The boundary between the subregions produced an edge effect in v7
- In v8, we adjusted this boundary to reduce the edge effect


North Atlantic right whale
Tracklines and sightings: Spring
v7 Model
Subregional model boundary at Block Island
North Atlantic right whale
Mean prediction: Spring
v7 Model
Abundance (CV):
Block Island to Canada: 350 (0.062)
Deeper than 1500m: 0
Long Island Sound: 0
South of Block Island: 44 (0.387)
Total: 394 (0.070)
Animals / 100 km² cell
>2.00
1.75 - 2.00
1.50 - 1.75
1.25 - 1.50
1.00 - 1.25
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.22 - 0.25
0.20 - 0.22
0.18 - 0.20
0.16 - 0.18
0.14 - 0.16
0.12 - 0.14
0.10 - 0.12
0.08 - 0.10
0.06 - 0.08
0.04 - 0.06
0.02 - 0.04
0.00 - 0.02
Edge effect
Edge effect
Model version: 7
Marine Geospatial Ecology Lab
125m Isobath
km
0 125 250 500
0 50 100 200
80°W 75°W 70°W 65°W 60°W 55°W
45°N 40°N 35°N 30°N 25°N
44°N 43°N 42°N 41°N 40°N
71°W 70°W 69°W 68°W 67°W


North Atlantic right whale
Tracklines and sightings: Spring
v8 Model
Shifted subregional boundary slightly east
North Atlantic right whale
Mean prediction: Spring
v8 Model
Abundance (CV):
Block Island to Canada: 347 (0.062)
Cape Cod Bay: 12 (0.283)
Deeper than 1500m: 0
Long Island Sound: 0
South of Block Island: 47 (0.391)
Total: 406 (0.070)
Animals / 100 km² cell
>2.00
1.75 - 2.00
1.50 - 1.75
1.25 - 1.50
1.00 - 1.25
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.22 - 0.25
0.20 - 0.22
0.18 - 0.20
0.16 - 0.18
0.14 - 0.16
0.12 - 0.14
0.10 - 0.12
0.08 - 0.10
0.06 - 0.08
0.04 - 0.06
0.02 - 0.04
0.00 - 0.02
Better match-up
Better match-up
Model version: 8
Marine Geospatial Ecology Lab
125m Isobath
km
0 125 250 500
0 50 100 200
80°W 75°W 70°W 65°W 60°W 55°W
45°N 40°N 35°N 30°N 25°N
44°N 43°N 42°N 41°N 40°N
71°W 70°W 69°W 68°W 67°W


North Atlantic right whale
Tracklines and sightings: Winter
v7 Model
Subregional model boundary at Block Island
km
0 125 250 500
km
0 50 100 200
North Atlantic right whale
Mean prediction: Winter
v7 Model
Abundance (CV):
Block Island to Canada: 162 (0.107)
Cape Fear to Block Island: 82 (0.242)
Deeper than 1500m: 0
Long Island Sound: 0
South of Cape Fear: 47 (0.058)
Total: 292 (0.091)
Animals / 100 km² cell
>2.00
1.75 - 2.00
1.50 - 1.75
1.25 - 1.50
1.00 - 1.25
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.22 - 0.25
0.20 - 0.22
0.18 - 0.20
0.16 - 0.18
0.14 - 0.16
0.12 - 0.14
0.10 - 0.12
0.08 - 0.10
0.06 - 0.08
0.04 - 0.06
0.02 - 0.04
0.00 - 0.02
Edge effect
Edge effect
Model version: 7
Marine Geospatial Ecology Lab
125m Isobath
km
0 125 250 500
km
0 50 100 200
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
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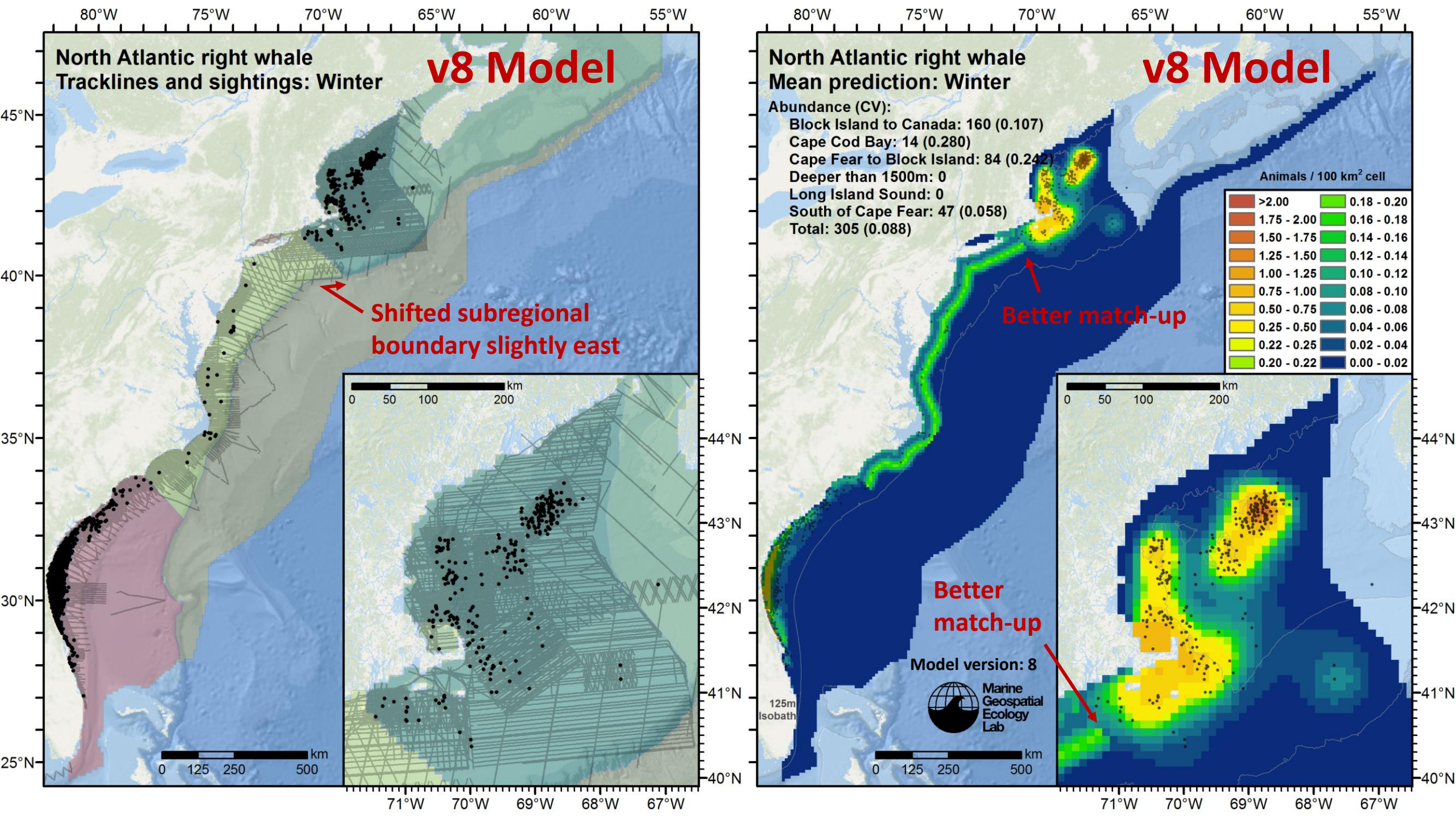
40°N
71°W
70°W
69°W
68°W
67°W


North Atlantic right whale
Tracklines and sightings: Winter
v8 Model
Shifted subregional boundary slightly east
North Atlantic right whale
Mean prediction: Winter
v8 Model
Abundance (CV):
Block Island to Canada: 160 (0.107)
Cape Cod Bay: 14 (0.280)
Cape Fear to Block Island: 84 (0.242)
Deeper than 1500m: 0
Long Island Sound: 0
South of Cape Fear: 47 (0.058)
Total: 305 (0.088)
Animals / 100 km² cell
>2.00
1.75 - 2.00
1.50 - 1.75
1.25 - 1.50
1.00 - 1.25
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.22 - 0.25
0.20 - 0.22
0.18 - 0.20
0.16 - 0.18
0.14 - 0.16
0.12 - 0.14
0.10 - 0.12
0.08 - 0.10
0.06 - 0.08
0.04 - 0.06
0.02 - 0.04
0.00 - 0.02
Better match-up
Better match-up
Model version: 8
Marine Geospatial Ecology Lab
125m Isobath
km
0 125 250 500
0 50 100 200
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
40°N
71°W
70°W
69°W
68°W
67°W

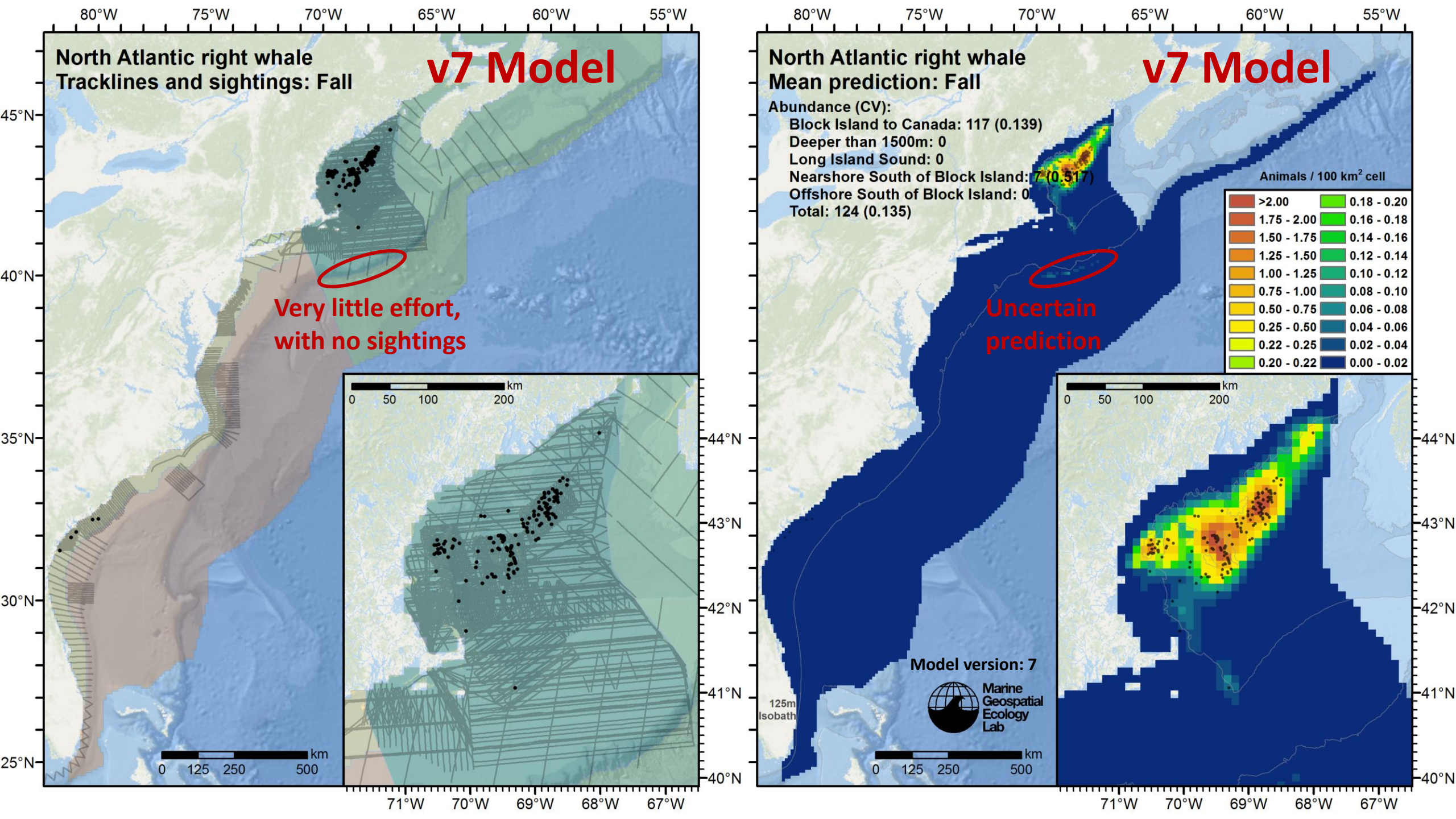
Edge effect in Fall along Georges Bank

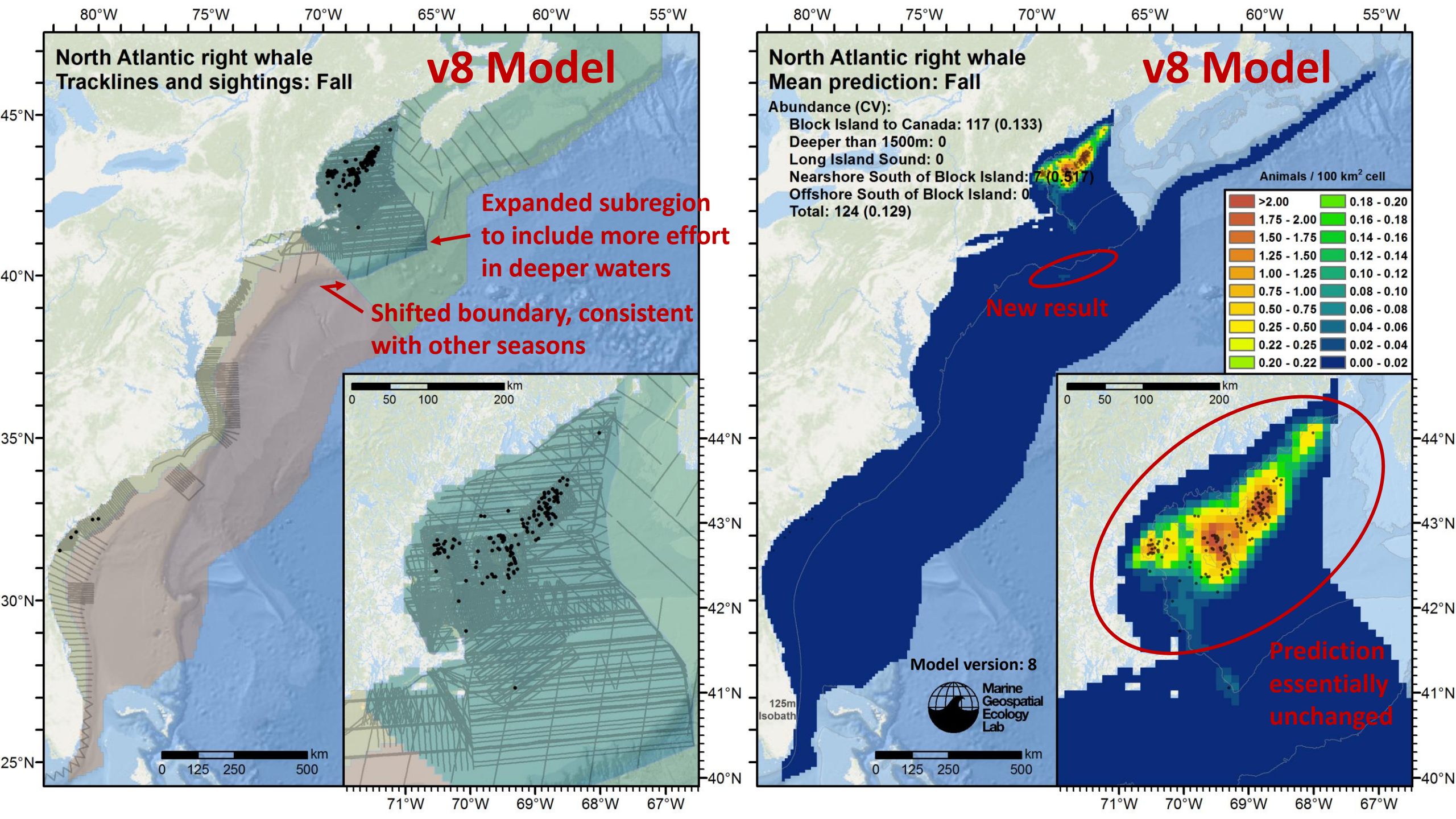
The v7 Fall season model predicted a strip of low density along southern Georges Bank, waters 1000-1500m deep, along the model edge (next slide).

High CVs and other diagnostics indicated this was an aberrant prediction. The fitted relationship for the Depth covariate indicated that density increased as depth increased, but data were very sparse at deep depths. To reduce uncertainty at deep depths, we expanded the subregion boundary to encompass the remaining survey effort along deeper areas of Georges Bank.

The resulting model (v8) predicted less density here and CVs improved.

However, we caution that right whales have been observed and acoustically detected in similarly deep waters (albeit more rarely than shallower waters). The best way to improve the model for this region is to conduct additional surveying, or to adjust our methodology to utilize additional classes of data.


North Atlantic right whale
Tracklines and sightings: Fall
v7 Model
Very little effort,
with no sightings
North Atlantic right whale
Mean prediction: Fall
Abundance (CV):
Block Island to Canada: 117 (0.139)
Deeper than 1500m: 0
Long Island Sound: 0
Nearshore South of Block Island: 7 (0.517)
Offshore South of Block Island: 0
Total: 124 (0.135)
v7 Model
Uncertain
prediction
Animals / 100 km² cell
>2.00
1.75 - 2.00
1.50 - 1.75
1.25 - 1.50
1.00 - 1.25
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.22 - 0.25
0.20 - 0.22
0.18 - 0.20
0.16 - 0.18
0.14 - 0.16
0.12 - 0.14
0.10 - 0.12
0.08 - 0.10
0.06 - 0.08
0.04 - 0.06
0.02 - 0.04
0.00 - 0.02
Model version: 7
Marine Geospatial Ecology Lab
125m Isobath
km
0 125 250 500
0 50 100 200
80°W 75°W 70°W 65°W 60°W 55°W
45°N 40°N 35°N 30°N 25°N
44°N 43°N 42°N 41°N 40°N
71°W 70°W 69°W 68°W 67°W


North Atlantic right whale
Tracklines and sightings: Fall
v8 Model
Expanded subregion to include more effort in deeper waters
Shifted boundary, consistent with other seasons
km
0 125 250 500
km
0 50 100 200
North Atlantic right whale
Mean prediction: Fall
v8 Model
Abundance (CV):
Block Island to Canada: 117 (0.133)
Deeper than 1500m: 0
Long Island Sound: 0
Nearshore South of Block Island: 7 (0.517)
Offshore South of Block Island: 0
Total: 124 (0.129)
Animals / 100 km² cell
>2.00
1.75 - 2.00
1.50 - 1.75
1.25 - 1.50
1.00 - 1.25
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.22 - 0.25
0.20 - 0.22
0.18 - 0.20
0.16 - 0.18
0.14 - 0.16
0.12 - 0.14
0.10 - 0.12
0.08 - 0.10
0.06 - 0.08
0.04 - 0.06
0.02 - 0.04
0.00 - 0.02
New result
Model version: 8
Marine Geospatial Ecology Lab
125m Isobath
km
0 125 250 500
km
0 50 100 200
Prediction essentially unchanged
80°W 75°W 70°W 65°W 60°W 55°W
45°N 40°N 35°N 30°N 25°N
44°N 43°N 42°N 41°N 40°N
71°W 70°W 69°W 68°W 67°W