Density Model for Northern Bottlenose Whale (*Hyperoodon ampullatus*) for the U.S. East Coast: Supplementary Report

Duke University Marine Geospatial Ecology Lab*

Model Version 1.2 - 2015-09-26

Citation

When referencing our methodology or results generally, please cite our open-access article:

Roberts JJ, Best BD, Mannocci L, Fujioka E, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, Khan CB, McLellan WM, Pabst DA, Lockhart GG (2016) Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Scientific Reports 6: 22615. doi: 10.1038/srep22615

To reference this specific model or Supplementary Report, please cite:

Roberts JJ, Best BD, Mannocci L, Fujioka E, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, Khan CB, McLellan WM, Pabst DA, Lockhart GG (2015) Density Model for Northern Bottlenose Whale (*Hyperoodon ampullatus*) for the U.S. East Coast Version 1.2, 2015-09-26, and Supplementary Report. Marine Geospatial Ecology Lab, Duke University, Durham, North Carolina.

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Revision History

Version	Date	Description of changes
1	2015-03-06	Initial version.
1.1	2015-05-14	Updated calculation of CVs. Switched density rasters to logarithmic breaks. No changes to the model.
1.2	2015-09-26	Updated the documentation. No changes to the model.

*For questions, or to offer feedback about this model or report, please contact Jason Roberts (jason.roberts@duke.edu)

Survey Data

Survey	Period	Length (1000 km)	Hours	Sightings
NEFSC Aerial Surveys	1995-2008	70	412	0
NEFSC NARWSS Harbor Porpoise Survey	1999-1999	6	36	0
NEFSC North Atlantic Right Whale Sighting Survey	1999-2013	432	2330	0
NEFSC Shipboard Surveys	1995-2004	16	1143	4
NJDEP Aerial Surveys	2008-2009	11	60	0
NJDEP Shipboard Surveys	2008-2009	14	836	0
SEFSC Atlantic Shipboard Surveys	1992-2005	28	1731	0
SEFSC Mid Atlantic Tursiops Aerial Surveys	1995-2005	35	196	0
SEFSC Southeast Cetacean Aerial Surveys	1992-1995	8	42	0
UNCW Cape Hatteras Navy Surveys	2011-2013	19	125	0
UNCW Early Marine Mammal Surveys	2002-2002	18	98	0
UNCW Jacksonville Navy Surveys	2009-2013	66	402	0
UNCW Onslow Navy Surveys	2007-2011	49	282	0
UNCW Right Whale Surveys	2005-2008	114	586	0
Virginia Aquarium Aerial Surveys	2012-2014	9	53	0
Total		895	8332	4

Table 2: Survey effort and sightings used in this model. Effort is tallied as the cumulative length of on-effort transects and hours the survey team was on effort. Sightings are the number of on-effort encounters of the modeled species for which a perpendicular sighting distance (PSD) was available. Off effort sightings and those without PSDs were omitted from the analysis.

Season	Months	Length (1000 km)	Hours	Sightings
All_Year	All	897	8332	4

Table 3: Survey effort and on-effort sightings having perpendicular sighting distances.

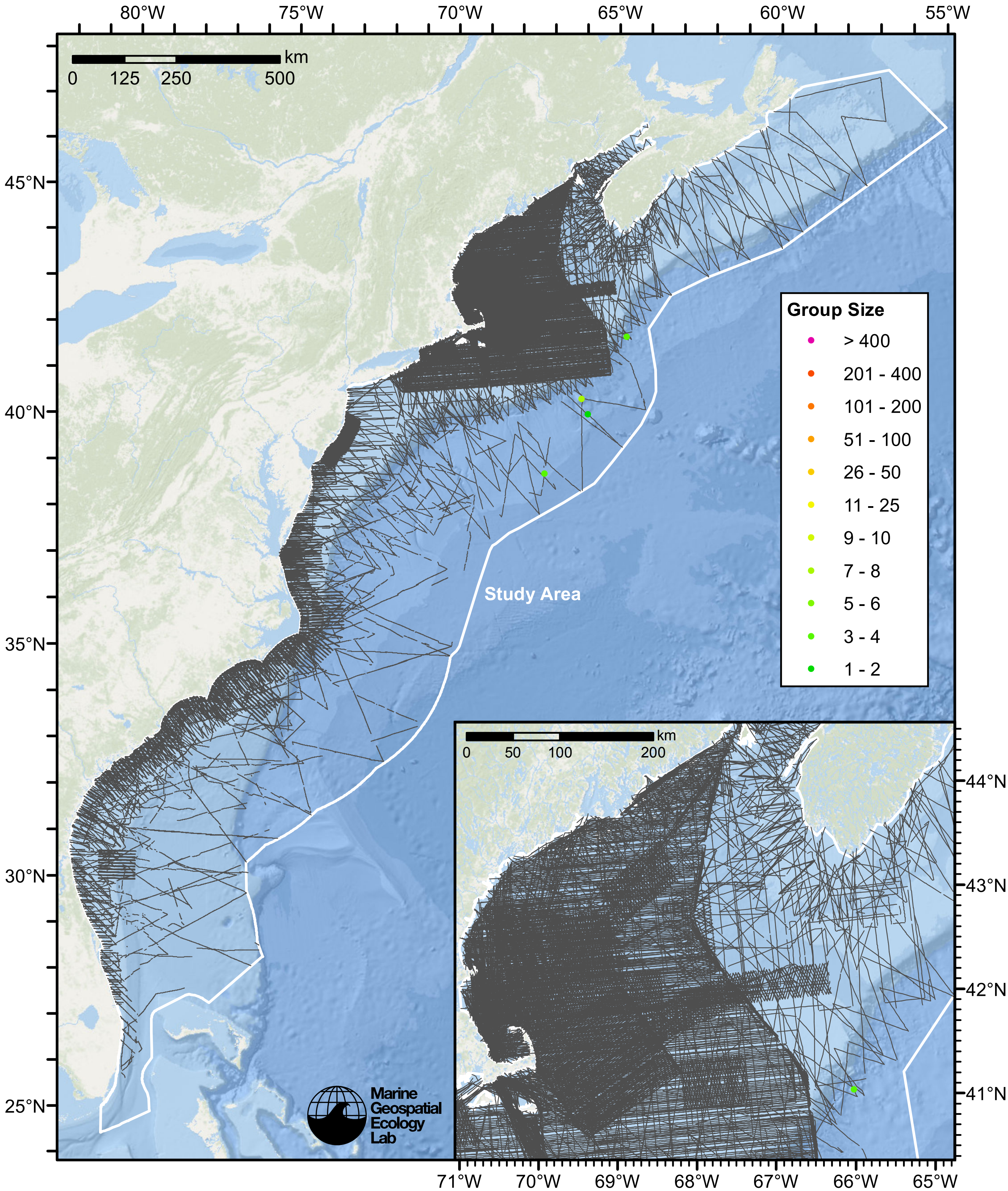

Figure 1: Northern bottlenose whale sightings and survey tracklines.

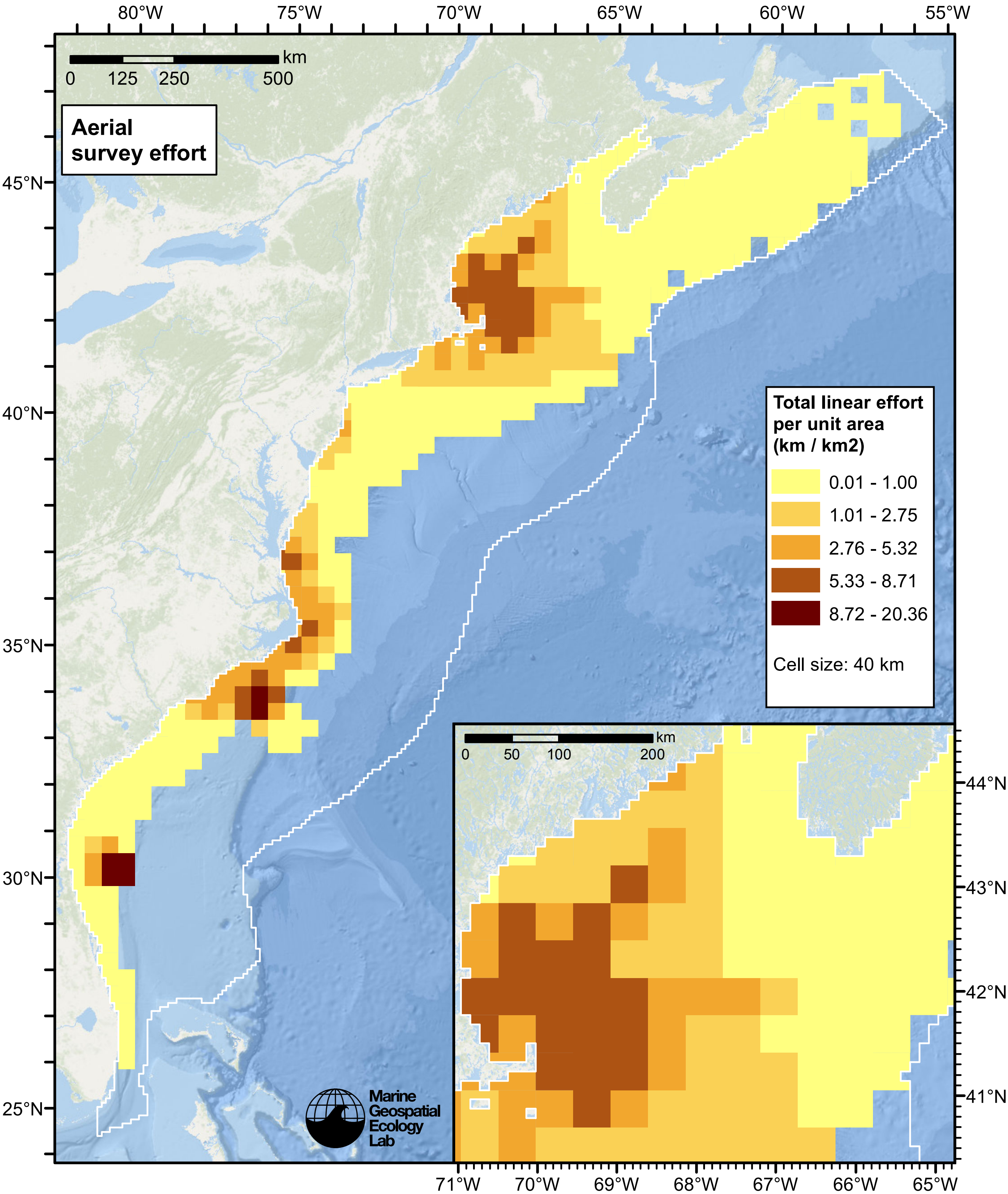

Figure 2: Aerial linear survey effort per unit area.

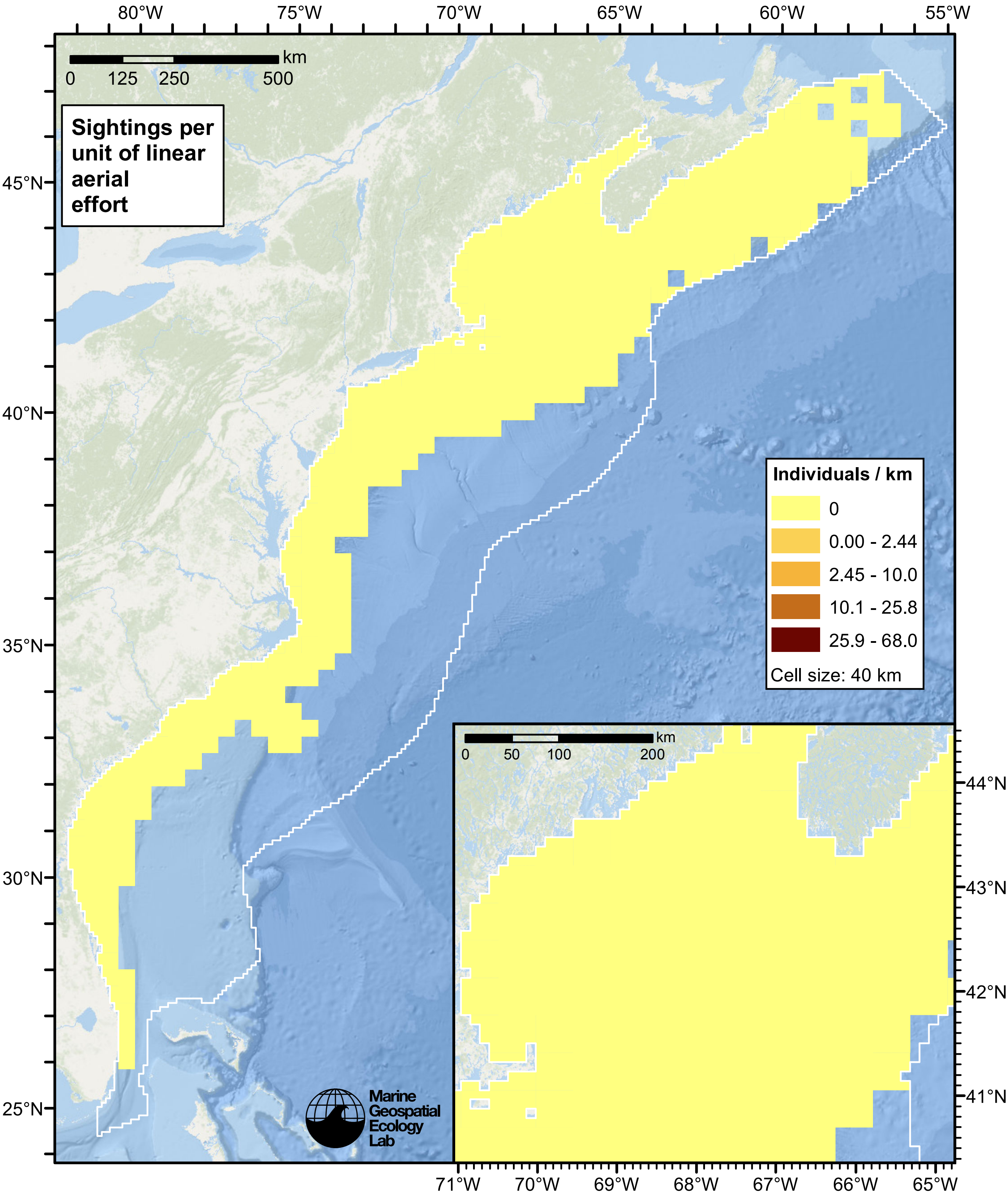

Figure 3: Northern bottlenose whale sightings per unit aerial linear survey effort.

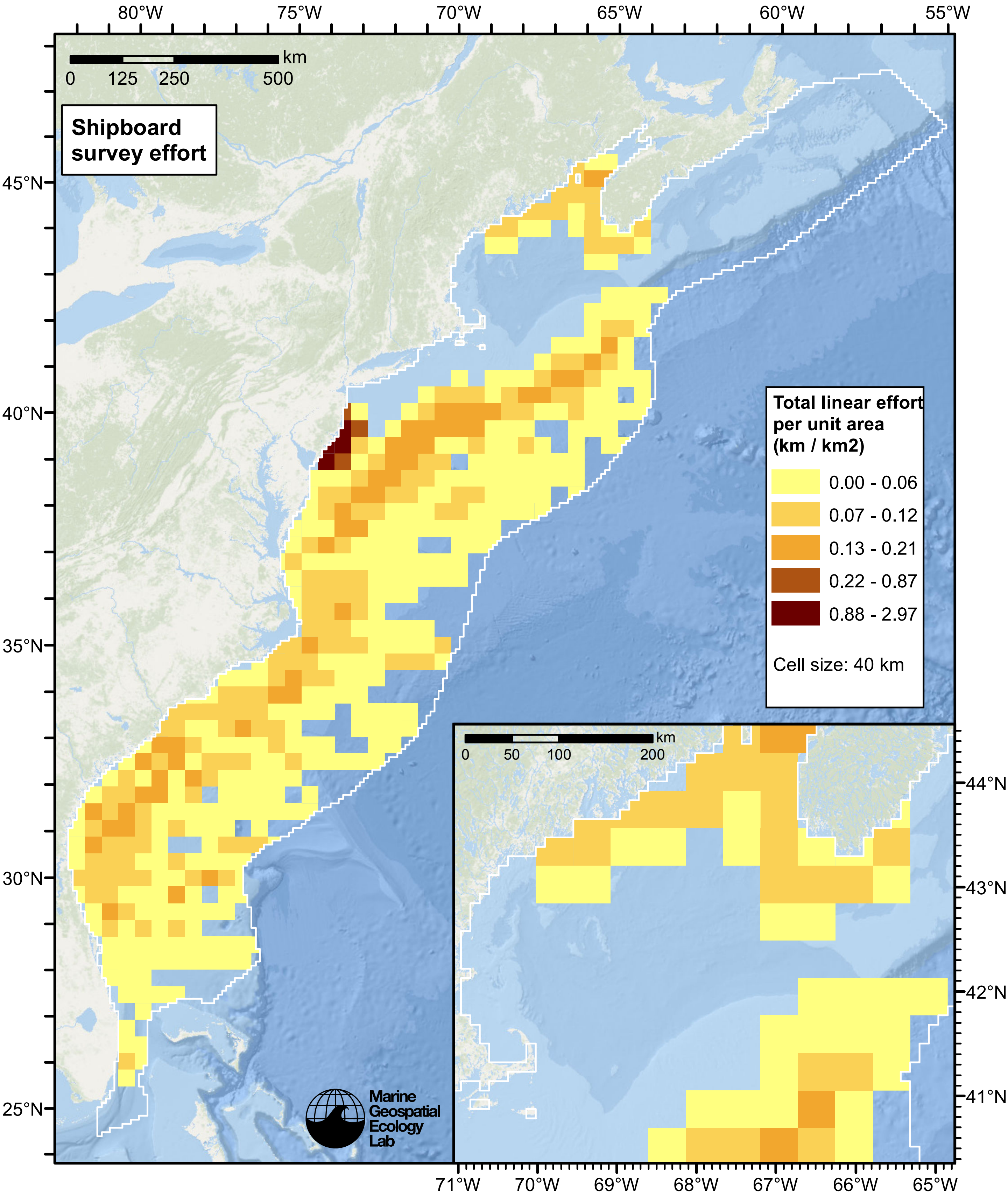

Figure 4: Shipboard linear survey effort per unit area.

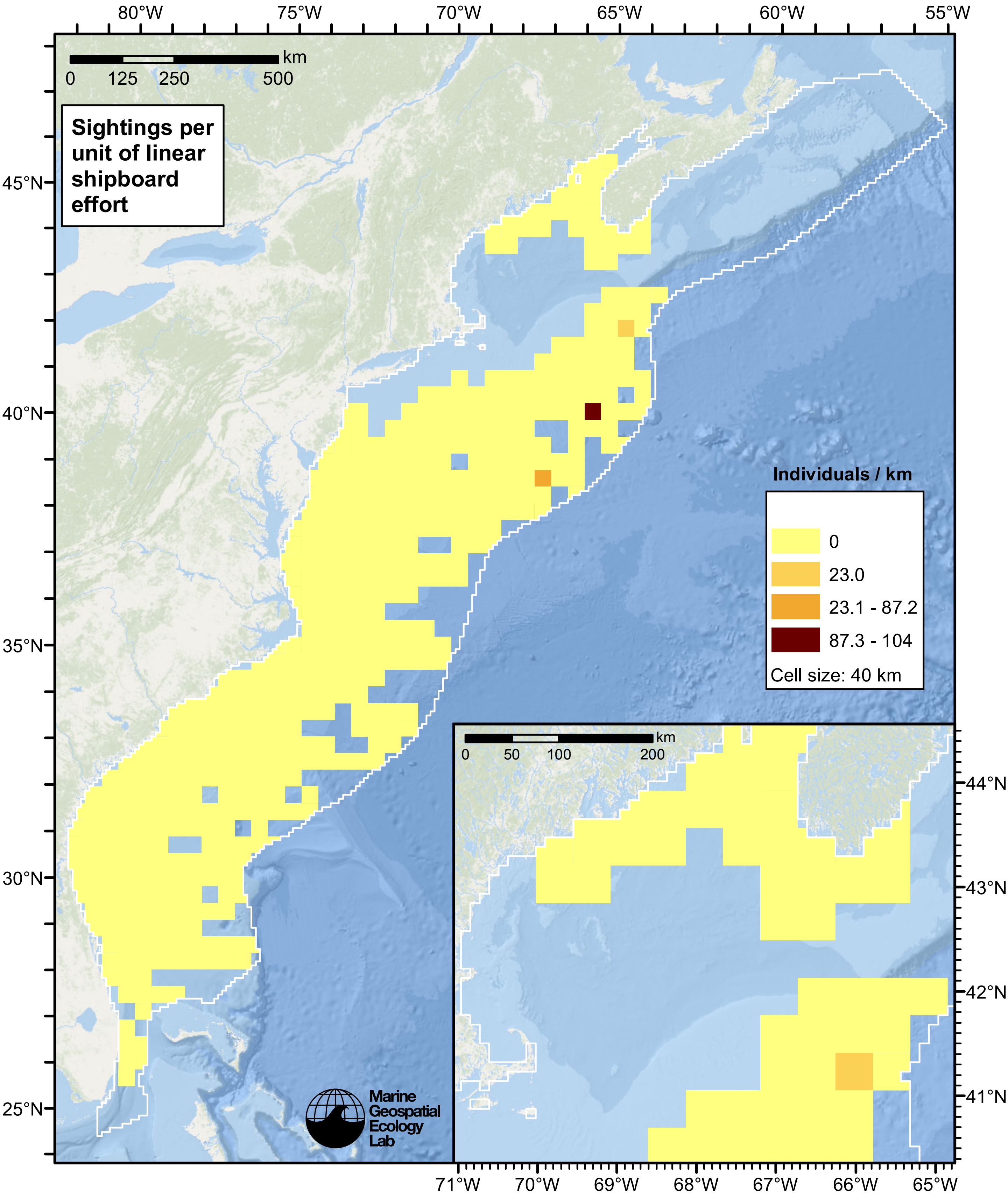

Figure 5: Northern bottlenose whale sightings per unit shipboard linear survey effort.

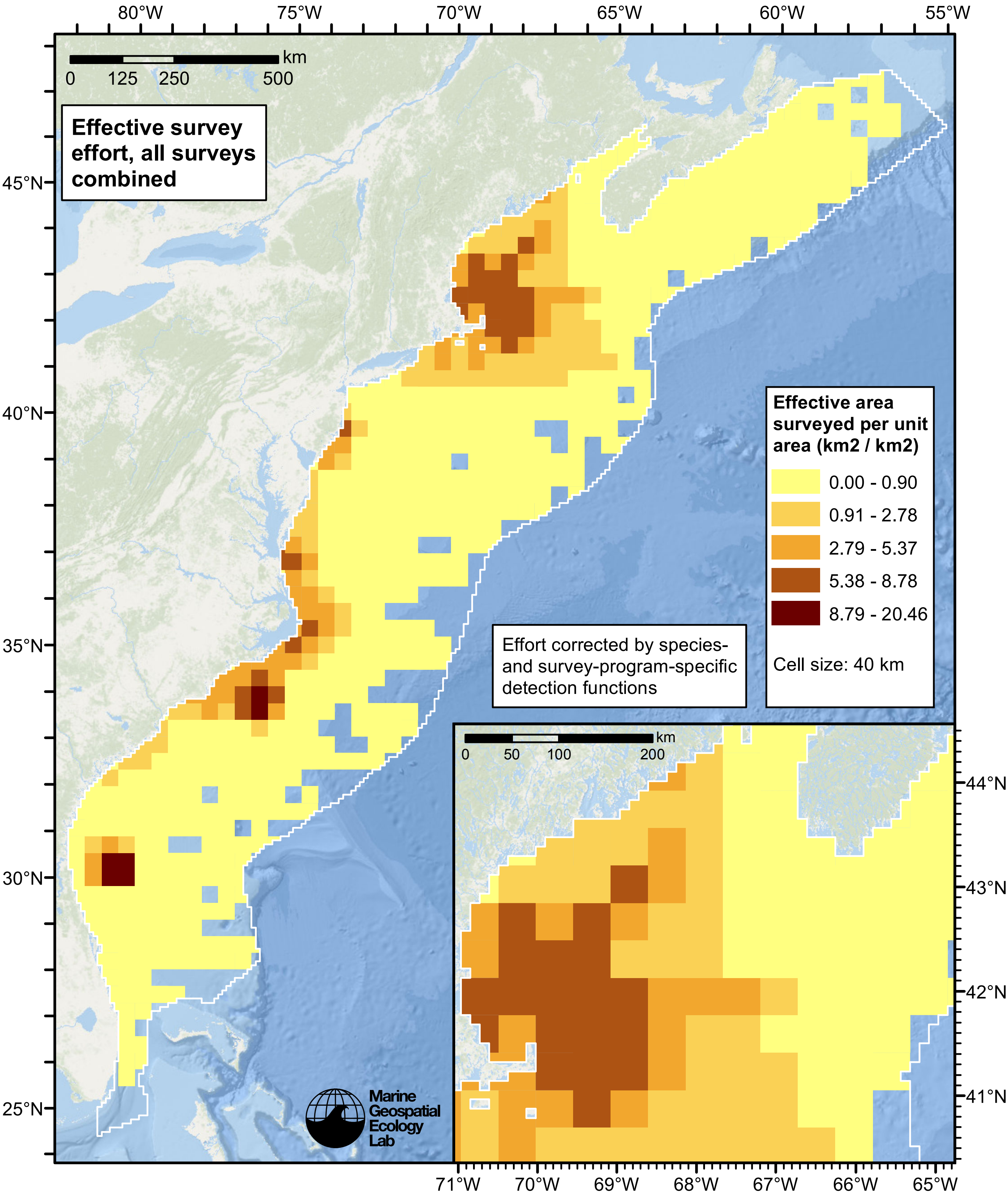

Figure 6: Effective survey effort per unit area, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

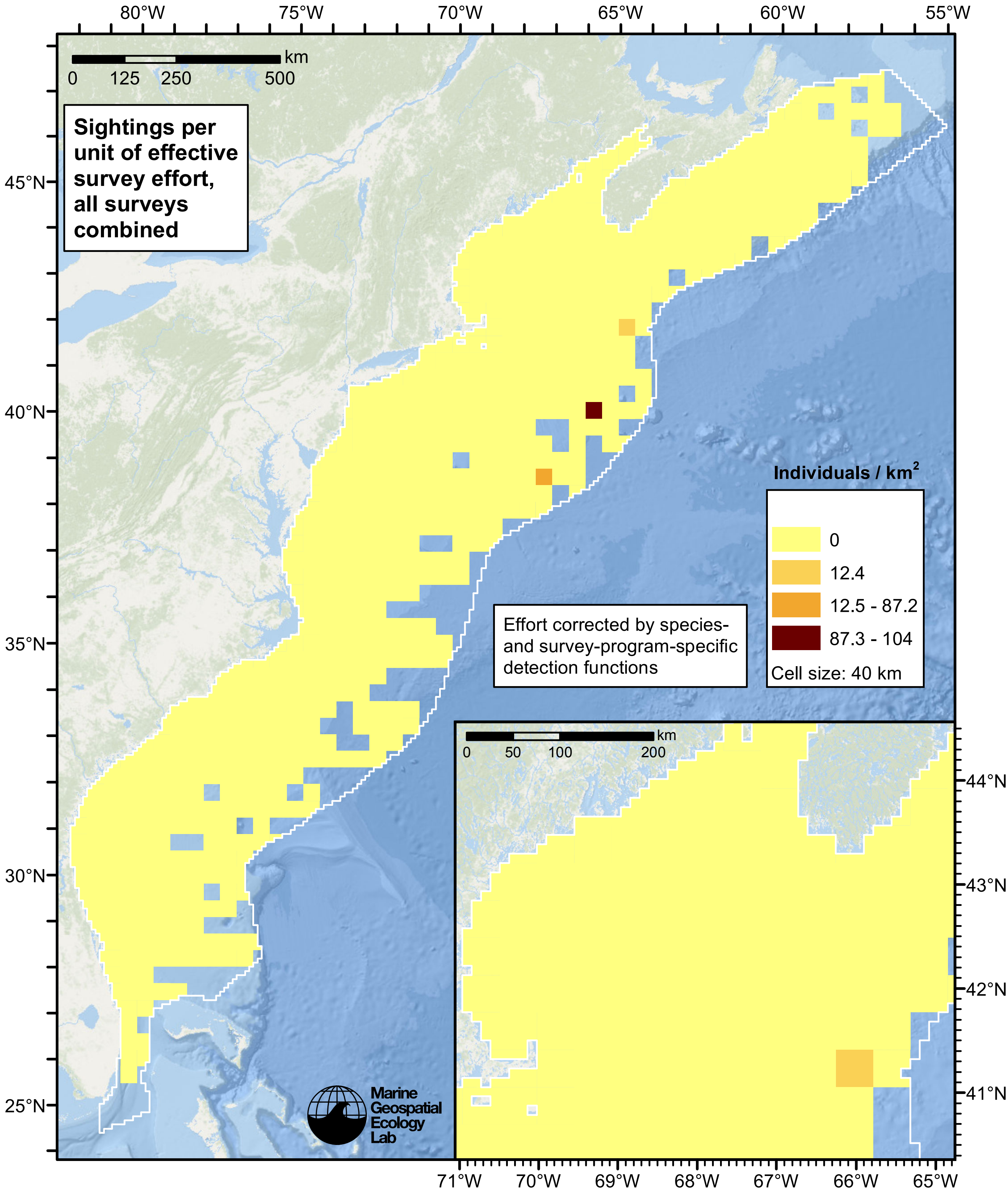

Figure 7: Northern bottlenose whale sightings per unit of effective survey effort, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

Detection Functions

The detection hierarchy figures below show how sightings from multiple surveys were pooled to try to achieve Buckland et. al's (2001) recommendation that at least 60-80 sightings be used to fit a detection function. Leaf nodes, on the right, usually represent individual surveys, while the hierarchy to the left shows how they have been grouped according to how similar we believed the surveys were to each other in their detection performance.

At each node, the red or green number indicates the total number of sightings below that node in the hierarchy, and is colored green if 70 or more sightings were available, and red otherwise. If a grouping node has zero sightings–i.e. all of the surveys within it had zero sightings–it may be collapsed and shown as a leaf to save space.

Each histogram in the figure indicates a node where a detection function was fitted. The actual detection functions do not appear in this figure; they are presented in subsequent sections. The histogram shows the frequency of sightings by perpendicular sighting distance for all surveys contained by that node. Each survey (leaf node) recieves the detection function that is closest to it up the hierarchy. Thus, for common species, sufficient sightings may be available to fit detection functions deep in the hierarchy, with each function applying to only a few surveys, thereby allowing variability in detection performance between surveys to be addressed relatively finely. For rare species, so few sightings may be available that we have to pool many surveys together to try to meet Buckland's recommendation, and fit only a few coarse detection functions high in the hierarchy.

A blue Proxy Species tag indicates that so few sightings were available that, rather than ascend higher in the hierarchy to a point that we would pool grossly-incompatible surveys together, (e.g. shipboard surveys that used big-eye binoculars with those that used only naked eyes) we pooled sightings of similar species together instead. The list of species pooled is given in following sections.

Shipboard Surveys

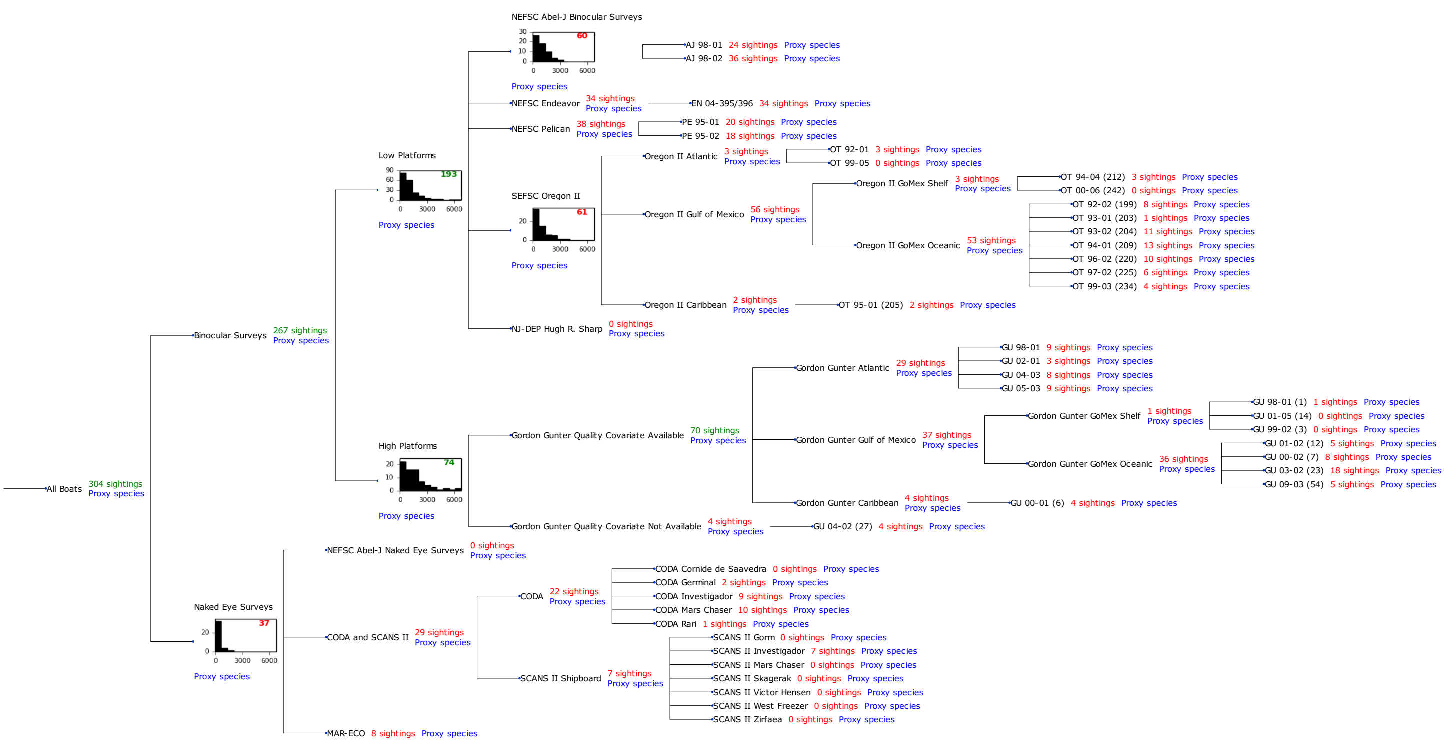

Figure 8: Detection hierarchy for shipboard surveys

Low Platforms

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Hyperoodon ampullatus	Northern bottlenose whale	4
Mesoplodon	Beaked whale	110
Mesoplodon bidens	Sowerby's beaked whale	14
Mesoplodon densirostris	Blainville's beaked whale	5
Mesoplodon europaeus	Gervais' beaked whale	0
Mesoplodon mirus	True's beaked whale	2
Ziphiidae	Unidentified beaked whale	20
Ziphius cavirostris	Cuvier's beaked whale	38
Total		193

Table 4: Proxy species used to fit detection functions for Low Platforms. The number of sightings, n, is before truncation.

The sightings were right truncated at 4000m.

Covariate	Description
beaufort	Beaufort sea state.
size	Estimated size (number of individuals) of the sighted group.

Table 5: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort	Yes	0.00	1577
hr			beaufort, size	Yes	1.32	1586
hn			beaufort	Yes	5.84	1593
hn			beaufort, size	Yes	6.26	1598
hr			size	Yes	10.28	1533
hn	cos	2		Yes	10.53	1337
hr				Yes	10.78	1491
hr	poly	4		Yes	12.77	1487
hr	poly	2		Yes	12.77	1485
hn	cos	3		Yes	15.54	1338
hn				Yes	17.58	1606
hn			size	Yes	17.65	1606
hn	herm	4		No		

Table 6: Candidate detection functions for Low Platforms. The first one listed was selected for the density model.

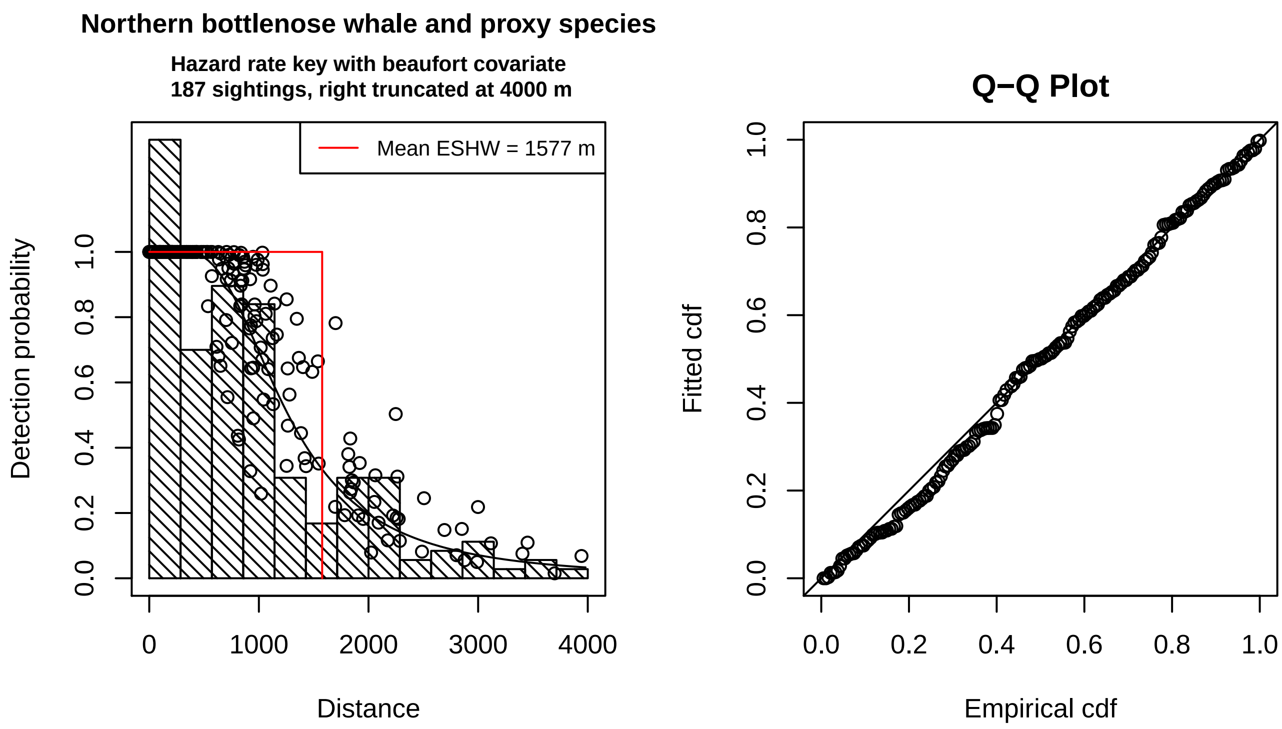

Figure 9: Detection function for Low Platforms that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  187
Distance range         :  0  -  4000
AIC                    :  2928.386

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate         se
(Intercept)  7.5894417 0.19447464
beaufort    -0.2189661 0.06555743

Shape parameters:
            estimate        se
(Intercept) 1.022041 0.1482374

                        Estimate          SE         CV
Average p              0.3739064  0.02891626 0.07733556
N in covered region 500.1251925 48.58643315 0.09714854
```

Additional diagnostic plots:

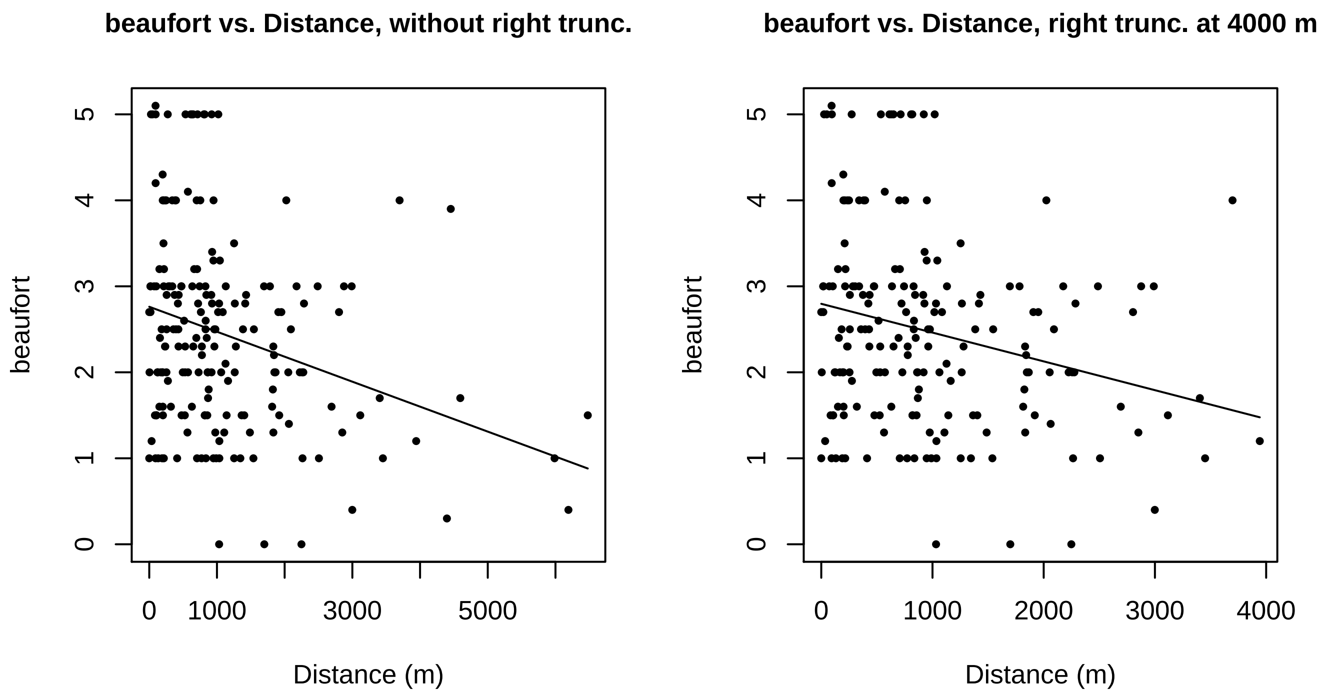

Figure 10: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

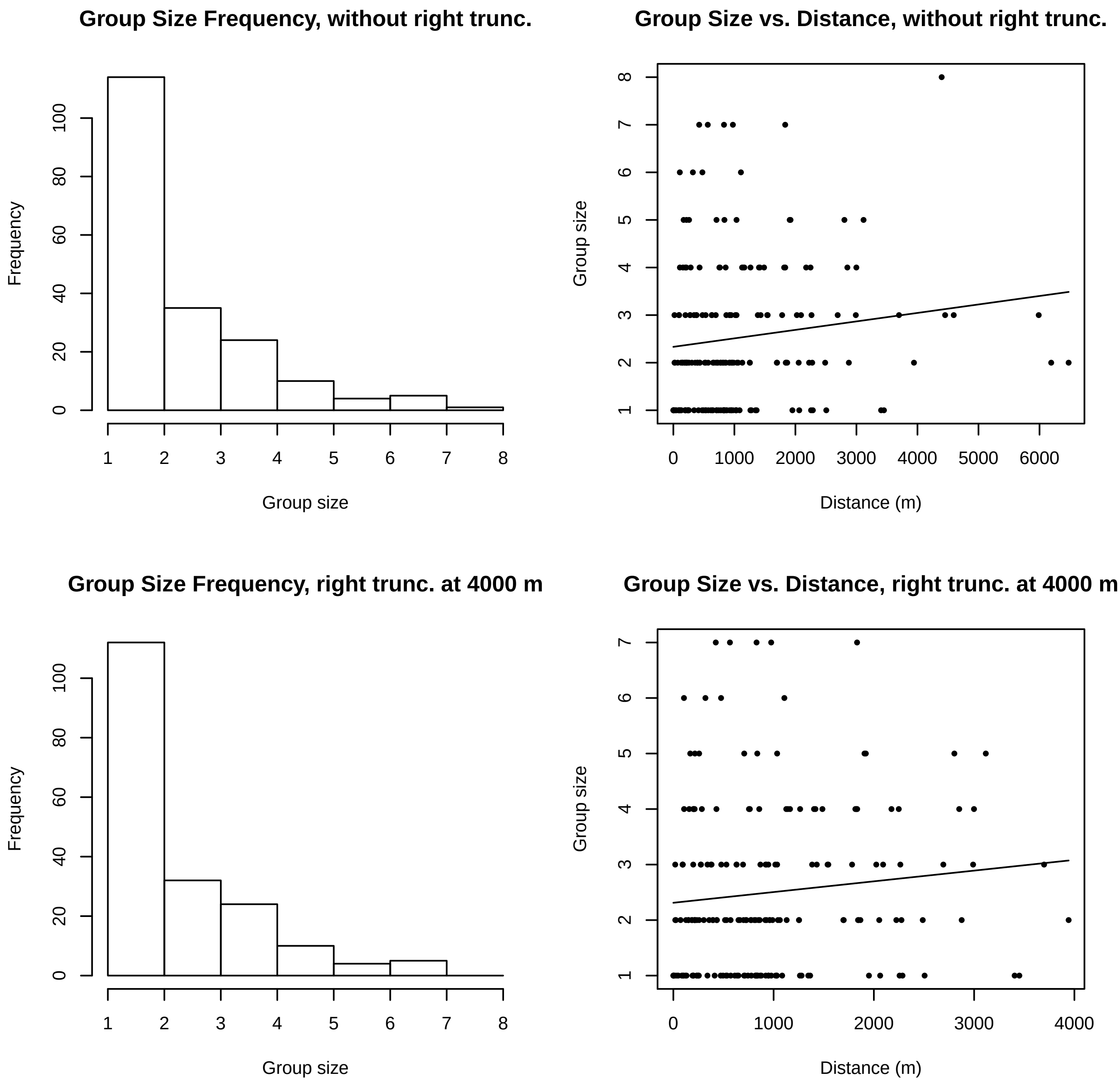

Figure 11: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NEFSC Abel-J Binocular Surveys

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Hyperoodon ampullatus	Northern bottlenose whale	1
Mesoplodon	Beaked whale	40

Mesoplodon bidens	Sowerby's beaked whale	7
Mesoplodon densirostris	Blainville's beaked whale	1
Mesoplodon europaeus	Gervais' beaked whale	0
Mesoplodon mirus	True's beaked whale	0
Ziphiidae	Unidentified beaked whale	0
Ziphius cavirostris	Cuvier's beaked whale	11
Total		60

Table 7: Proxy species used to fit detection functions for NEFSC Abel-J Binocular Surveys. The number of sightings, n, is before truncation.

The sightings were right truncated at 3000m.

Covariate	Description
beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 8: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort	Yes	0.00	1497
hn				Yes	0.33	1577
hn			beaufort	Yes	1.26	1596
hr				Yes	1.73	1583
hn	cos	2		Yes	1.95	1438
hn	cos	3		Yes	2.33	1568
hn			quality	Yes	2.33	1577
hr			quality	Yes	3.61	1588
hr			size	Yes	3.70	1590
hr	poly	2		Yes	3.73	1576
hr	poly	4		Yes	3.73	1583
hr			quality, size	Yes	5.58	1594
hn	herm	4		No		
hn			size	No		
hn			beaufort, quality	No		
hr			beaufort, quality	No		
hn			beaufort, size	No		
hr			beaufort, size	No		

hn	quality, size	No
hn	beaufort, quality, size	No
hr	beaufort, quality, size	No

Table 9: Candidate detection functions for NEFSC Abel-J Binocular Surveys. The first one listed was selected for the density model.

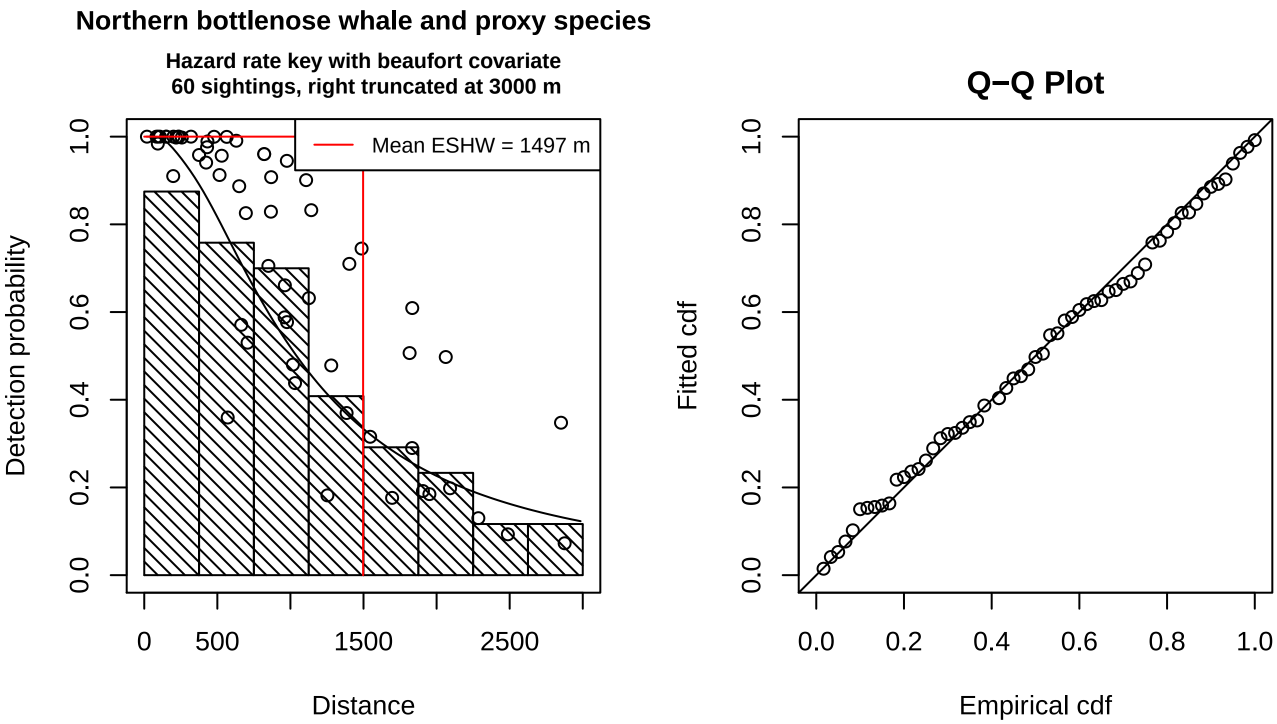

Figure 12: Detection function for NEFSC Abel-J Binocular Surveys that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  60
Distance range         :  0  -  3000
AIC                    :  937.8206

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  8.2147119 0.6827762
beaufort    -0.5658867 0.2695133

Shape parameters:
             estimate        se
(Intercept) 0.5794025 0.3371294

                       Estimate          SE         CV
```

```
Average p              0.4373965  0.09035365 0.2065715
N in covered region 137.1753009 31.60296893 0.2303838
```

Additional diagnostic plots:

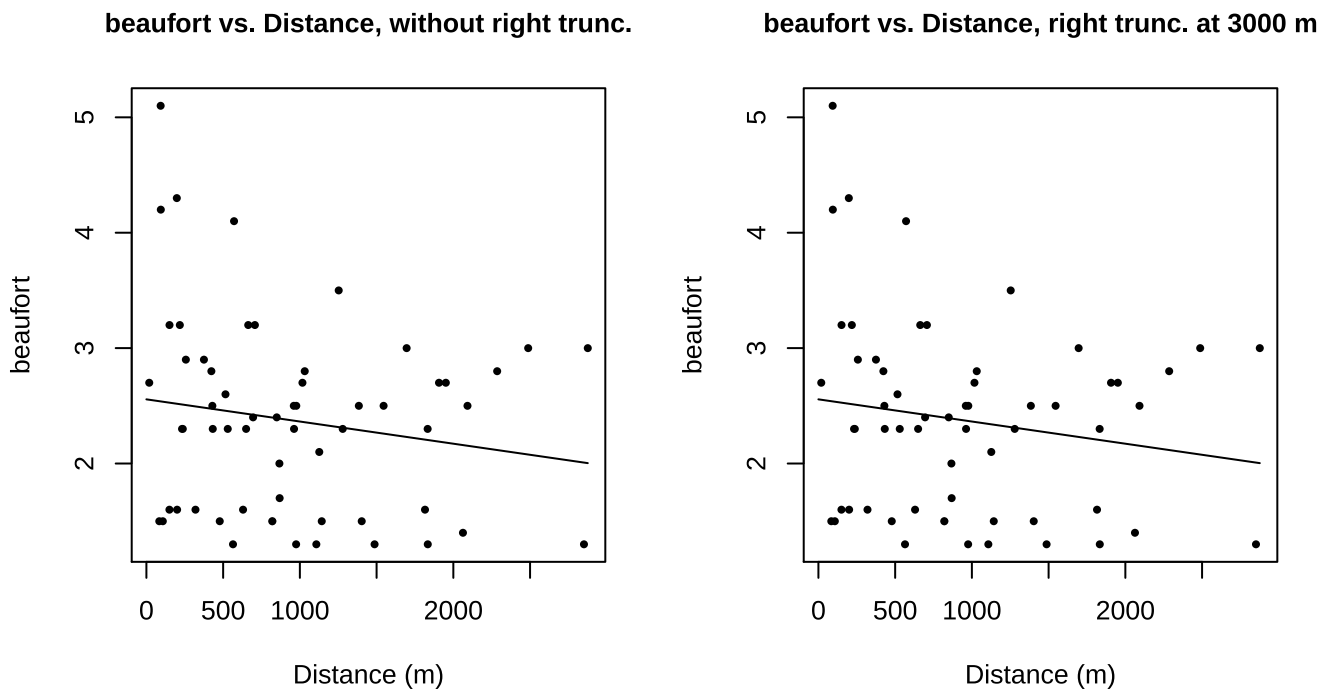

Figure 13: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

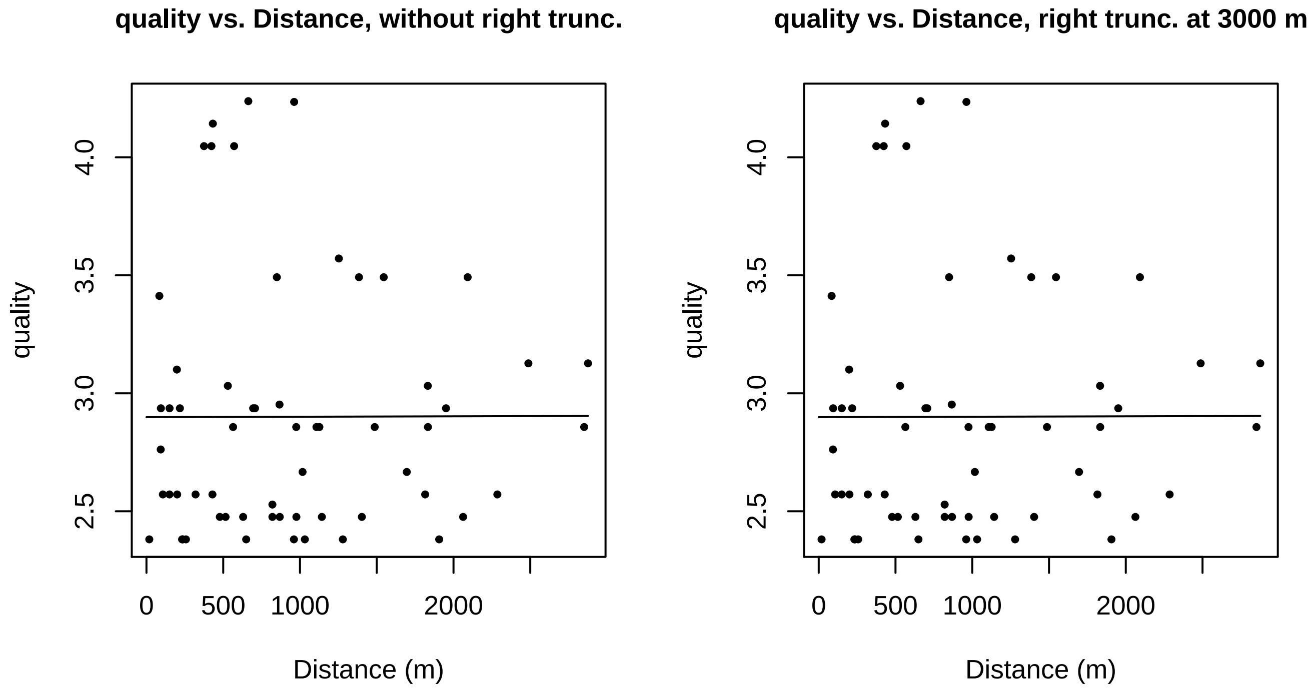

Figure 14: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

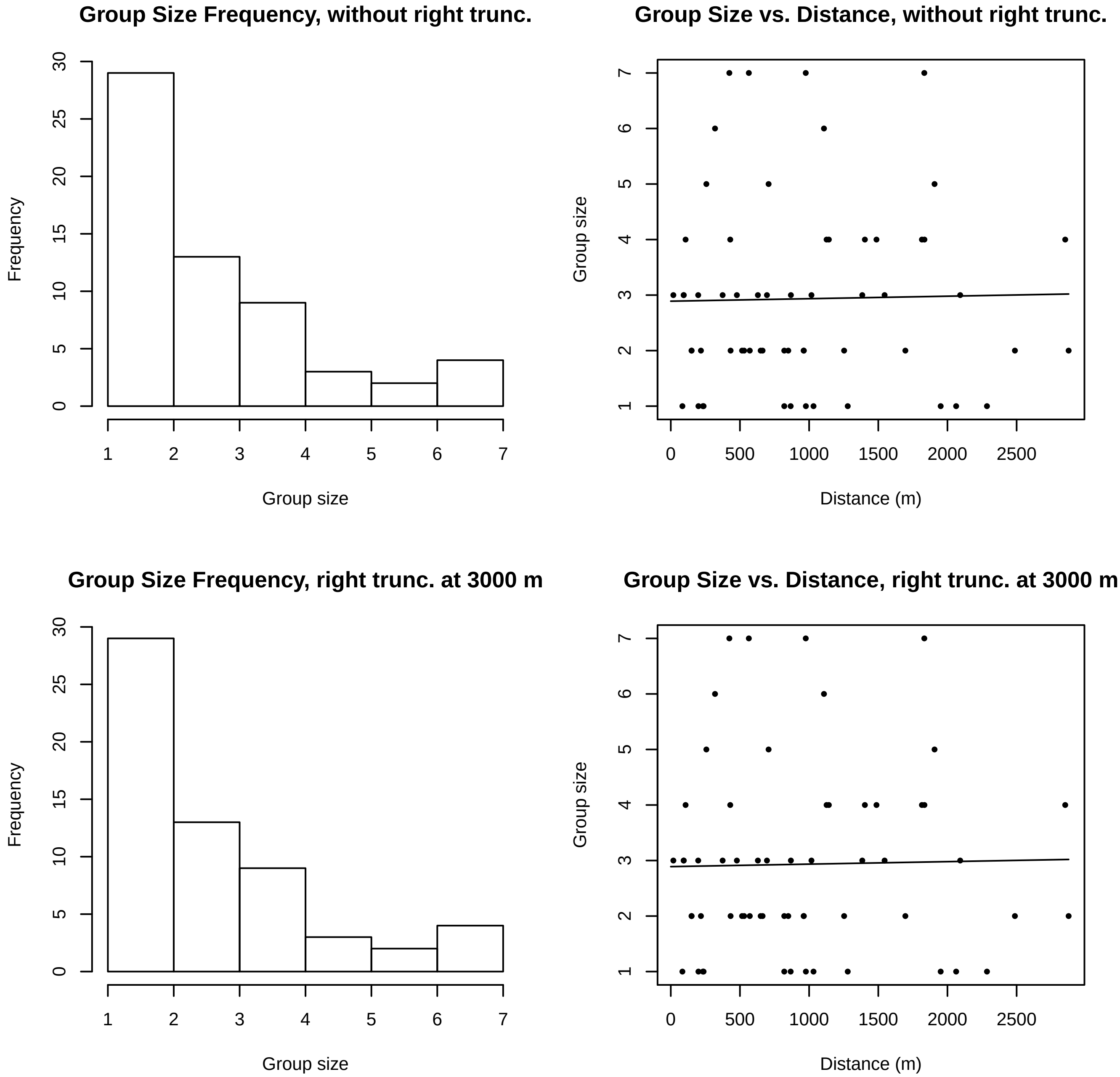

Figure 15: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

SEFSC Oregon II

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Hyperoodon ampullatus	Northern bottlenose whale	0
Mesoplodon	Beaked whale	27

Mesoplodon bidens	Sowerby's beaked whale	0
Mesoplodon densirostris	Blainville's beaked whale	2
Mesoplodon europaeus	Gervais' beaked whale	0
Mesoplodon mirus	True's beaked whale	0
Ziphiidae	Unidentified beaked whale	20
Ziphius cavirostris	Cuvier's beaked whale	12
Total		61

Table 10: Proxy species used to fit detection functions for SEFSC Oregon II. The number of sightings, n, is before truncation.

The sightings were right truncated at 3000m.

Covariate	Description
beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 11: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn			size	Yes	0.00	1462
hn			quality, size	Yes	1.87	1464
hn			beaufort, size	Yes	1.93	1439
hn			beaufort, quality, size	Yes	3.81	1443
hr			size	Yes	4.43	1836
hr			beaufort, size	Yes	6.06	1870
hr			quality, size	Yes	6.30	1857
hr			beaufort, quality, size	Yes	7.97	1878
hn			beaufort	Yes	12.65	1399
hn			beaufort, quality	Yes	12.80	1386
hn	cos	2		Yes	13.73	1009
hr				Yes	13.84	838
hr			quality	Yes	14.86	818
hr			beaufort	Yes	14.96	1086
hr	poly	2		Yes	15.56	773
hr	poly	4		Yes	15.59	804
hr			beaufort, quality	Yes	16.30	895
hn	cos	3		Yes	16.79	1027

hn			quality	Yes	17.29	1423
hn				Yes	19.39	1390
hn	herm	4		No		

Table 12: Candidate detection functions for SEFSC Oregon II. The first one listed was selected for the density model.

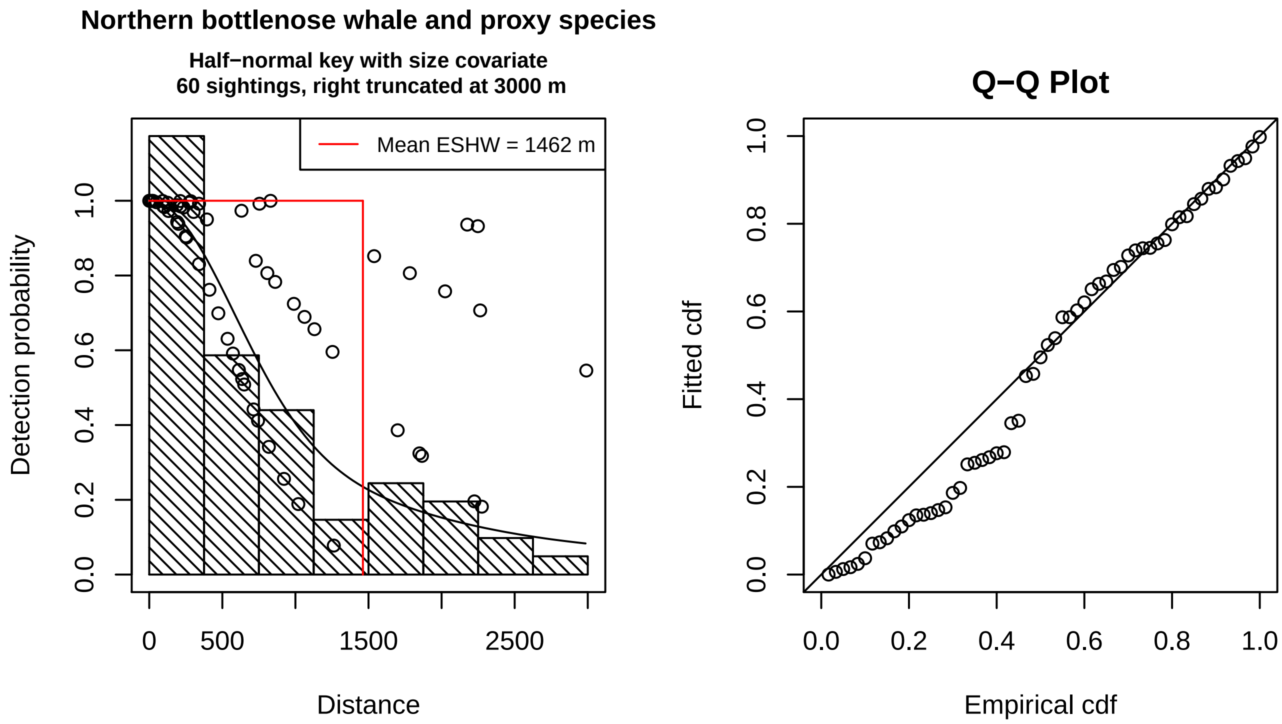

Figure 16: Detection function for SEFSC Oregon II that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  60
Distance range         :  0  -  3000
AIC                    :  907.5102

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
             estimate        se
(Intercept) 5.5341018 0.3555926
size        0.7910821 0.2350200

                        Estimate          SE        CV
Average p              0.3665954  0.04554798 0.1242459
N in covered region 163.6681685 27.38897440 0.1673445
```

Additional diagnostic plots:

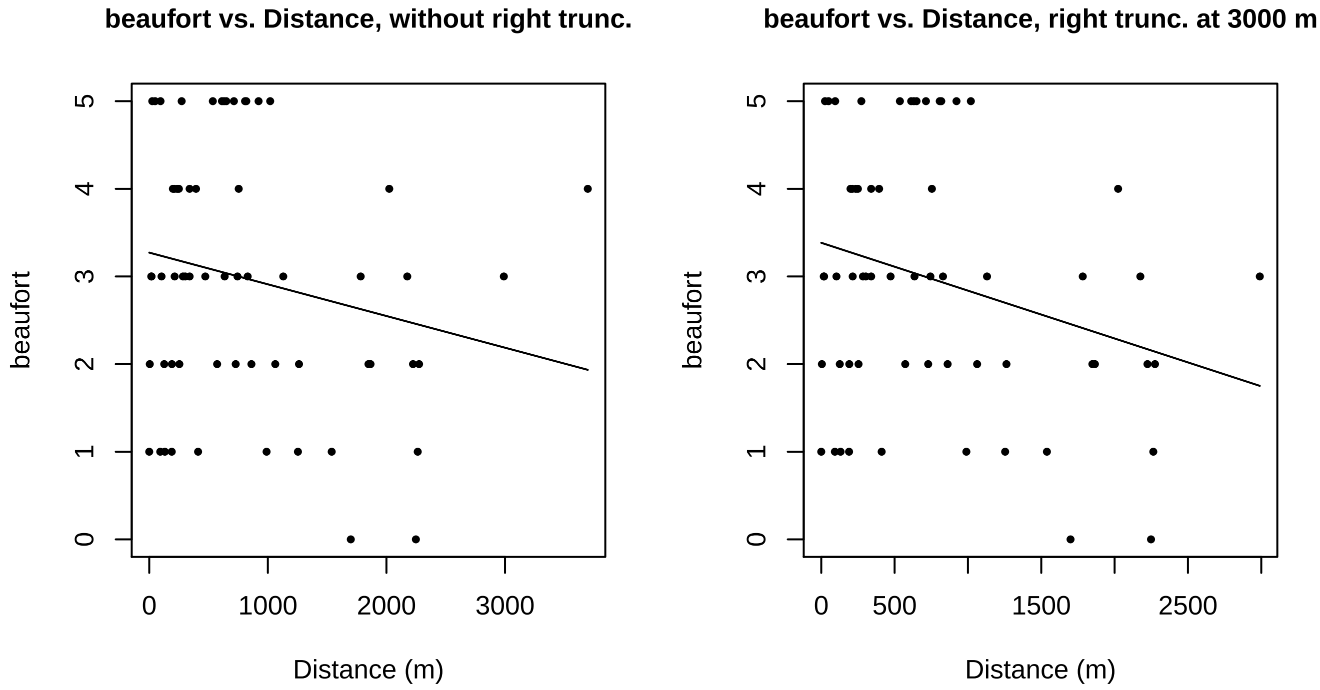

Figure 17: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

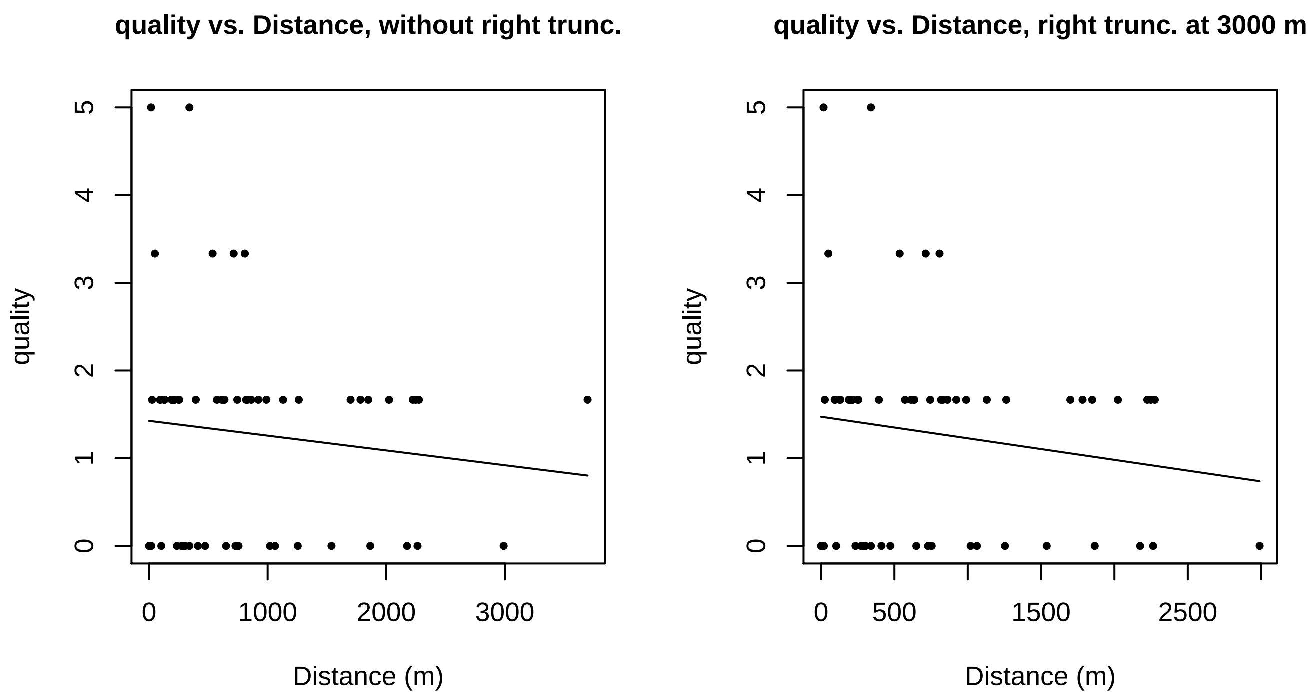

Figure 18: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

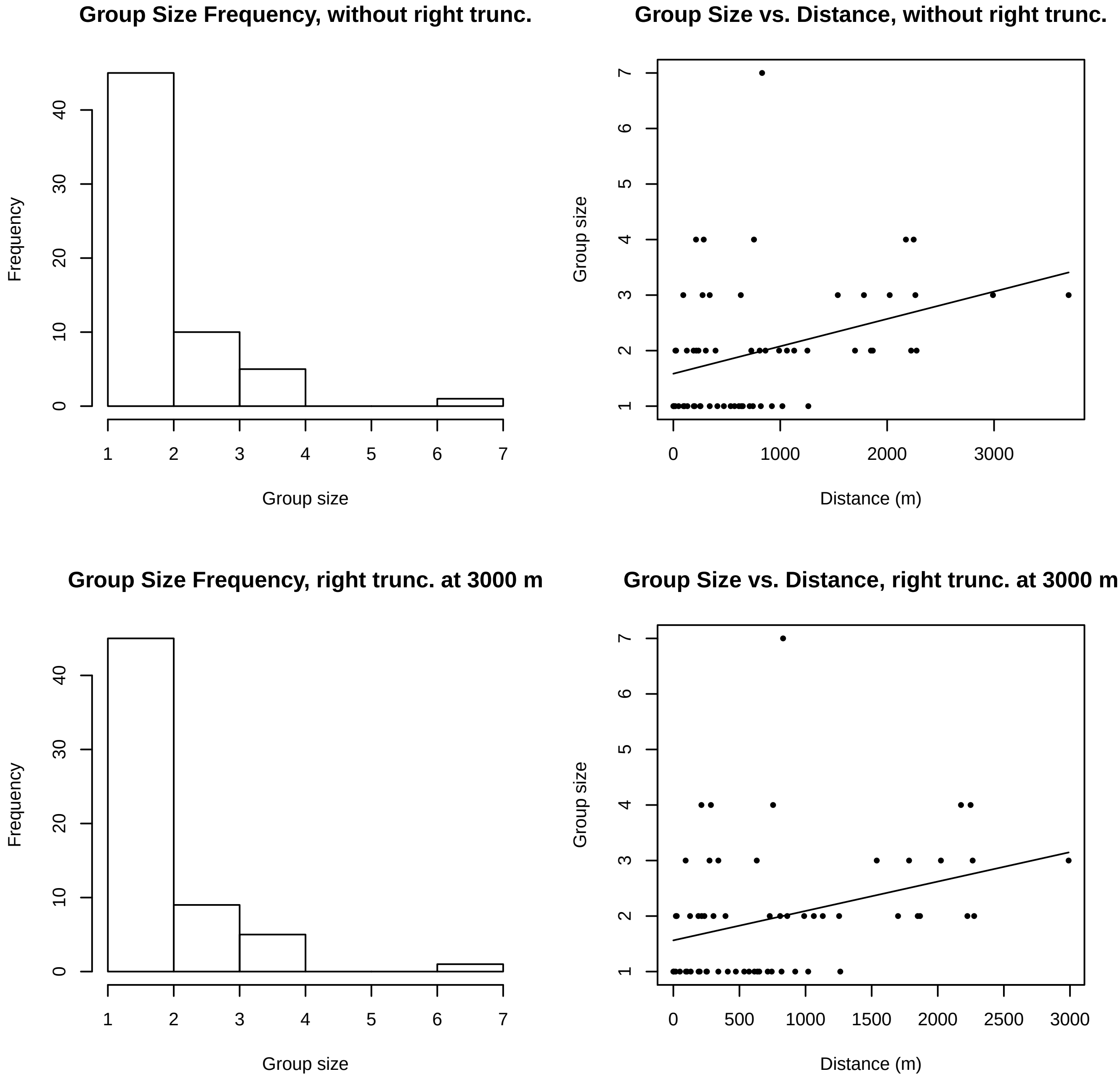

Figure 19: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

High Platforms

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Hyperoodon ampullatus	Northern bottlenose whale	0
Mesoplodon	Beaked whale	23

Mesoplodon bidens	Sowerby's beaked whale	0
Mesoplodon densirostris	Blainville's beaked whale	1
Mesoplodon europaeus	Gervais' beaked whale	1
Mesoplodon mirus	True's beaked whale	0
Ziphiidae	Unidentified beaked whale	39
Ziphius cavirostris	Cuvier's beaked whale	10
Total		74

Table 13: Proxy species used to fit detection functions for High Platforms. The number of sightings, n, is before truncation.

The sightings were right truncated at 6000m.

Covariate	Description
beaufort	Beaufort sea state.
size	Estimated size (number of individuals) of the sighted group.

Table 14: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort	Yes	0.00	2258
hr			beaufort, size	Yes	1.17	2284
hn			beaufort	Yes	1.66	2657
hr				Yes	2.76	2377
hn	cos	2		Yes	3.22	2063
hn			beaufort, size	Yes	3.45	2657
hr			size	Yes	4.10	2361
hr	poly	2		Yes	4.76	2377
hr	poly	4		Yes	4.76	2376
hn				Yes	4.87	2512
hn			size	Yes	6.25	2507
hn	cos	3		Yes	6.71	2367
hn	herm	4		No		

Table 15: Candidate detection functions for High Platforms. The first one listed was selected for the density model.

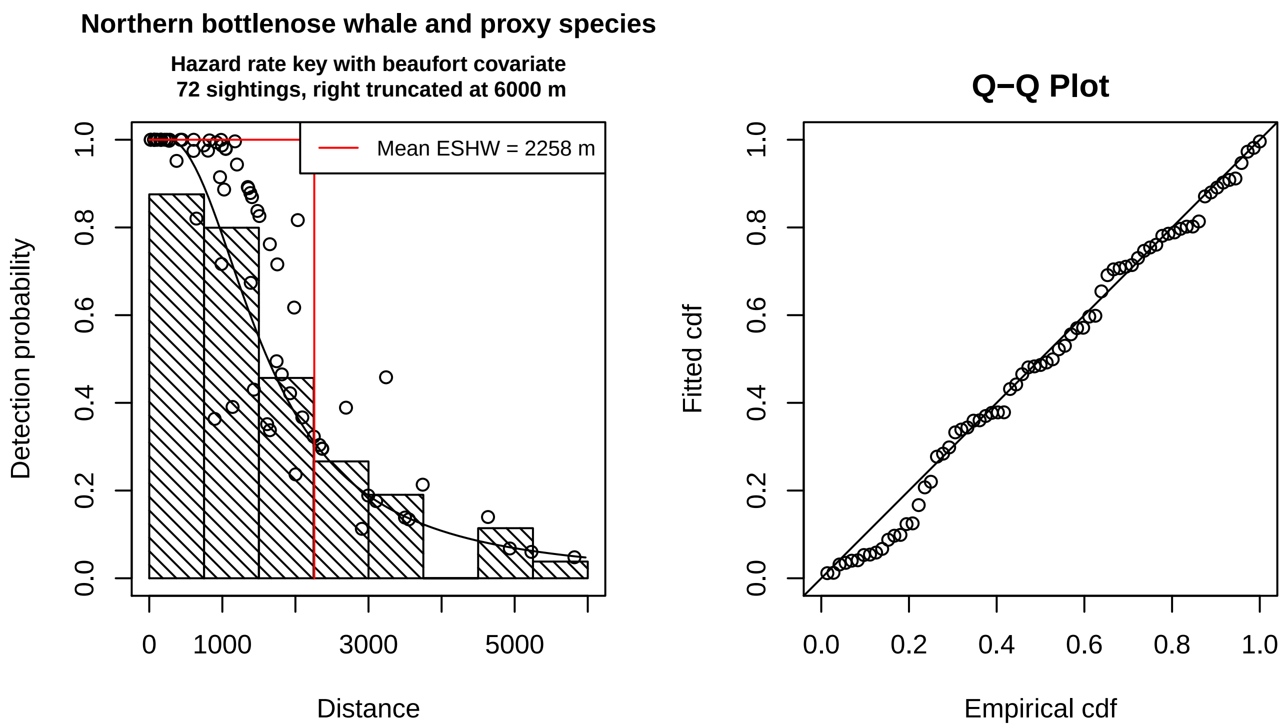

Figure 20: Detection function for High Platforms that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  72
Distance range         :  0  -  6000
AIC                    :  1194.489

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  7.8592780 0.3569027
beaufort    -0.2855186 0.1289843

Shape parameters:
            estimate        se
(Intercept) 0.780544 0.2484679

                        Estimate          SE        CV
Average p              0.3425961  0.05166303 0.1507987
N in covered region 210.1600272 37.79311295 0.1798302
```

Additional diagnostic plots:

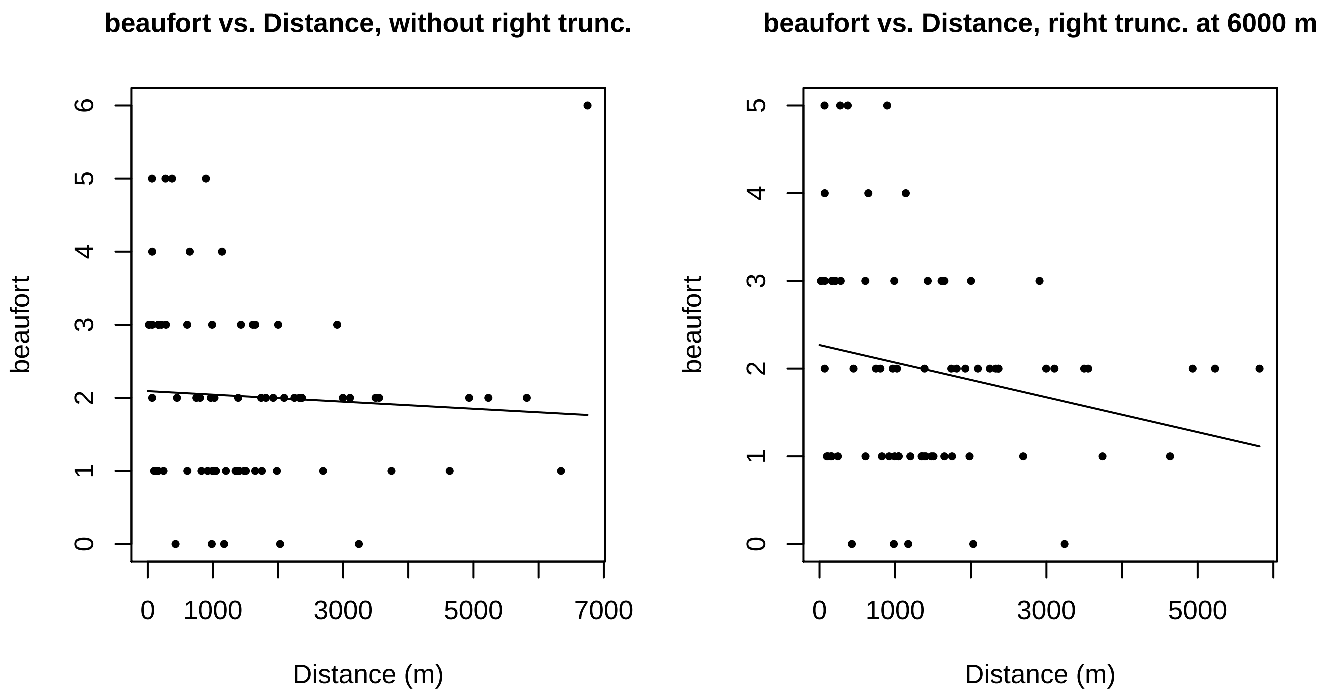

Figure 21: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

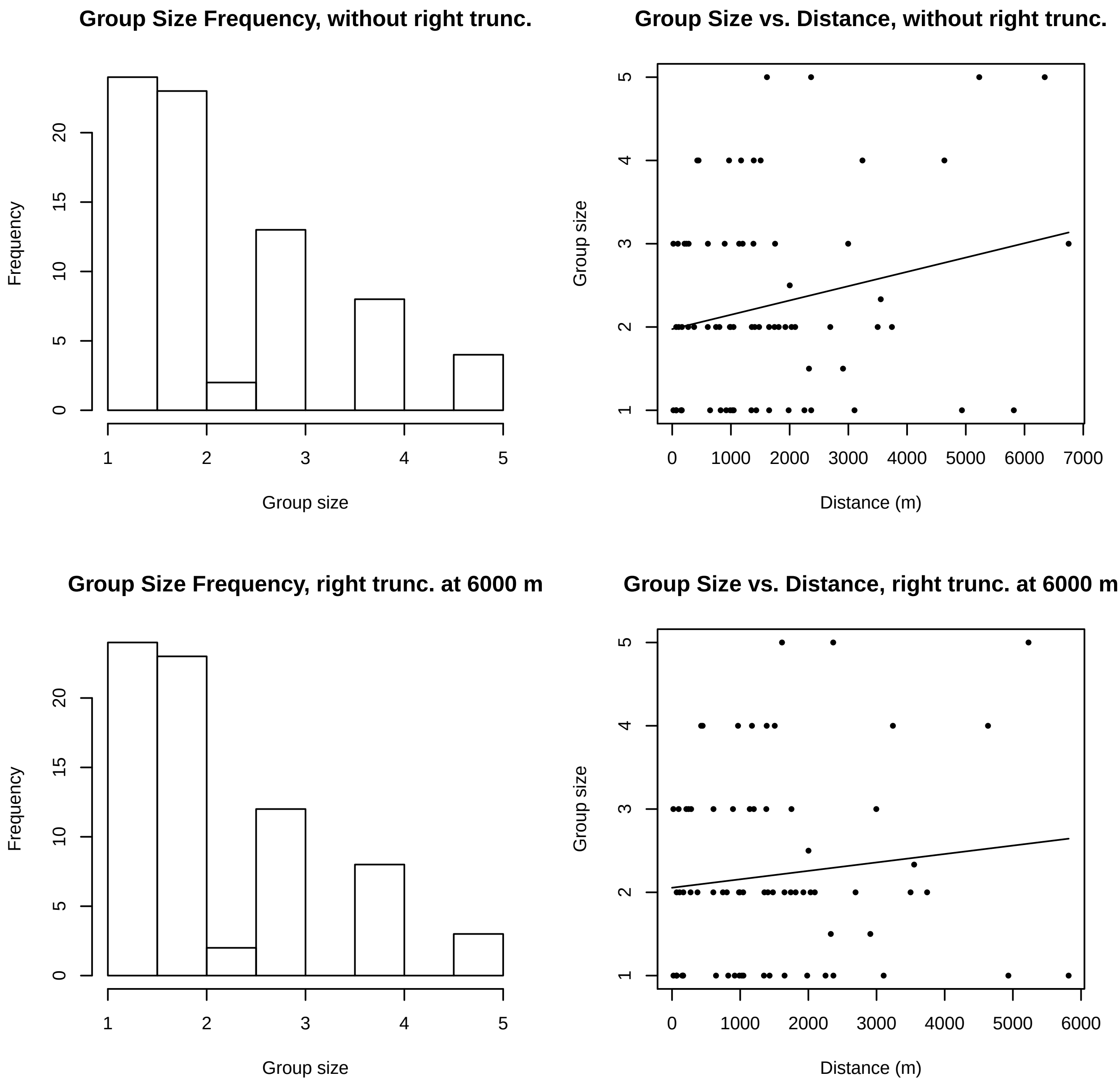

Figure 22: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Naked Eye Surveys

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Hyperoodon ampullatus	Northern bottlenose whale	0
Mesoplodon	Beaked whale	21

Mesoplodon bidens	Sowerby's beaked whale	5
Mesoplodon densirostris	Blainville's beaked whale	0
Mesoplodon europaeus	Gervais' beaked whale	0
Mesoplodon mirus	True's beaked whale	0
Ziphiidae	Unidentified beaked whale	1
Ziphius cavirostris	Cuvier's beaked whale	10
Total		37

Table 16: Proxy species used to fit detection functions for Naked Eye Surveys. The number of sightings, n, is before truncation.

The sightings were right truncated at 1500m.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr				Yes	0.00	439
hn	cos	2		Yes	0.56	445
hr	poly	2		Yes	1.95	380
hr	poly	4		Yes	2.00	435
hn				Yes	2.39	551
hn	cos	3		Yes	2.44	424
hn	herm	4		No		

Table 17: Candidate detection functions for Naked Eye Surveys. The first one listed was selected for the density model.

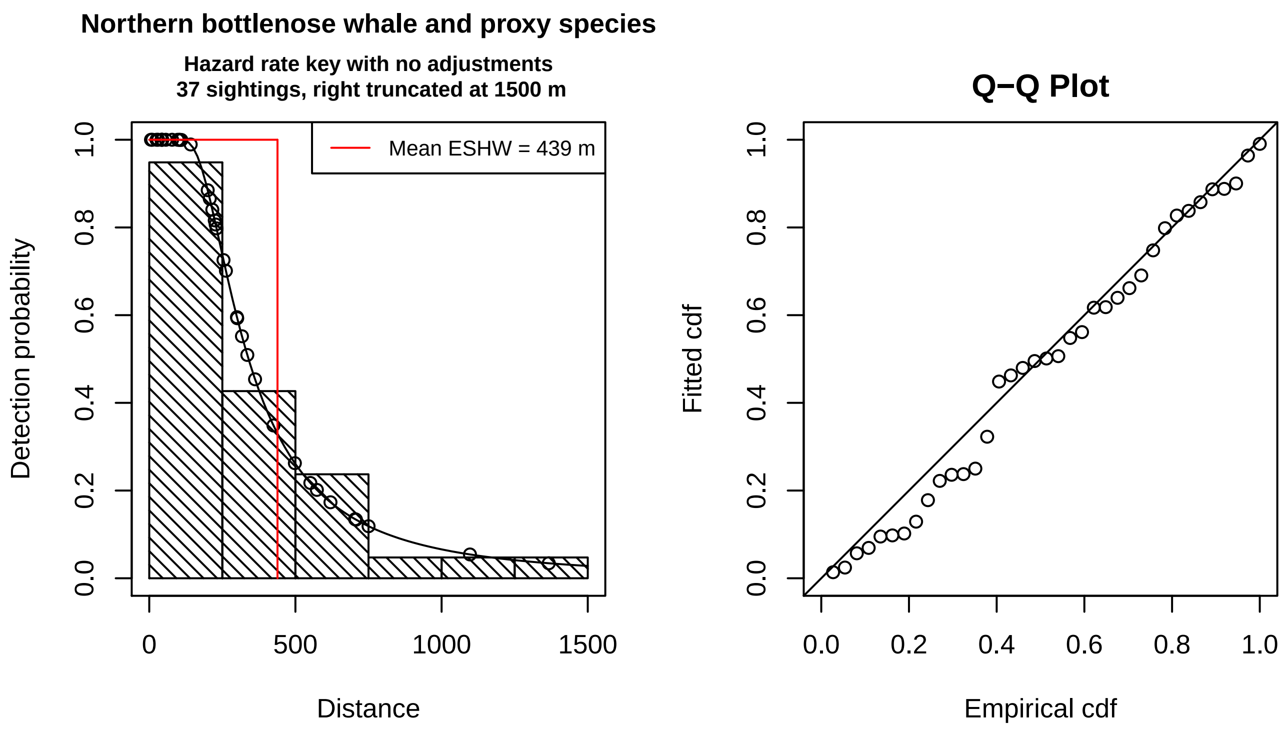

Figure 23: Detection function for Naked Eye Surveys that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  37
Distance range         :  0  -  1500
AIC                    :  503.3464

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
            estimate        se
(Intercept) 5.657308 0.3088619

Shape parameters:
             estimate        se
(Intercept) 0.7645473 0.2807783

                        Estimate          SE        CV
Average p              0.2924246  0.05911418 0.2021519
N in covered region 126.5283456 30.99015713 0.2449266
```

Aerial Surveys

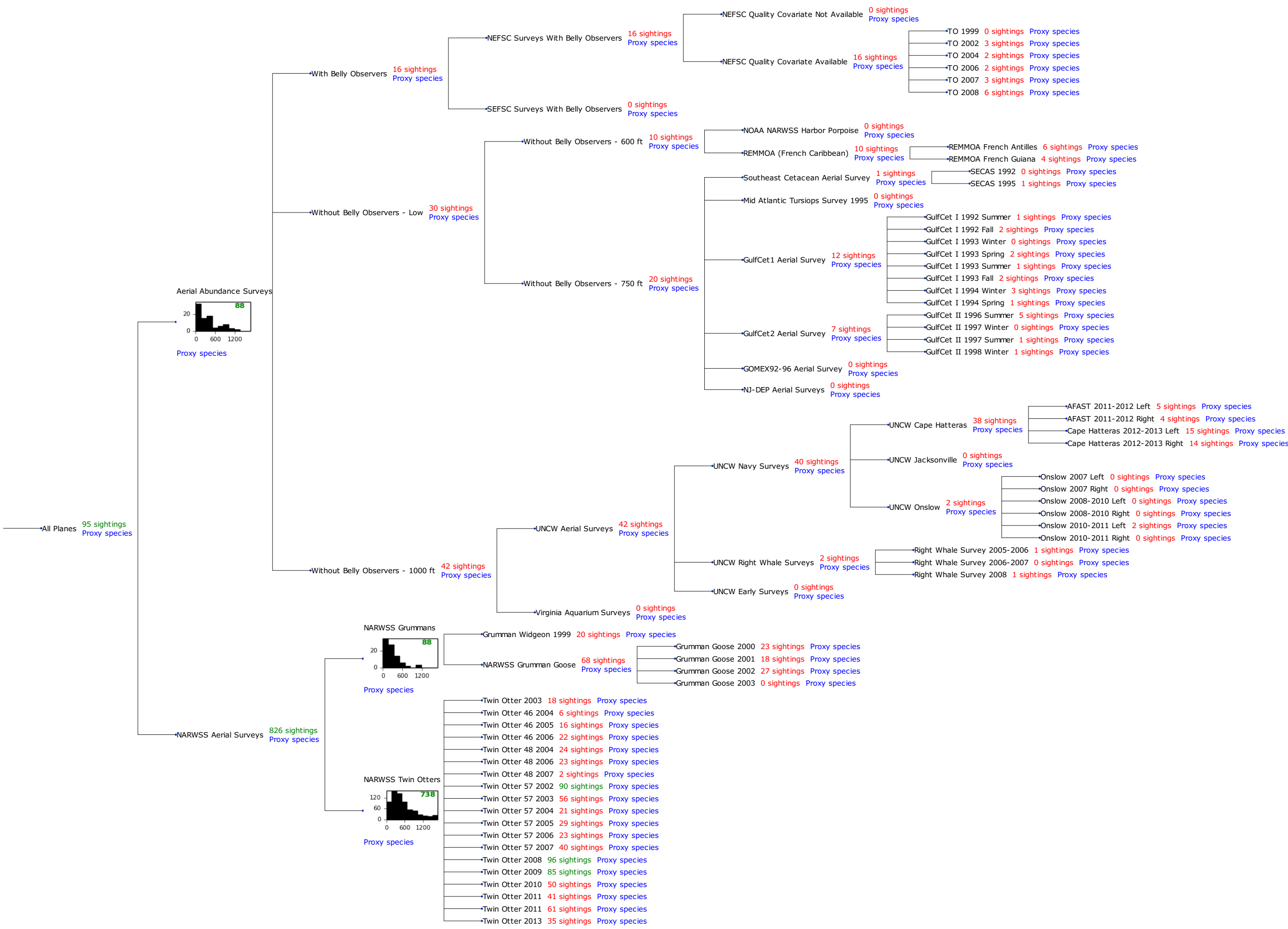

Figure 24: Detection hierarchy for aerial surveys

Aerial Abundance Surveys

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Hyperoodon ampullatus	Northern bottlenose whale	0
Mesoplodon	Beaked whale	44
Mesoplodon bidens	Sowerby's beaked whale	0
Mesoplodon densirostris	Blainville's beaked whale	0
Mesoplodon europaeus	Gervais' beaked whale	3
Mesoplodon mirus	True's beaked whale	1
Ziphiidae	Unidentified beaked whale	17
Ziphius cavirostris	Cuvier's beaked whale	23
Total		88

Table 18: Proxy species used to fit detection functions for Aerial Abundance Surveys. The number of sightings, n, is before truncation.

The sightings were right truncated at 1500m.

Covariate	Description
beaufort	Beaufort sea state.
size	Estimated size (number of individuals) of the sighted group.

Table 19: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn	cos	3		Yes	0.00	478
hr	poly	4		Yes	2.16	479
hr	poly	2		Yes	2.50	472
hn	cos	2		Yes	3.05	544
hr				Yes	3.73	492
hn				Yes	4.42	647
hr			size	Yes	5.70	495
hn			beaufort	Yes	6.21	647
hn	herm	4		No		
hr			beaufort	No		
hn			size	No		
hn			beaufort, size	No		
hr			beaufort, size	No		

Table 20: Candidate detection functions for Aerial Abundance Surveys. The first one listed was selected for the density model.

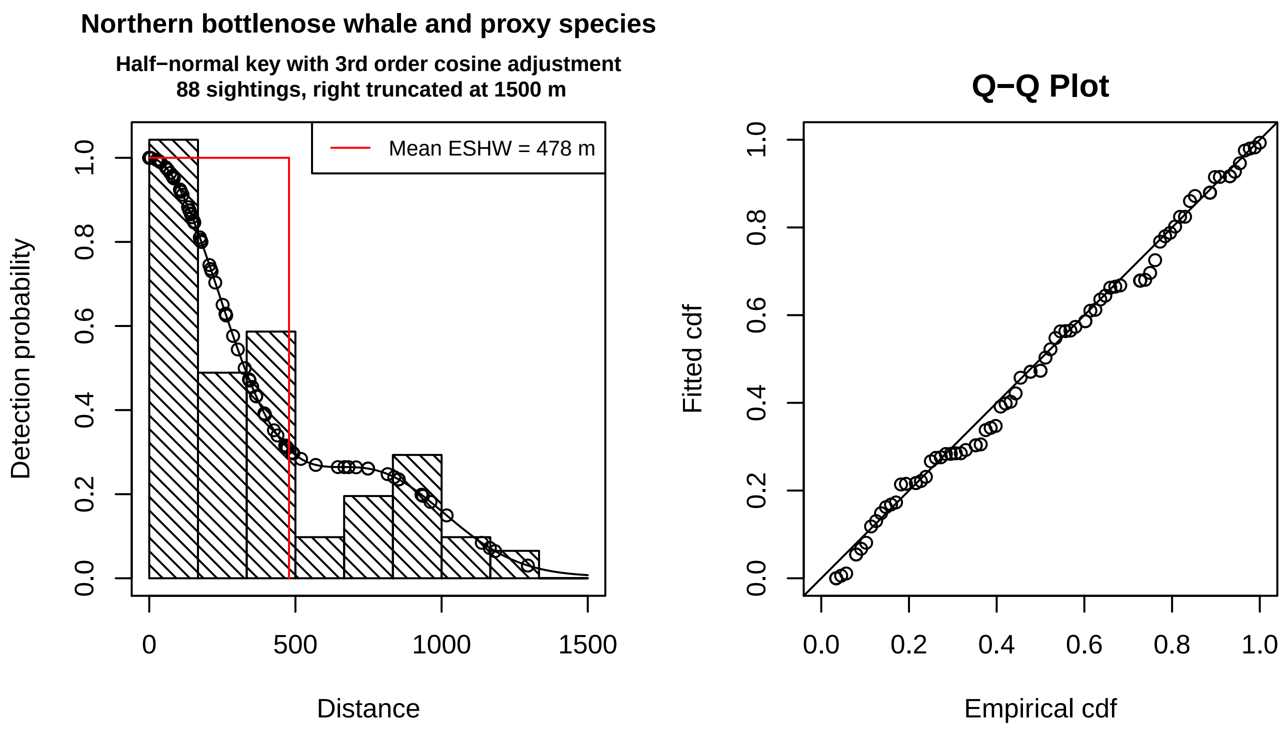

Figure 25: Detection function for Aerial Abundance Surveys that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  88
Distance range         :  0  -  1500
AIC                    :  1221.593

Detection function:
 Half-normal key function with cosine adjustment term of order 3

Detection function parameters
Scale Coefficients:
            estimate         se
(Intercept) 6.257817 0.07793328

Adjustment term parameter(s):
              estimate        se
cos, order 3 0.3665265 0.1373015


Monotonicity constraints were enforced.
                        Estimate          SE        CV
Average p              0.3186994  0.03987822 0.1251280
N in covered region 276.1222563 42.23774068 0.1529675

Monotonicity constraints were enforced.
```

Additional diagnostic plots:

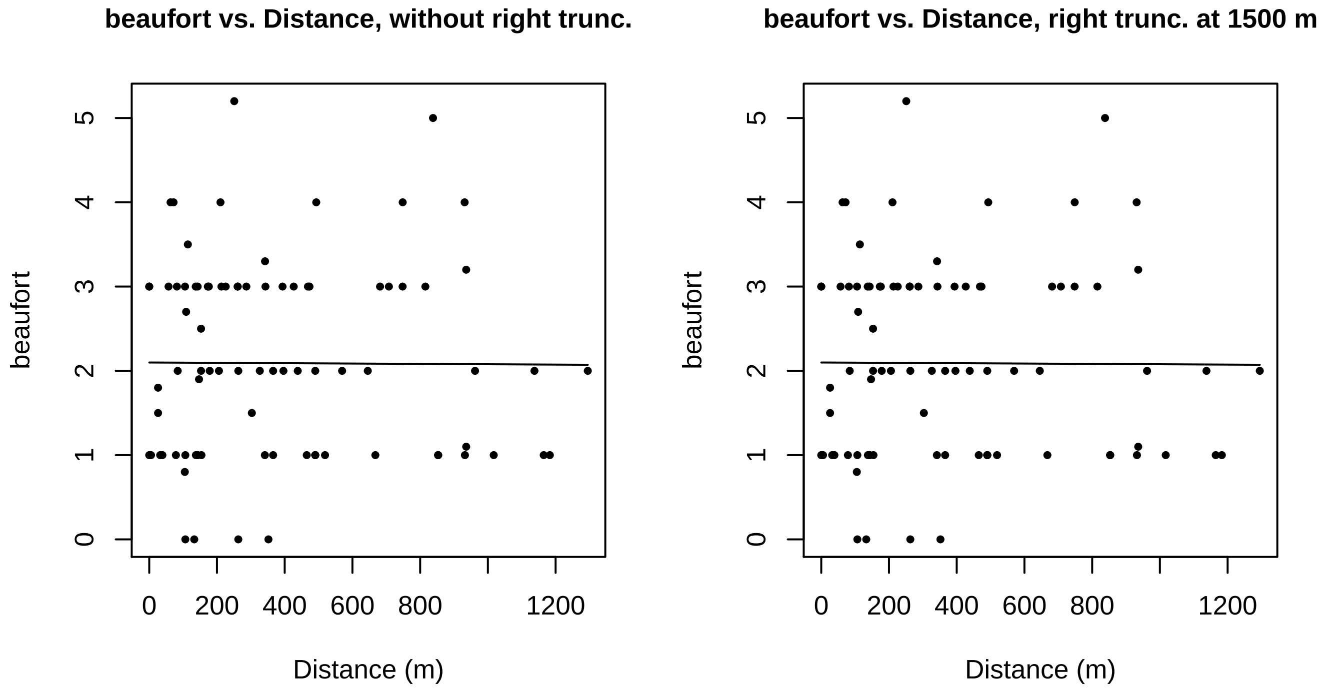

Figure 26: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

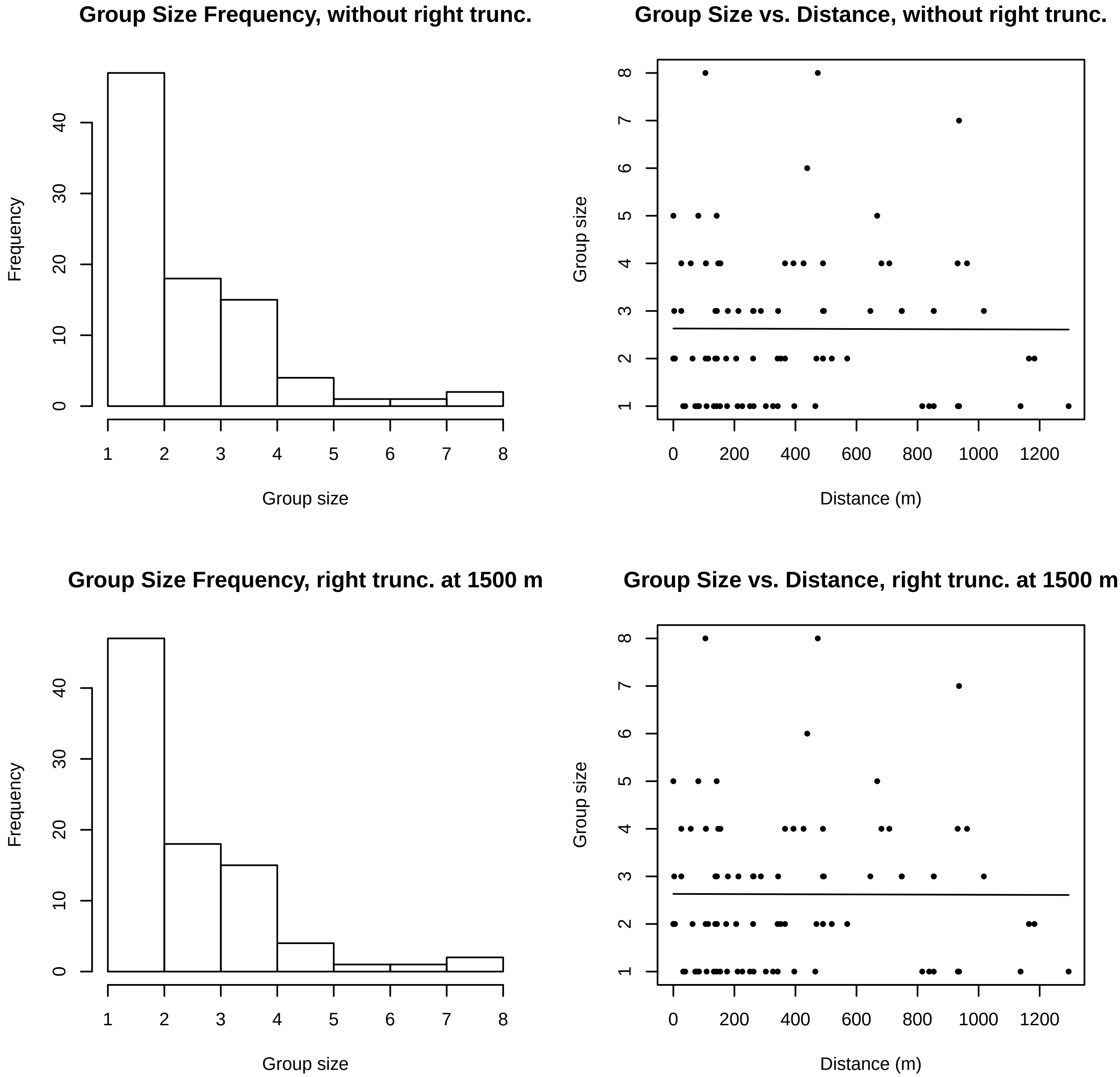

Figure 27: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NARWSS Grummans

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Balaenoptera acutorostrata	Minke whale	88
Hyperoodon ampullatus	Northern bottlenose whale	0

Kogia	Pygmy or dwarf sperm whale	0
Kogia breviceps	Pygmy sperm whale	0
Kogia sima	Dwarf sperm whale	0
Mesoplodon	Beaked whale	0
Mesoplodon bidens	Sowerby's beaked whale	0
Mesoplodon densirostris	Blainville's beaked whale	0
Mesoplodon europaeus	Gervais' beaked whale	0
Mesoplodon mirus	True's beaked whale	0
Ziphiidae	Unidentified beaked whale	0
Ziphius cavirostris	Cuvier's beaked whale	0
Total		88

Table 21: Proxy species used to fit detection functions for NARWSS Grummans. The number of sightings, n, is before truncation.

The sightings were right truncated at 1500m.

Covariate	Description
beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 22: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			quality	Yes	0.00	453
hr			beaufort, quality	Yes	0.77	450
hr				Yes	9.44	392
hr			beaufort	Yes	9.85	400
hn	cos	2		Yes	10.32	385
hr	poly	4		Yes	10.67	391
hr	poly	2		Yes	10.94	389
hn			quality	Yes	11.22	444
hn	cos	3		Yes	14.03	371
hn				Yes	15.50	454
hn	herm	4		No		
hn			beaufort	No		
hn			size	No		
hr			size	No		

hn	beaufort, quality	No
hn	beaufort, size	No
hr	beaufort, size	No
hn	quality, size	No
hr	quality, size	No
hn	beaufort, quality, size	No
hr	beaufort, quality, size	No

Table 23: Candidate detection functions for NARWSS Grummans. The first one listed was selected for the density model.

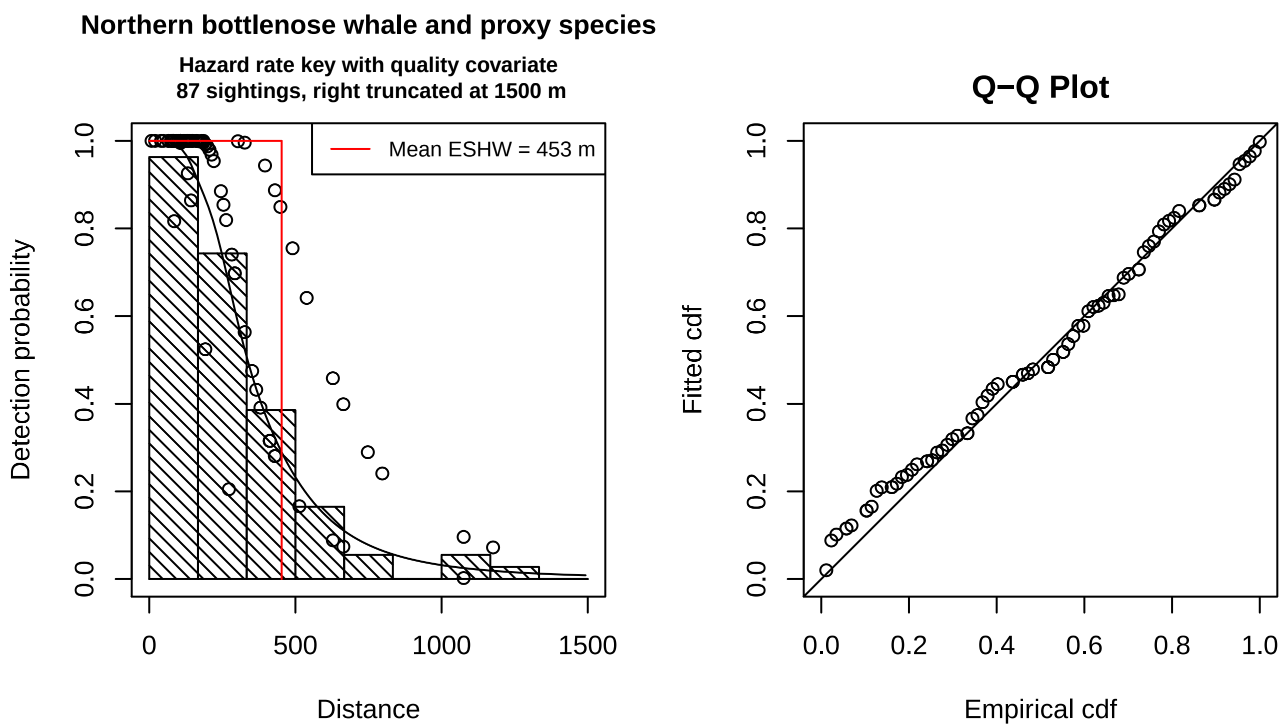

Figure 28: Detection function for NARWSS Grummans that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  87
Distance range         :  0  -  1500
AIC                    :  1138.005

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.2965502 0.1595186
quality     -0.4514297 0.1184985
```

```
Shape parameters:
            estimate        se
(Intercept) 1.209062 0.1735281

                        Estimate          SE        CV
Average p              0.2659991  0.02922489 0.1098684
N in covered region 327.0687298 47.30717620 0.1446399
```

Additional diagnostic plots:

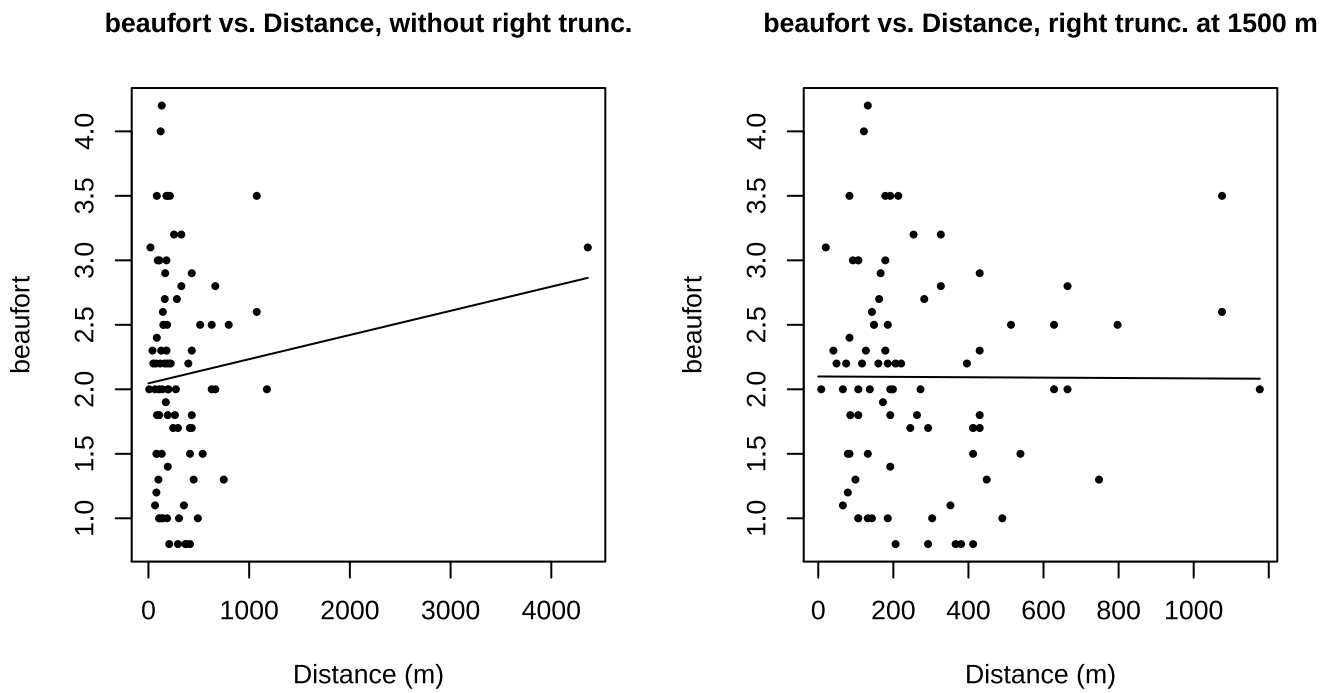

Figure 29: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

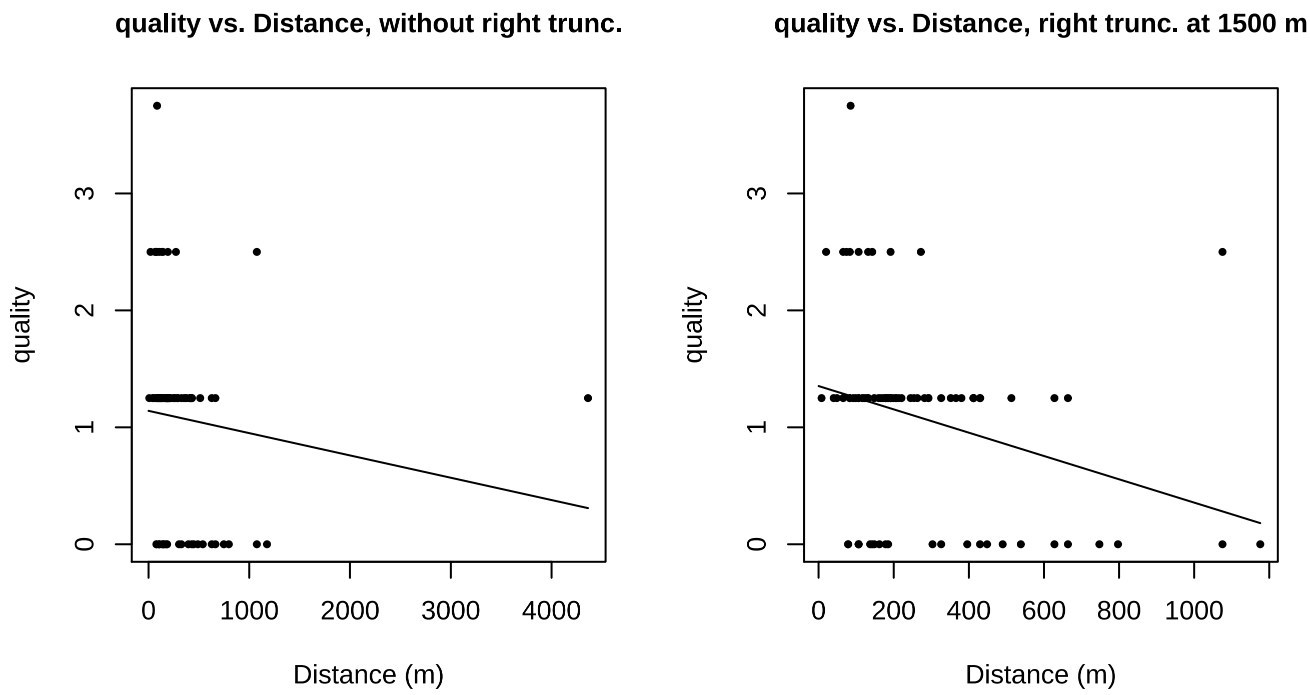

Figure 30: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

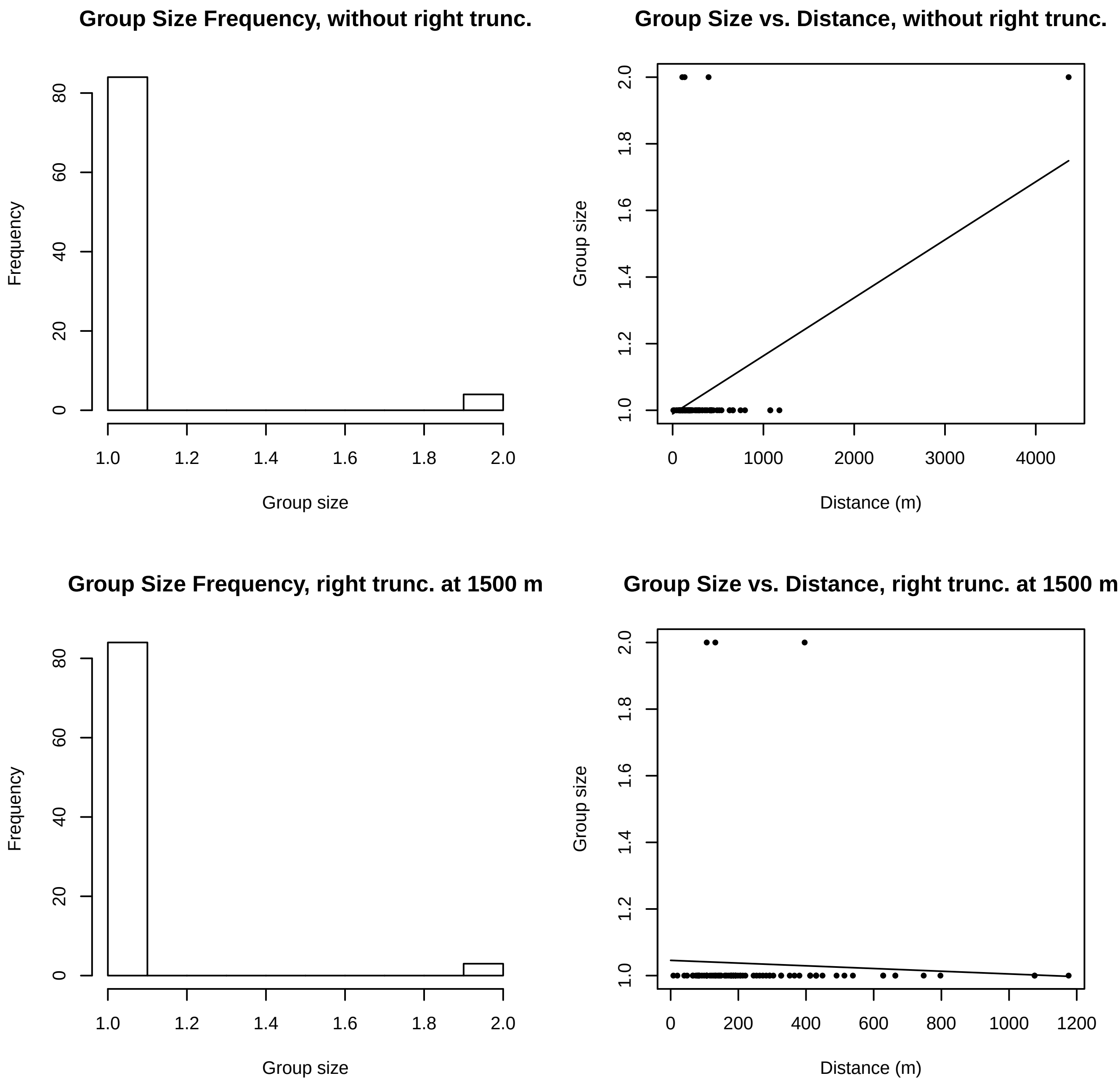

Figure 31: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NARWSS Twin Otters

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These “proxy species” are listed below.

Reported By Observer	Common Name	n
Balaenoptera acutorostrata	Minke whale	731
Hyperoodon ampullatus	Northern bottlenose whale	0

Kogia	Pygmy or dwarf sperm whale	0
Kogia breviceps	Pygmy sperm whale	0
Kogia sima	Dwarf sperm whale	0
Mesoplodon	Beaked whale	7
Mesoplodon bidens	Sowerby's beaked whale	0
Mesoplodon densirostris	Blainville's beaked whale	0
Mesoplodon europaeus	Gervais' beaked whale	0
Mesoplodon mirus	True's beaked whale	0
Ziphiidae	Unidentified beaked whale	0
Ziphius cavirostris	Cuvier's beaked whale	0
Total		738

Table 24: Proxy species used to fit detection functions for NARWSS Twin Otters. The number of sightings, n, is before truncation.

The sightings were right truncated at 2000m. Due to a reduced frequency of sightings close to the trackline that plausibly resulted from the behavior of the observers and/or the configuration of the survey platform, the sightings were left truncted as well. Sightings closer than 107 m to the trackline were omitted from the analysis, and it was assumed that the the area closer to the trackline than this was not surveyed. This distance was estimated by inspecting histograms of perpendicular sighting distances. The vertical sighting angles were heaped at 10 degree increments up to 80 degrees and 1 degree increments thereafter, so the candidate detection functions were fitted using linear bins scaled accordingly.

Covariate	Description
beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 25: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn	cos	2		Yes	0.00	599
hr				Yes	2.34	683
hr			beaufort	Yes	3.88	687
hr			quality	Yes	3.94	677
hr	poly	4		Yes	3.96	667
hr	poly	2		Yes	3.97	660
hr			size	Yes	4.06	684
hr			beaufort, quality	Yes	5.56	681
hr			beaufort, size	Yes	5.56	687
hr			quality, size	Yes	5.68	678
hr			beaufort, quality, size	Yes	7.26	682

hn	cos	3		Yes	27.27	670
hn				Yes	29.24	772
hn	herm	4		Yes	30.17	770
hn			beaufort	Yes	30.57	772
hn			size	Yes	31.02	772
hn			quality	Yes	31.22	772
hn			beaufort, size	Yes	32.38	772
hn			quality, size	Yes	33.01	772
hn			beaufort, quality	No		
hn			beaufort, quality, size	No		

Table 26: Candidate detection functions for NARWSS Twin Otters. The first one listed was selected for the density model.

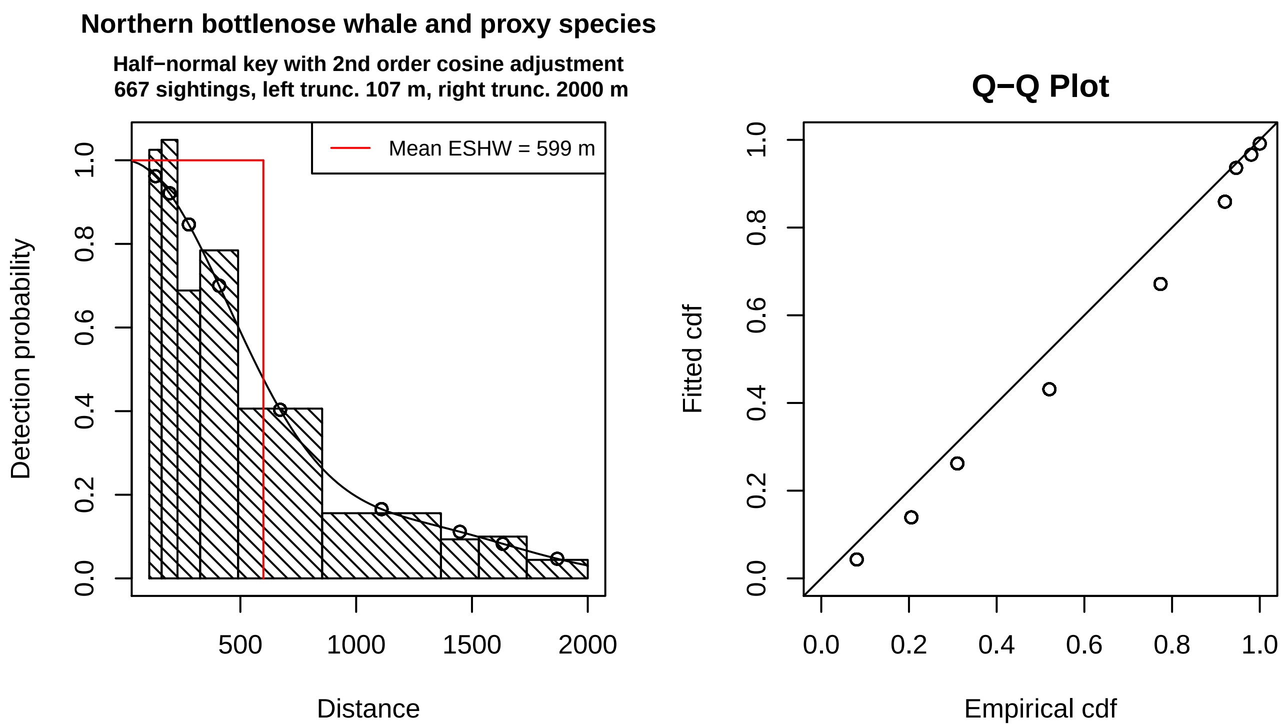

Figure 32: Detection function for NARWSS Twin Otters that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  667
Distance range         :  106.5979  -  2000
AIC                    :  2606.934

Detection function:
 Half-normal key function with cosine adjustment term of order 2
```

```
Detection function parameters
Scale Coefficients:
             estimate         se
(Intercept) 6.630948 0.03193456

Adjustment term parameter(s):
               estimate        se
cos, order 2 0.3626816 0.0605525


Monotonicity constraints were enforced.
                        Estimate           SE         CV
Average p              0.2996382   0.01430097 0.04772748
N in covered region 2226.0181079 128.41500922 0.05768821

Monotonicity constraints were enforced.
```

Additional diagnostic plots:

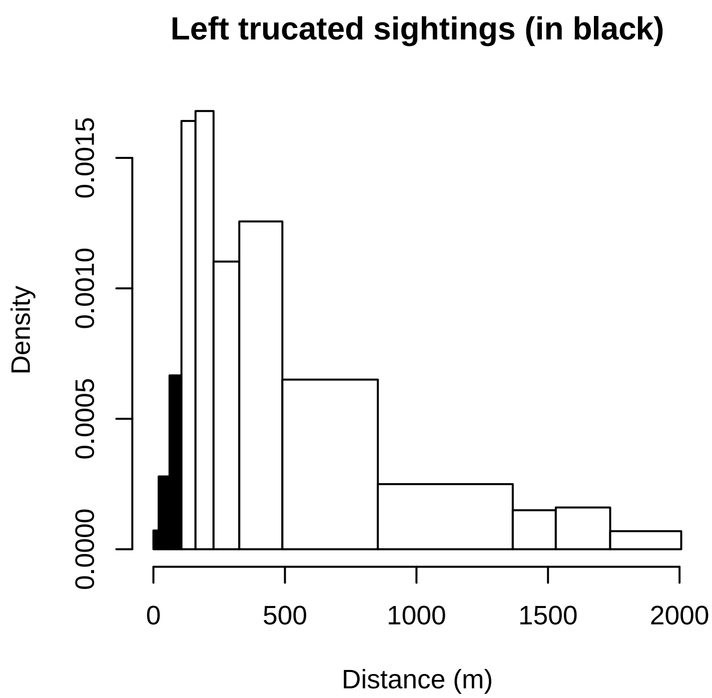

Figure 33: Density of sightings by perpendicular distance for NARWSS Twin Otters. Black bars on the left show sightings that were left truncated.

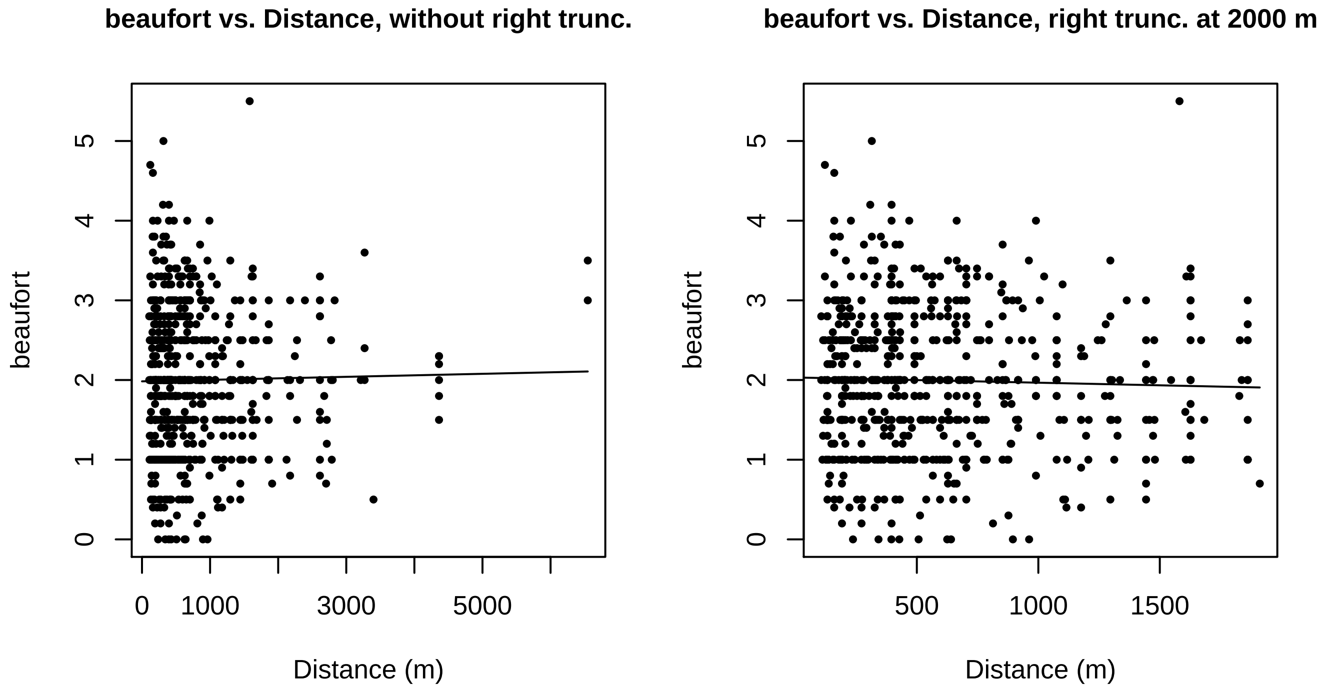

Figure 34: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

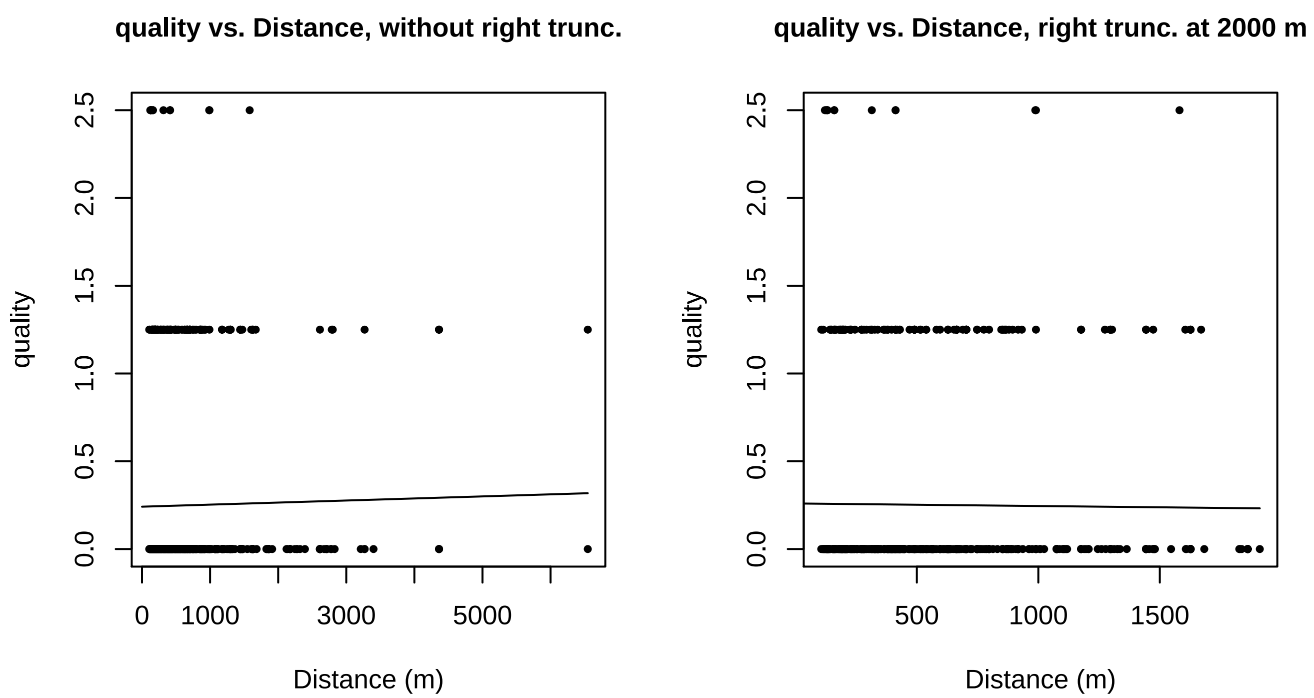

Figure 35: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

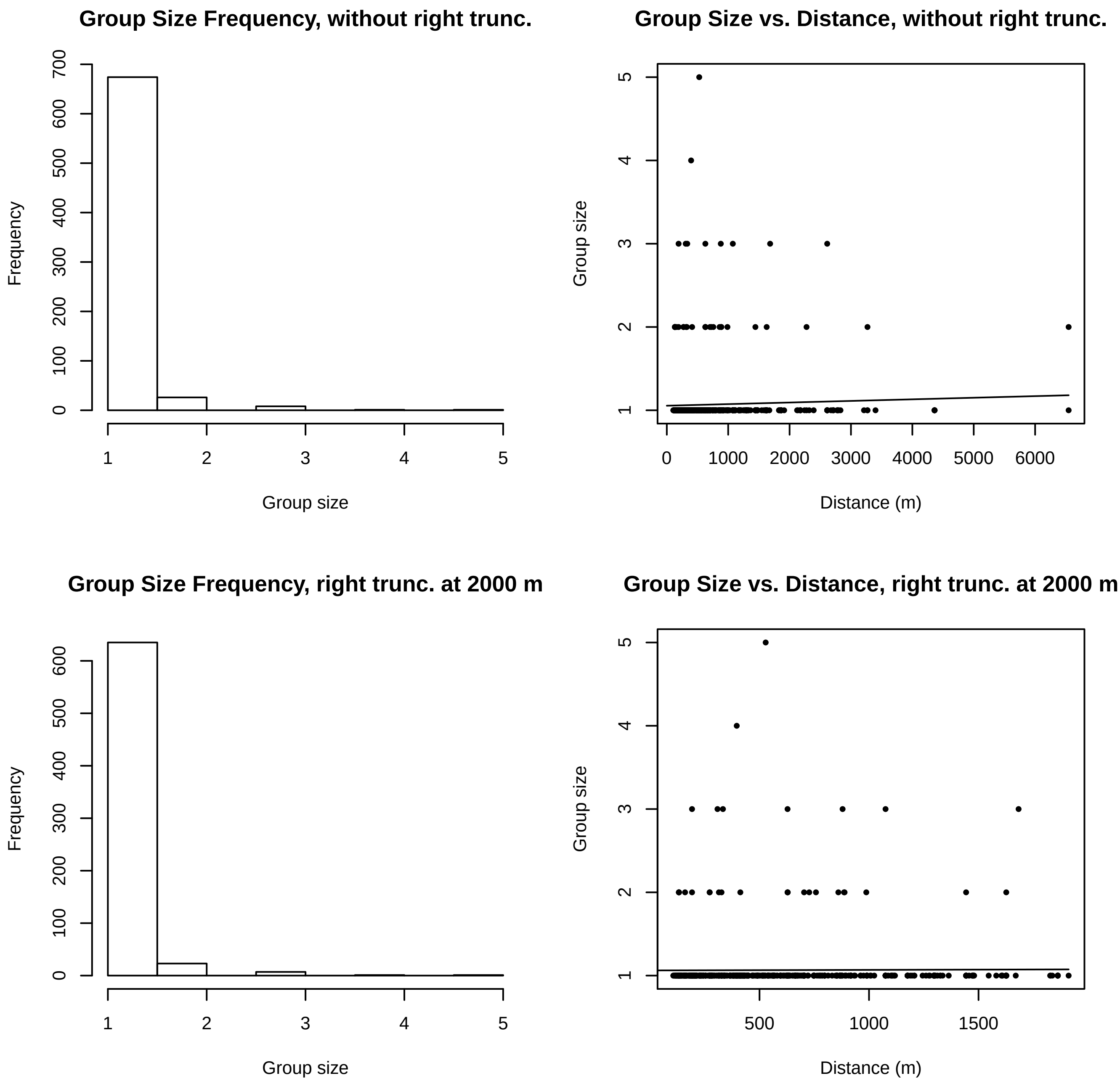

Figure 36: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

g(0) Estimates

Platform	Surveys	Group Size	*g(0)*	Biases Addressed	Source
Shipboard	All	Any	0.49	Perception	Palka (2006)
Shipboard	NEFSC Endeavor	Any	0.49	Perception	Palka (2006)
Aerial	All	Any	0.187	Availability	Hooker et al. (2009)

Table 27: Estimates of *g(0)* used in this density model.

Palka (2006) provided a survey-specific, species-specific g(0) estimate (0.49) for northern bottlenose whales sighted on NOAA NEFSC's 2004 Endeavor shipboard survey. This survey used a dual-team methodology to account for perception bias. It did not account for availability bias (Palka 2005b). We used Palka's g(0) estimate for the lower team, which was the primary team and the one for which we had sightings.

Similar to other beaked whales, northern bottlenose whales are a long-diving species for which availability bias could be significant, as animals might be submerged for a substantial proportion of the time that their surface position would visible to transiting shipboard observers. Barlow (1999) built a simulation model for g(0) that accounted for both availability and perception bias for long-diving animals observed on shipboard surveys that utilized 25x binoculars. He reported g(0) estimates of 0.23 and 0.45 for Ziphius cavirostris (Cuvier's beaked whale) and a group of several species of the Mesoplodon genus, respectively. While he did not report an estimate for bottlenose whales, we considered the possibility of using his Z. cavirostris or Mesoplodon spp. estimate as a substitute, as follows.

First, using the median durations of long dives and surfacing series reported by Barlow (his Table 3), we estimated that his Z. cavirostris and Mesoplodon spp. spent 6.8% and 10.7% of their time at the surface. His data were based on dive behavior observed visually during NOAA research cruises. Next, we computed time- at-surface percentages for two Z. cavirostris and two Mesoplodon densirostris monitored with time depth recorders (Baird et al. 2006, Baird et al. 2008), as reported by Hooker et al. (2009). Using the mean dive and surface interval durations for all dives listed in Table 2 of Hooker et al. (n=125 for Z. cavirostris, n=431 for M. densirostris), we obtained a time-at-surface of 4.9% and 10.2%, respectively, for the two species. Finding these percentages roughly comparable to those we obtained from Barlow's data, we then computed the time-at-surface percentage for all dives reported by Hooker et al. for two northern bottlenose whales (n=179), obtaining 16.9%.

Although the data are very sparse, Hooker et al.'s northern bottlenose whales spent more time at the surface than either Z. cavirostris or M. densirostris. Despite performing the deepest dives of the three species, the northern bottlenose whales had the shortest mean dive durations for all three dives classes analyzed by Hooker et al. (see their Table 2). Together, these results suggest that northern bottlenose whales may be available at the surface more than Z. cavirostris or Mesoplodonts. Barlow estimated g(0)=0.45 for Mesoplodon spp., this might be a reasonable lower bound for g(0) for northern bottlenose whale. Given that, we opted to apply Palka's estimate of 0.49 to all shipboard surveys in our study. While this decision is based on sparse data, its effect on our model is limited: only one northern bottlenose whale was sighted on any other shipboard survey in our study (on the Abel-J in 1998).

We found no estimate of g(0) in the literature for northern bottlenose whales sighted on aerial surveys. Utilizing equation (3) of Carretta et al. (2000) (which follows Barlow et al. 1988), we computed the availability bias component of g(0) (0.187) from the mean surface and dive intervals (90.1 s and 7.40 min) for all dives recorded for two northern bottlenose whales (n=179), as reported by by Hooker et al. (2009). We did not incorporate an estimate of perception bias so our g(0) estimate is likely to be biased high. In any case, the value of g(0) for aerial surveys has no effect on our model, as no northern bottlenose whales were sighted on any of our aerial surveys.

Density Model

A recent review of northern bottlenose whale population structure in the North Atlantic reported that they are found north of approximately 37.5 N and deeper than 500m, but seem to prefer depths between 800-1800m along the continental slope (Whitehead and Hooker 2012). They are extremely uncommon or rare in waters of the U.S. Exclusive Economic Zone (Waring et al. 2009). Farther north, along the Scotian Shelf, they are more common, especially near submarine canyons known as the Gully, Shortland Canyon, and Haldimand Canyon (Wimmer and Whitehead 2004). The mean size of the Scotian Shelf population was estimated by photo identification mark-recapture methodology to be 163, including adults and immature animals (Whitehead and Wimmer 2005, Whitehead and Hooker 2012). Individuals do move between the canyons but do not appear to seasonally migrate (Wimmer and Whitehead 2004). The Scotian Shelf population appears to be genetically distinct from the two other closest known populations, in northern Labrador and northern Iceland (Dalebout et al. 2006).

The surveys in our database reported only four sightings. All were deeper than 500m and were south and east of Georges Bank. The surveys reported no sightings on the Scotian Shelf or its continental slope.

With so few sightings, we could not attempt to model abundance from environmental predictors. To reflect the findings reported in the literature, we split the study area at the 500m depth contour and along the center of the Gulf Stream (identifying its mean position from a 22 year climatology computed from Aviso daily geostrophic currents). We used the Gulf Stream as the southernmost limit of the species range rather than the latitude 37.5 N reported by Whitehead and Hooker (2012) because the Gulf Stream is the dominant oceanographic feature that divides ecological regions in the area. In the northern, off-shelf area, where the four northern bottlenose whale sightings occurred, we estimated mean density. In the southern and on-shelf area, where no sightings occurred, we assumed the species was absent. This was consistent with a compilation of sightings reported by Wimmer and Whitehead (2004).

We split the study area again at the approximate boundary between the Gulf of Maine and the Scotian Shelf. Survey effort was relatively sparse on the Scotian Shelf and our surveys reported no sightings, even though the canyons along the continental slope here are known to support a population of northern bottlenose whales, and that Canada Department of Fisheries and Oceans and others have reported sightings on the shelf itself (Wimmer and Whitehead 2004). Given the possible habitat differences between the Scotian Shelf and the area southwest of it where our sightings occurred, we elected not to offer an abundance prediction for the Scotian Shelf as part of this project.

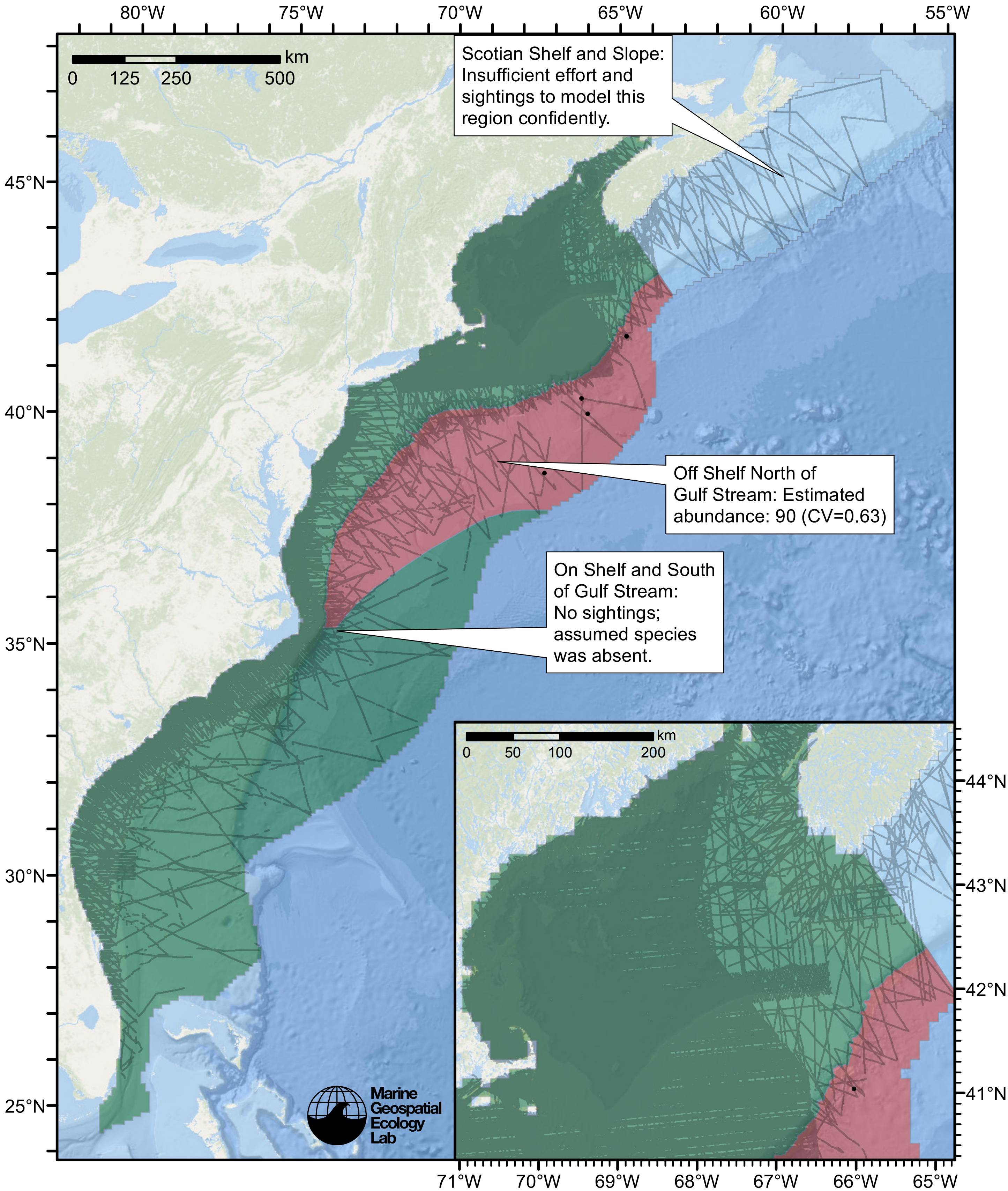

Figure 37: Northern bottlenose whale density model schematic. All sightings are shown, including those that were truncated when detection functions were fitted. The coefficient of variation (CV) underestimates the true uncertainty of our estimate, as it only incorporated the uncertainty of the GAM stage of our model. Other sources of uncertainty include the detection functions and g(0) estimates. It was not possible to incorporate these into our CV without undertaking a computationally-prohibitive bootstrap; we hope to attempt that in a future version of our model.

Abundance Estimates

Dates	Model or study	Estimated abundance	CV	Assumed g(0)=1	In our models
1995-2013	Our model	90	0.63	No	
1998-2003	Scotian Shelf population, photo ID mark-recapture (Whitehead and Wimmer 2005)	163			

Table 28: Estimated mean abundance within the study area for our model and independent estimates from NOAA and/or the scientific literature. The Dates column gives the dates to which the estimates apply. For our model, these are the years for survey data were available. Our coefficient of variation (CV) estimates are probably too low, as they only incorporated the uncertainty of the GAM stage of our models. Other sources of uncertainty include the detection functions and g(0) estimates. It was not possible to incorporate these into our CVs without undertaking a computationally-prohibitive bootstrap; we hope to attempt that in a future version of our models. The Assumed g(0)=1 column specifies whether the abundance estimate assumed that detection was certain along the survey trackline. Studies that assumed this did not correct for availability or perception bias, and therefore underestimated abundance. The In our models column specifies whether the survey data from the study was also used in our models. If not, the study provides a completely independent estimate of abundance. Note that our abundance estimates are averaged over the whole year, while the other estimates apply to specific months or seasons. Please see the Discussion section below for our evaluation of our models compared to the other estimates.

Discussion

At the time of this writing, NOAA had never produced an abundance estimate for northern bottlenose whales in the north Atlantic. The only other relevant estimate we identified in the literature was Whitehead and Wimmer's (2005) estimate of 163 animals for the Scotian Shelf population. The Scotian Shelf presumably represents better habitat than the area to which our estimate applies. We consider our estimate not implausible, as it is lower than Whitehead and Wimmer's estimate for the Scotian Shelf.

Lawson and Gosselin (2009) reported three sightings of northern bottlenose whales on the Scotian Shelf as part of the Canadian TNASS survey but did not estimate abundance. We made several attempts to contact J. Lawson but received no response. We remain hopeful that a collaboration can be established in the future, and that the Canadian TNASS data may be incorporated into a new version of our model. This may permit us to offer an abundance estimate for the Scotian Shelf.

References

Baird RW, Webster DL, McSweeney DJ, Ligon AD, Schorr GS, Barlow J (2006) Diving behaviour of Cuvier's (Ziphius cavirostris) and Blainville's (Mesoplodon densirostris) beaked whales in Hawai'i. Can J Zool 84: 1120-1128.

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