Density Model for Fin Whale (*Balaenoptera physalus*) for the U.S. Gulf of Mexico: Supplementary Report

Duke University Marine Geospatial Ecology Lab*

Model Version 1.3 - 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 Fin Whale (*Balaenoptera physalus*) for the U.S. Gulf of Mexico Version 1.3, 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	2015-01-23	Initial version.
1.1	2015-02-02	Updated the documentation. No changes to the model.
1.2	2015-05-14	Updated calculation of CVs. Switched density rasters to logarithmic breaks. No changes to the model.
1.3	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
SEFSC GOMEX92-96 Aerial Surveys	1992-1996	27	152	1
SEFSC Gulf of Mexico Shipboard Surveys, 2003-2009	2003-2009	19	1156	0
SEFSC GulfCet I Aerial Surveys	1992-1994	50	257	0
SEFSC GulfCet II Aerial Surveys	1996-1998	22	124	0
SEFSC GulfSCAT 2007 Aerial Surveys	2007-2007	18	95	0
SEFSC Oceanic CetShip Surveys	1992-2001	49	3102	0
SEFSC Shelf CetShip Surveys	1994-2001	10	707	0
Total		195	5593	1

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.

Period	Length (1000 km)	Hours	Sightings
1992-2009	195	5592	1
1998-2009	62	2679	0
% Lost	68	52	100

Table 3: Survey effort and on-effort sightings having perpendicular sighting distances. % Lost shows the percentage of effort or sightings lost by restricting the analysis to surveys performed in 1998 and later, the era in which remotely-sensed chlorophyll and derived productivity estimates are available. See Figure 1 for more information.

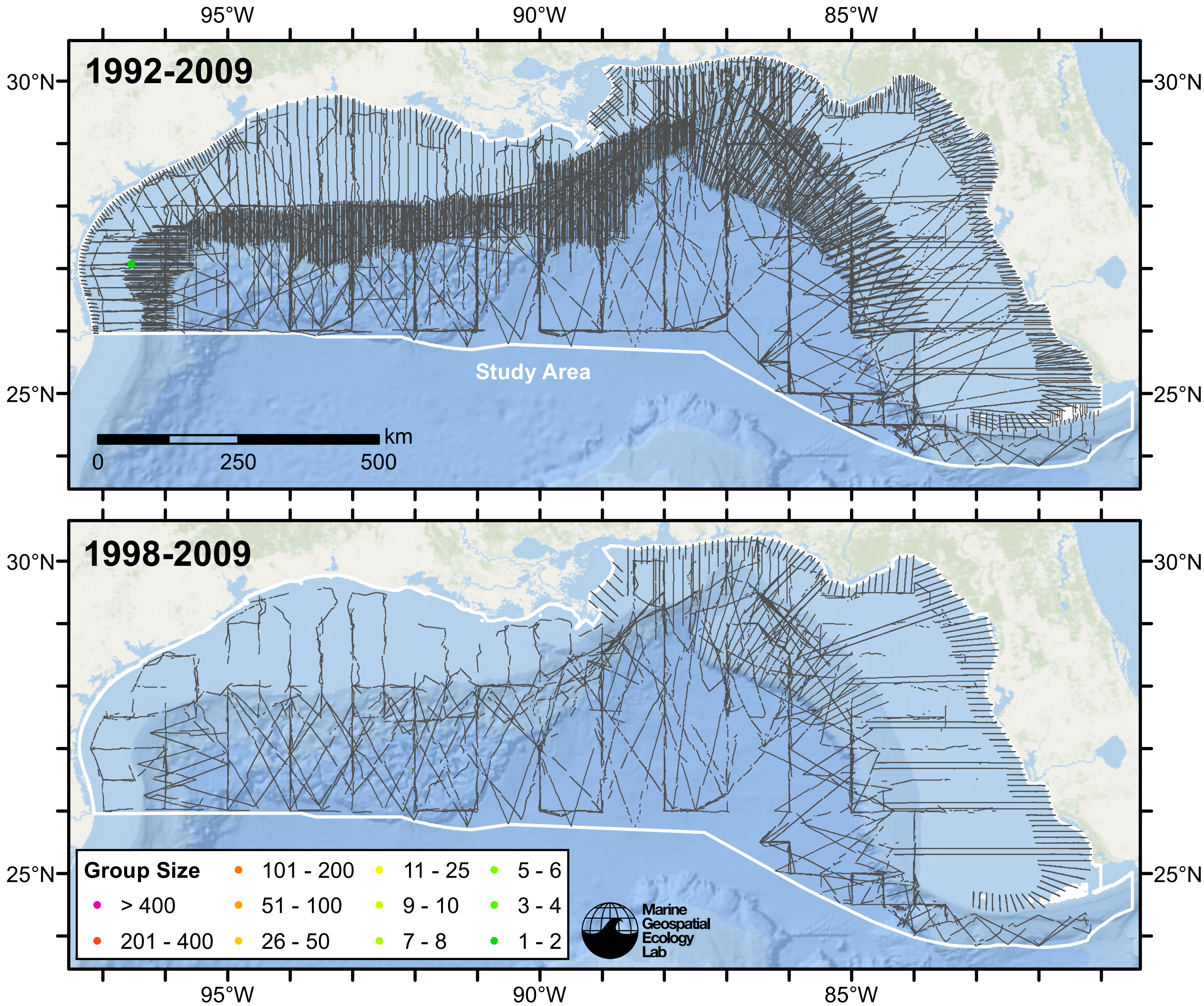

Figure 1: Fin whale sightings and survey tracklines. The top map shows all surveys. The bottom map shows surveys performed in 1998 or later. the era in which remotely-sensed chlorophyll and derived productivity estimates are available. Models fitted to contemporaneous (day-of-sighting) estimates of those predictors only utilize these surveys. These maps illustrate the survey data lost in order to utilize those predictors. Models fitted to climatological estimates of those predictors do not suffer this data loss.

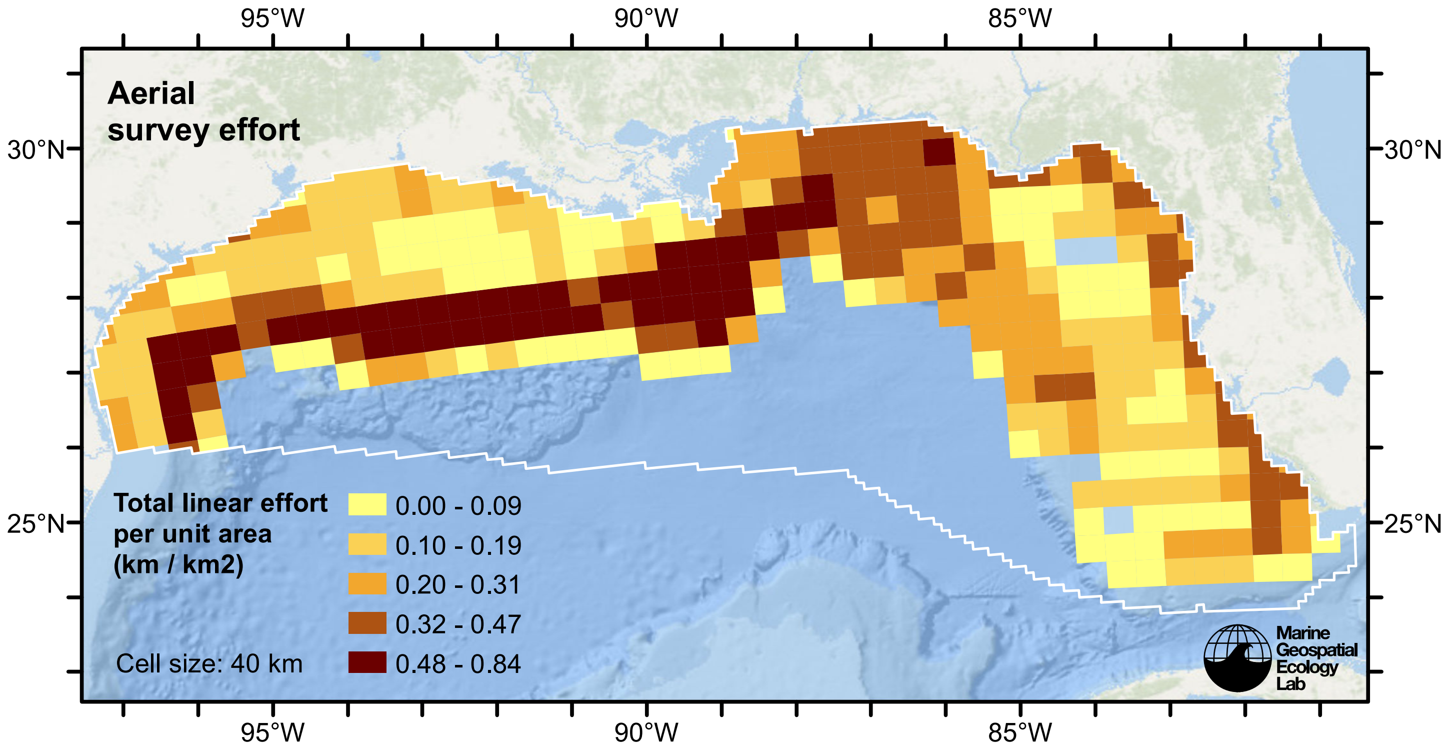

Figure 2: Aerial linear survey effort per unit area.

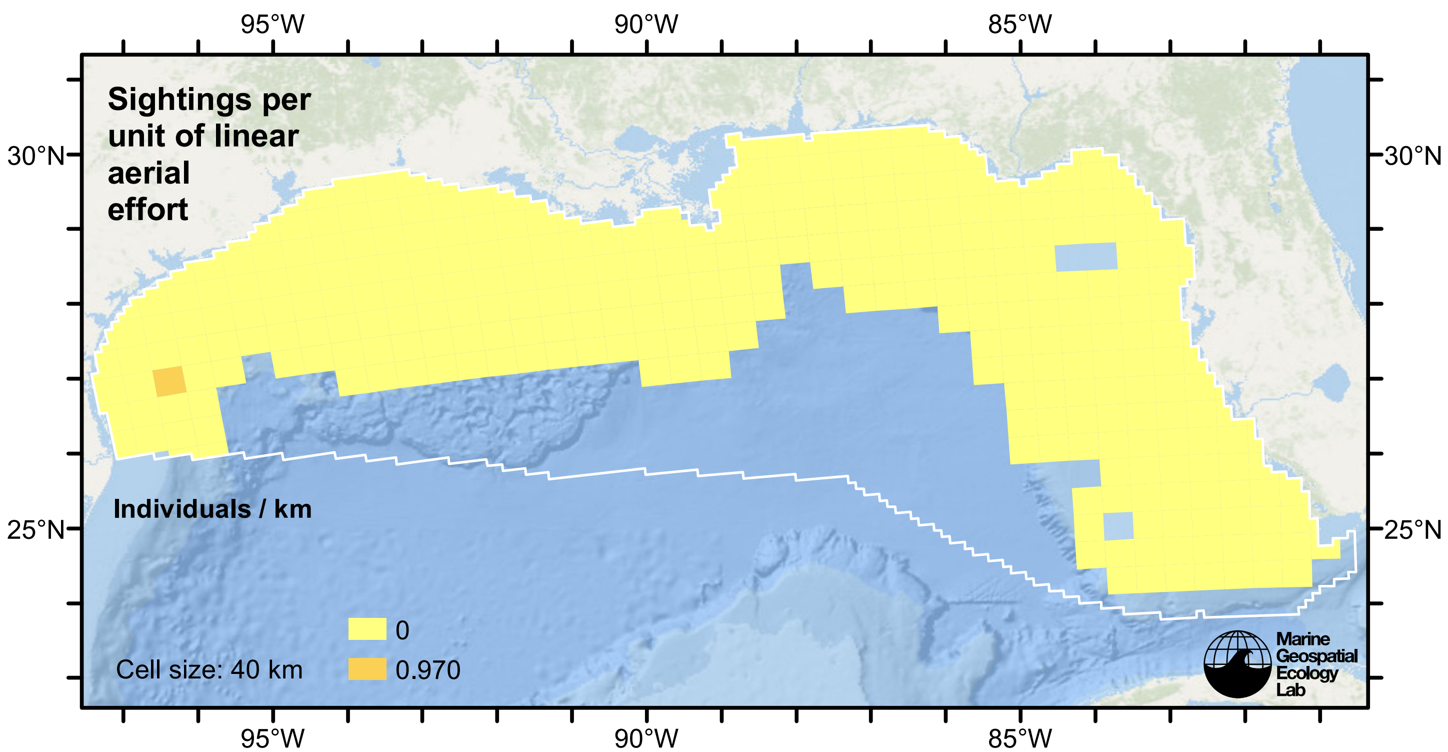

Figure 3: Fin whale sightings per unit aerial linear survey effort.

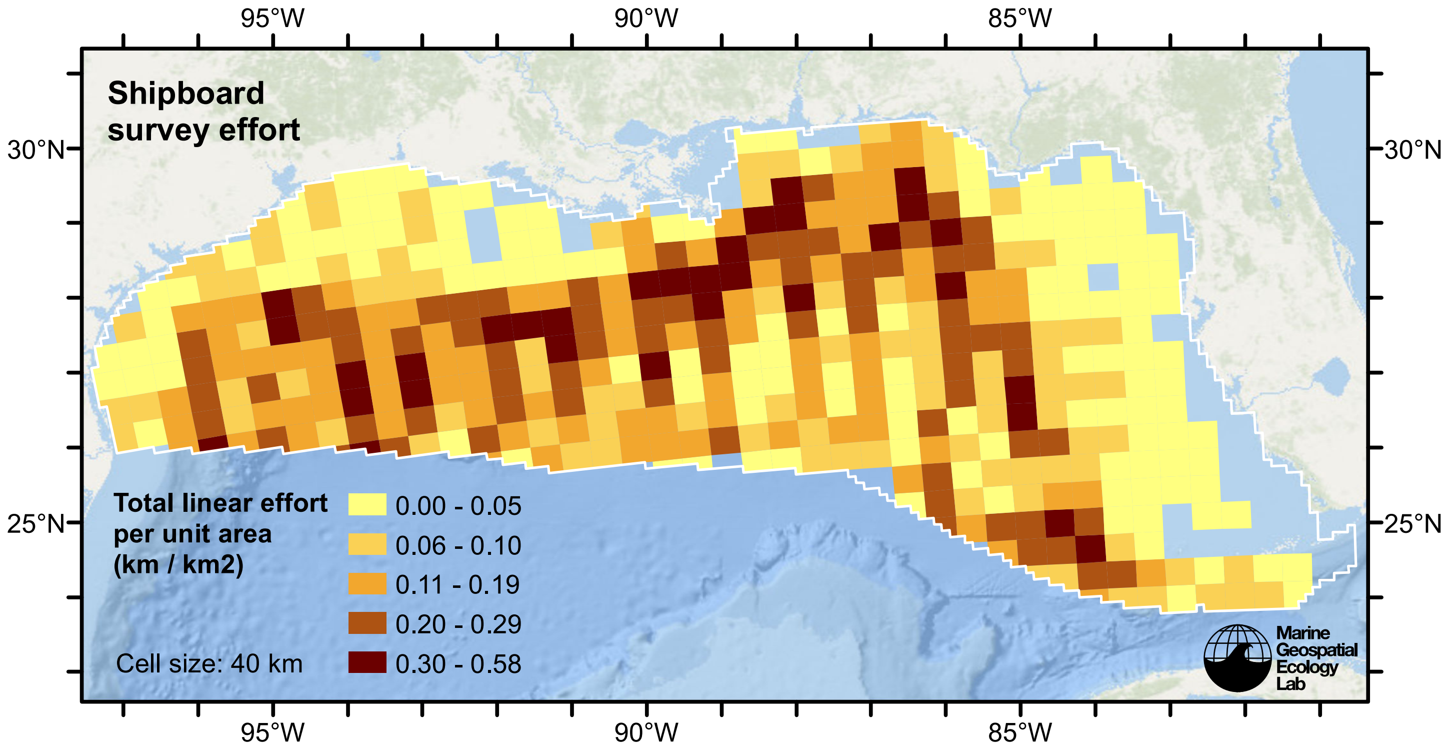

Figure 4: Shipboard linear survey effort per unit area.

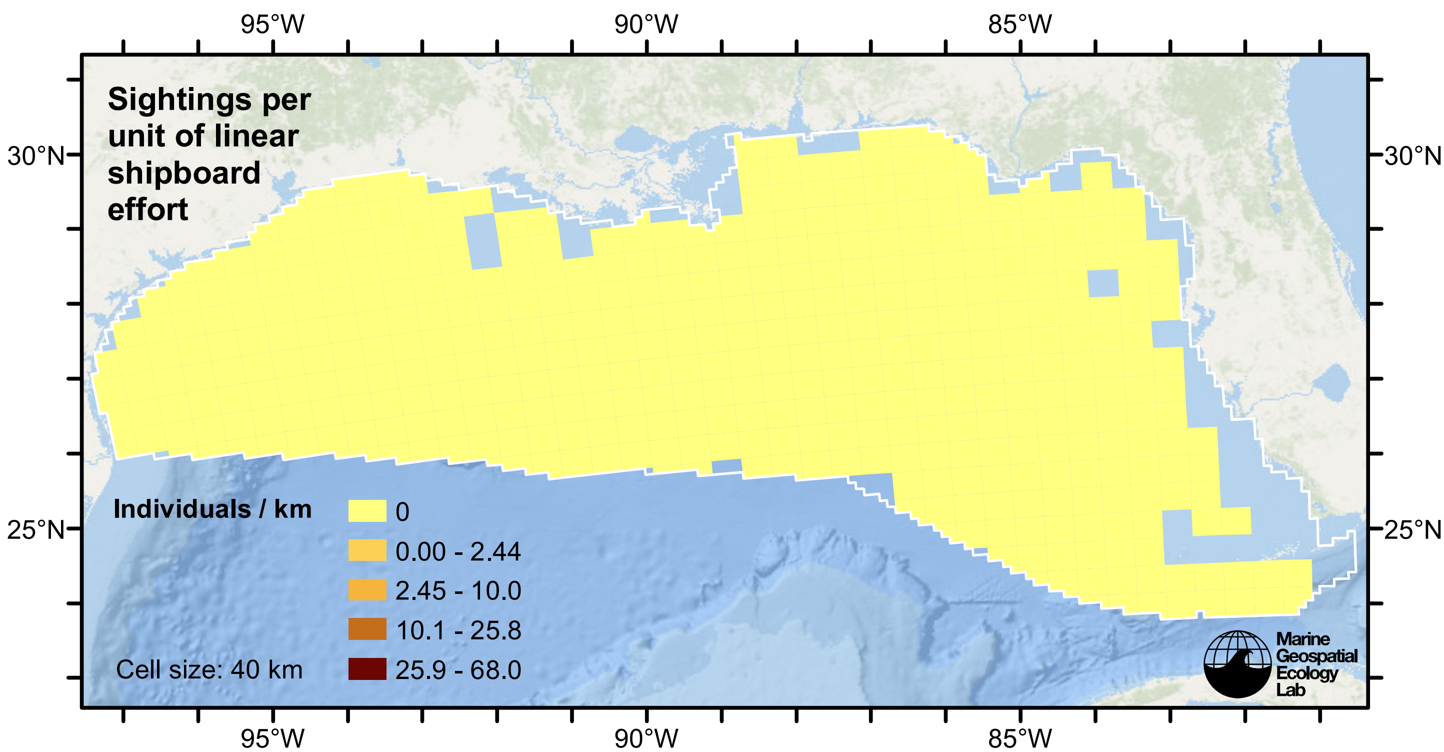

Figure 5: Fin whale sightings per unit shipboard linear survey effort.

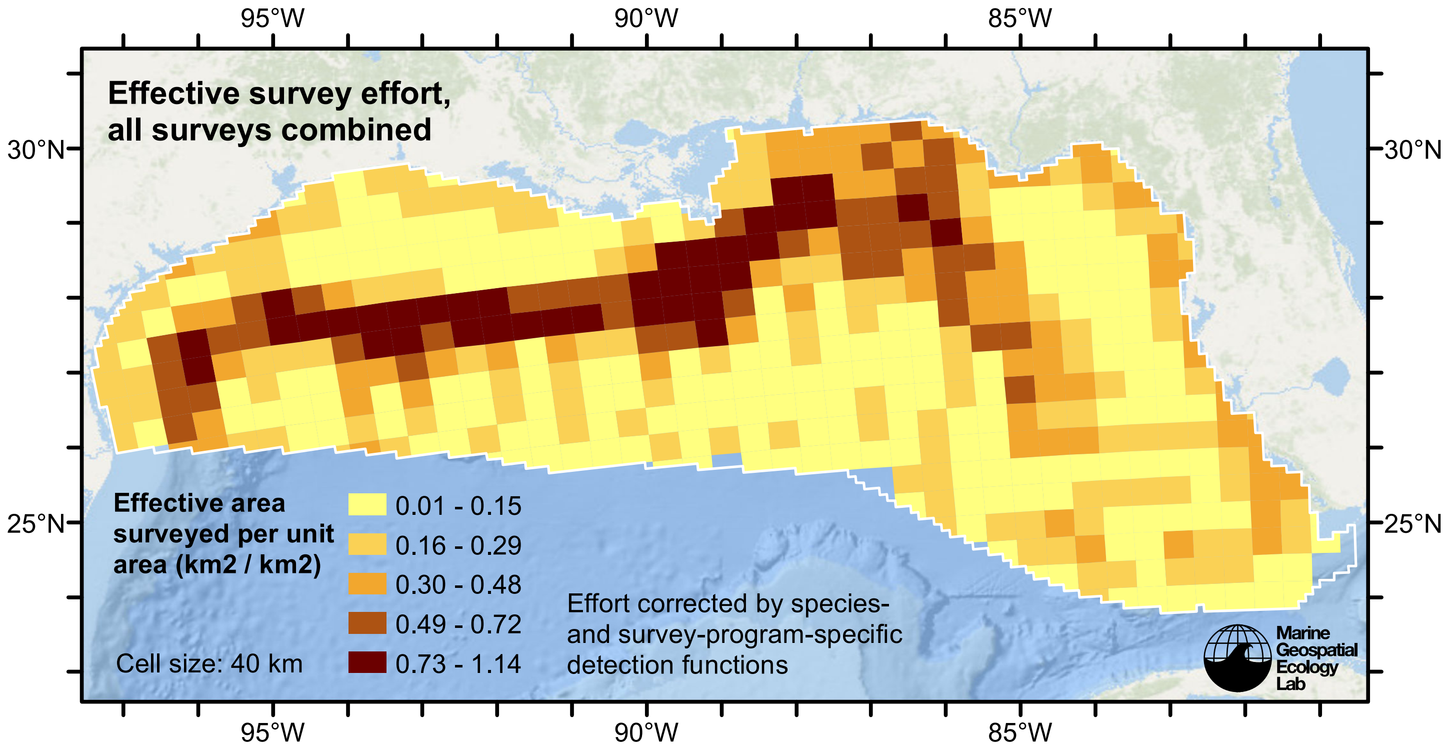

Figure 6: Effective survey effort per unit area, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

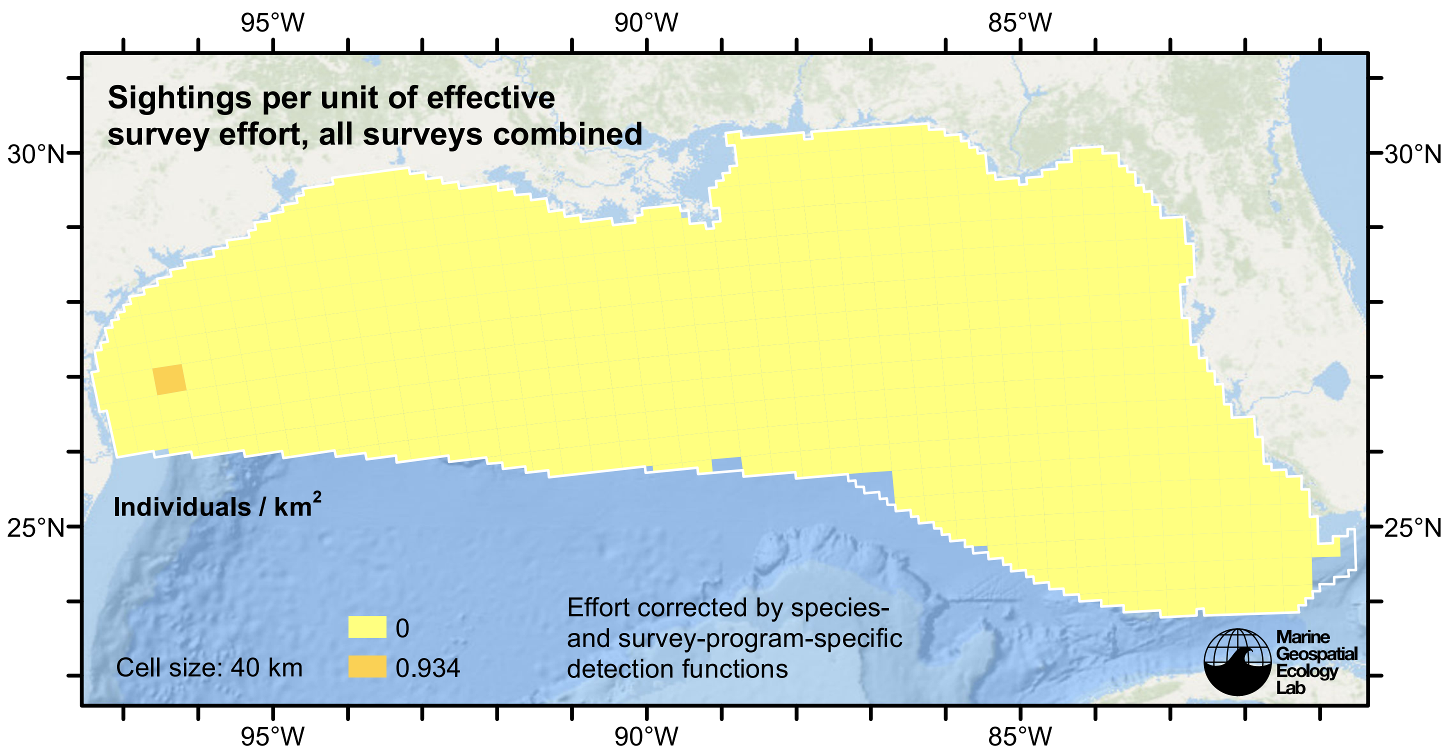

Figure 7: Fin whale sightings per unit of effective survey effort, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

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

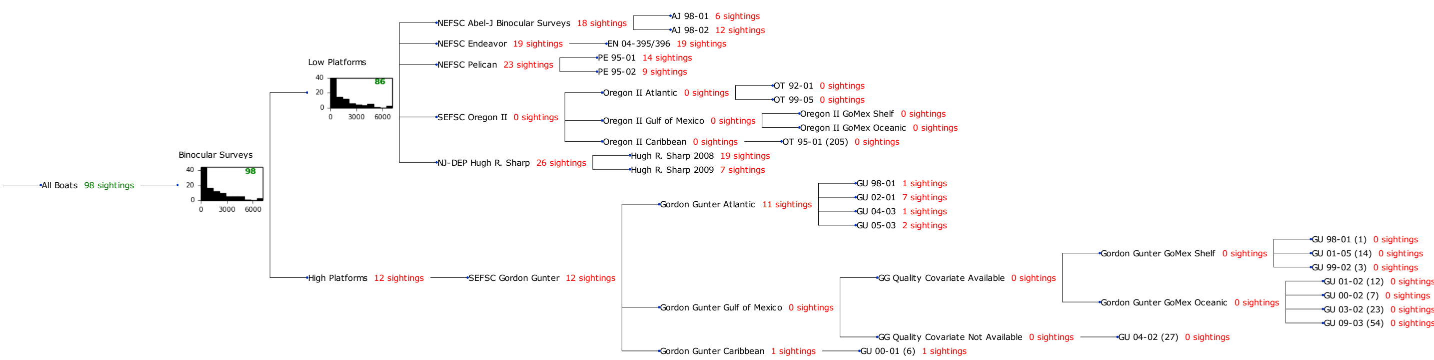

Figure 8: Detection hierarchy for shipboard surveys

Binocular Surveys

The sightings were right truncated at 5000m.

Covariate	Description
beaufort	Beaufort sea state.

Table 4: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr				Yes	0.00	1414
hr			beaufort	Yes	0.92	1505

hr	poly	4		Yes	1.85	1418
hr	poly	2		Yes	2.00	1414
hn	cos	2		Yes	2.48	1809
hn			beaufort	Yes	11.78	2540
hn	cos	3		Yes	13.12	2027
hn				Yes	14.20	2524
hn	herm	4		Yes	15.86	2515
hn	cos	1		No		

Table 5: Candidate detection functions for Binocular Surveys. The first one listed was selected for the density model.

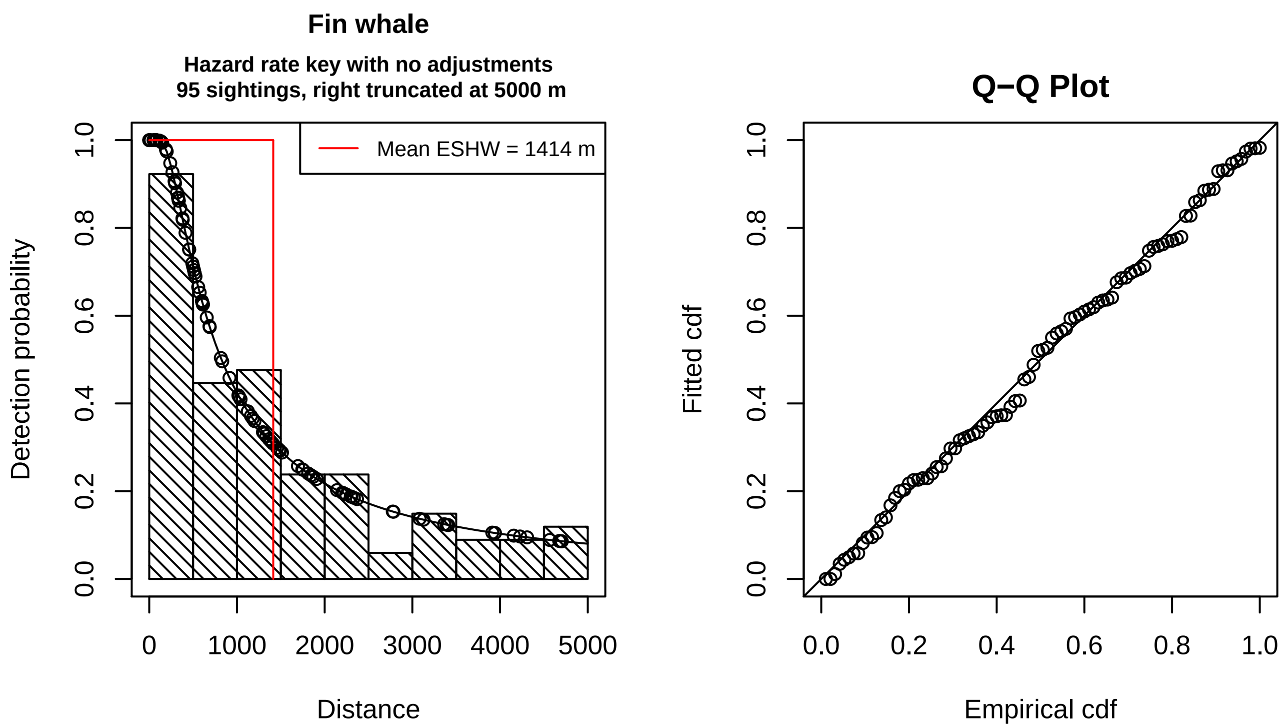

Figure 9: Detection function for Binocular Surveys that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  95
Distance range         :  0  -  5000
AIC                    :  1561.759

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
            estimate        se
```

```
(Intercept) 6.401429 0.4538613

Shape parameters:
             estimate        se
(Intercept) 0.1588674 0.2113658

                       Estimate          SE        CV
Average p             0.2827566  0.06458143 0.2283994
N in covered region 335.9780163 82.10261441 0.2443690
```

Additional diagnostic plots:

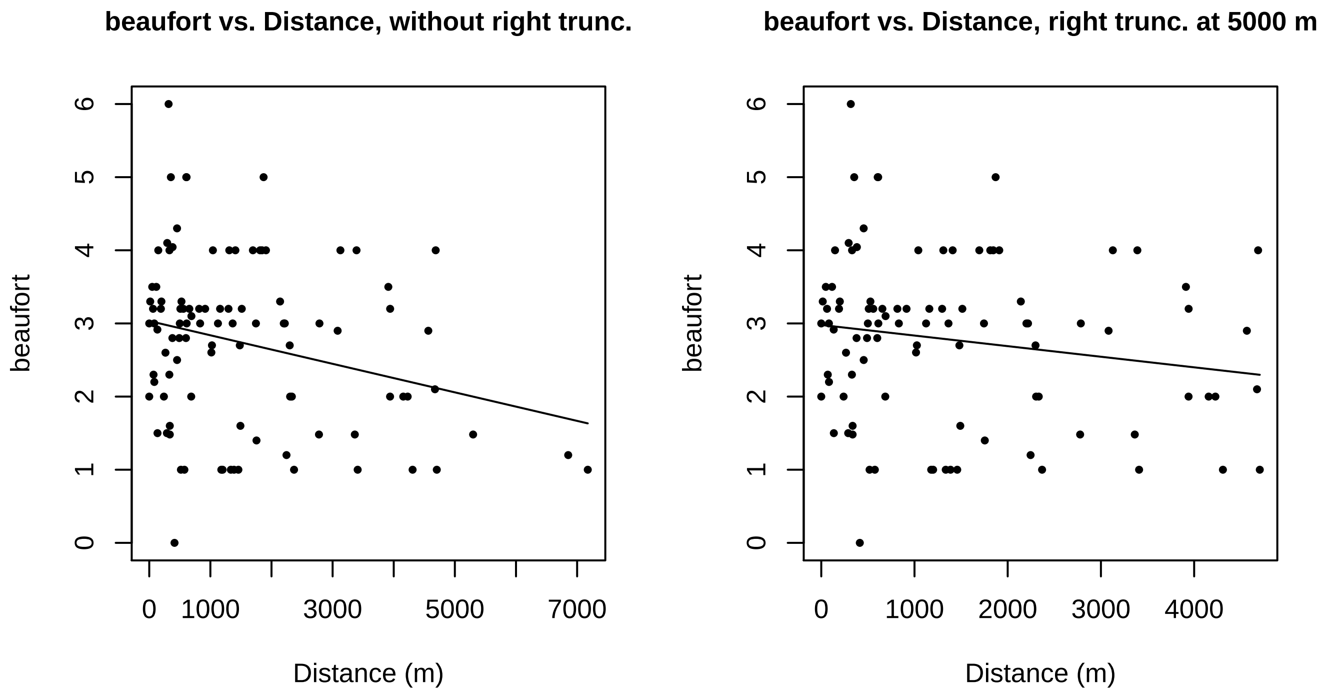

Figure 10: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

Low Platforms

The sightings were right truncated at 5000m.

Covariate	Description
beaufort	Beaufort sea state.

Table 6: Covariates tested in candidate “multi-covariate distance sampling” (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr				Yes	0.00	1427
hn	cos	2		Yes	1.61	1717

hr			beaufort	Yes	1.63	1463
hr	poly	4		Yes	2.00	1427
hr	poly	2		Yes	2.00	1427
hn			beaufort	Yes	12.34	2424
hn				Yes	13.27	2420
hn	cos	3		Yes	13.49	2026
hn	herm	4		Yes	14.92	2413
hn	cos	1		No		

Table 7: Candidate detection functions for Low Platforms. The first one listed was selected for the density model.

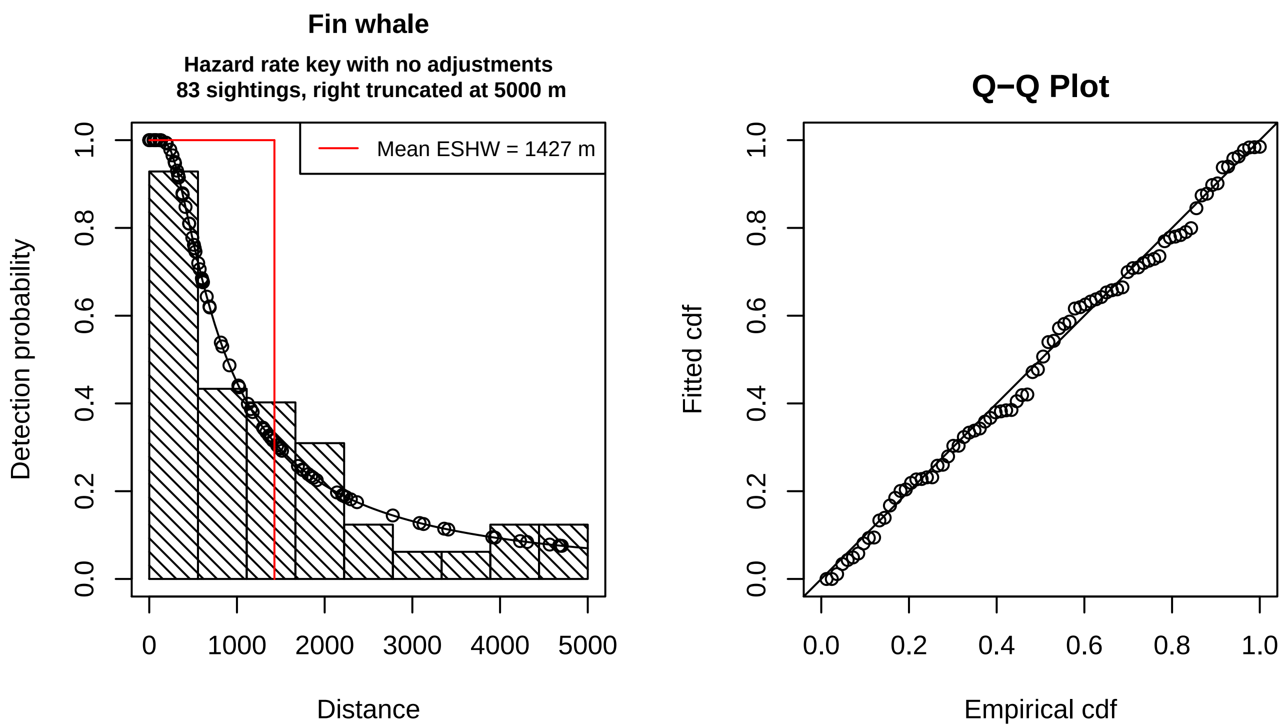

Figure 11: Detection function for Low Platforms that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  83
Distance range         :  0  -  5000
AIC                    :  1358.713

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
            estimate        se
```

```
(Intercept) 6.508864 0.4148118

Shape parameters:
             estimate        se
(Intercept) 0.2672509 0.2180009

                       Estimate          SE        CV
Average p             0.2854652  0.06275673 0.2198402
N in covered region 290.7534550 69.37901822 0.2386180
```

Additional diagnostic plots:

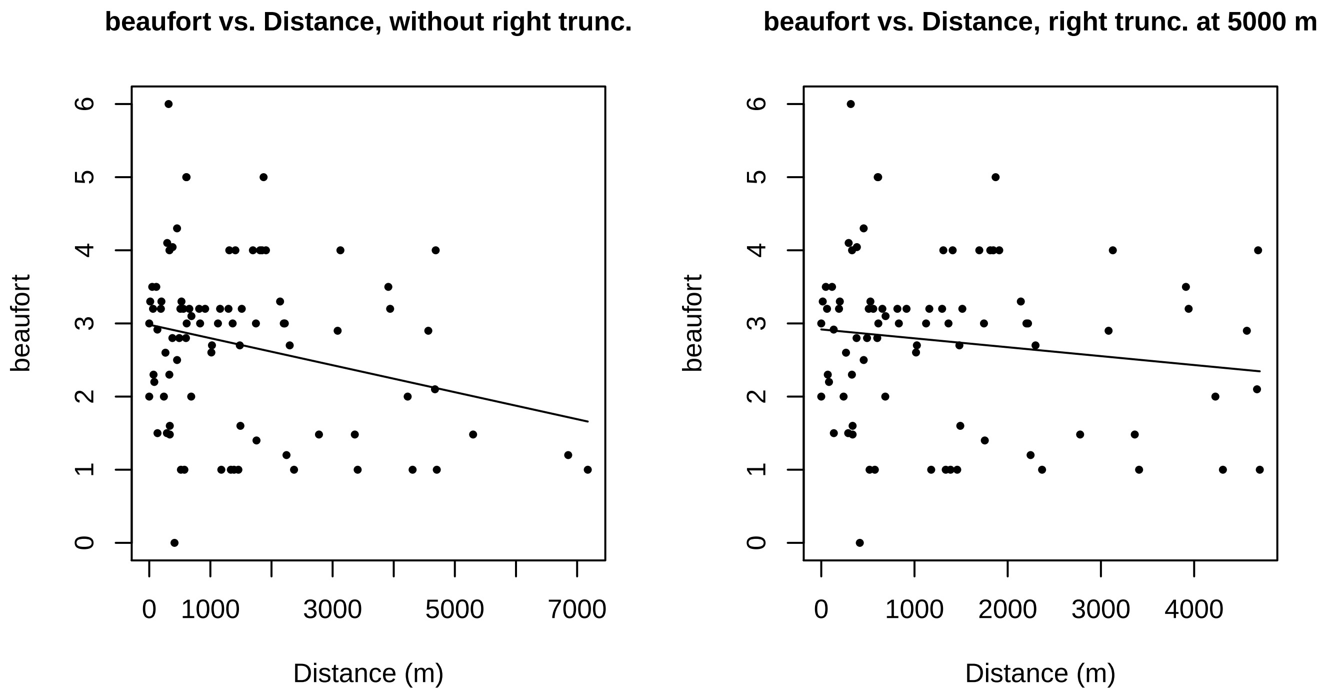

Figure 12: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

Aerial Surveys

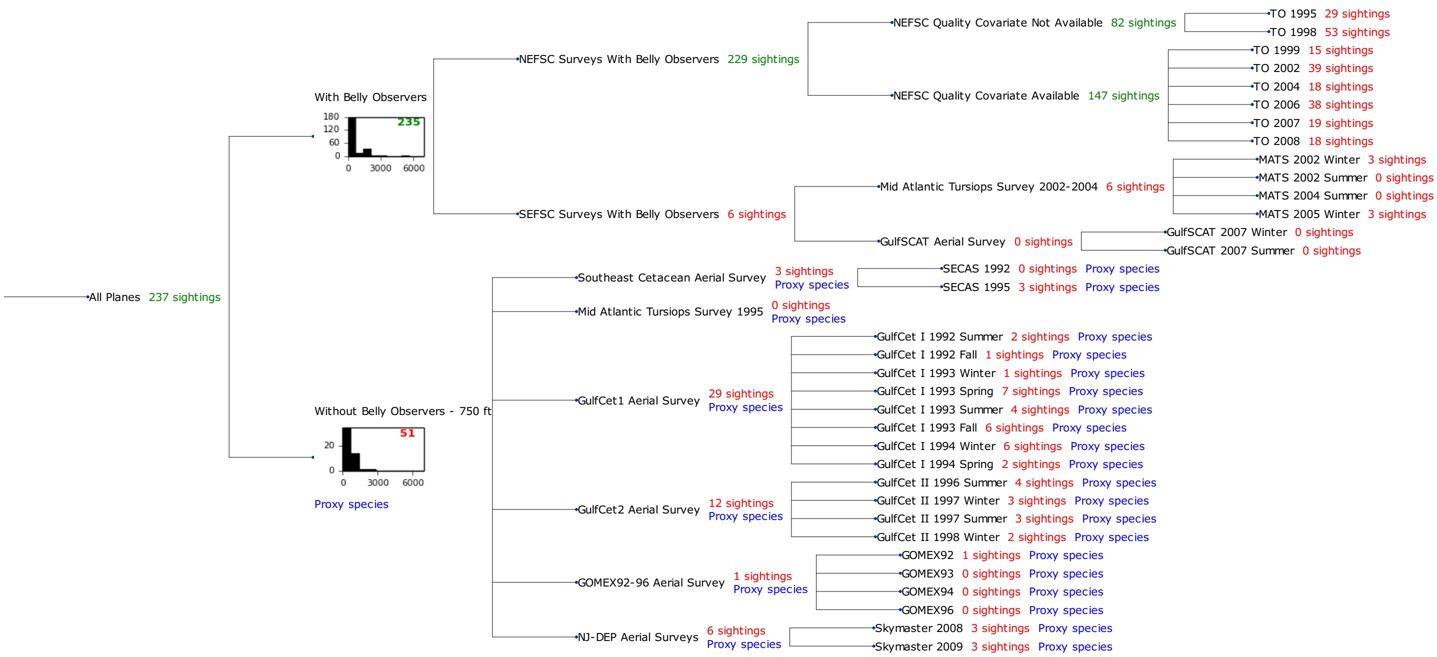

Figure 13: Detection hierarchy for aerial surveys

With Belly Observers

The sightings were right truncated at 1000m.

Covariate	Description
beaufort	Beaufort sea state.
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)
hn				Yes	0.00	474
hn	cos	3		Yes	1.22	436
hn	herm	4		Yes	1.79	485
hn			size	Yes	1.94	474
hn	cos	2		Yes	1.99	470
hr	poly	2		Yes	2.06	453
hr	poly	4		Yes	4.09	422
hr				Yes	6.16	525
hr			size	Yes	8.15	525
hn			beaufort	No		
hr			beaufort	No		

hn	beaufort, size	No
hr	beaufort, size	No

Table 9: Candidate detection functions for With Belly Observers. The first one listed was selected for the density model.

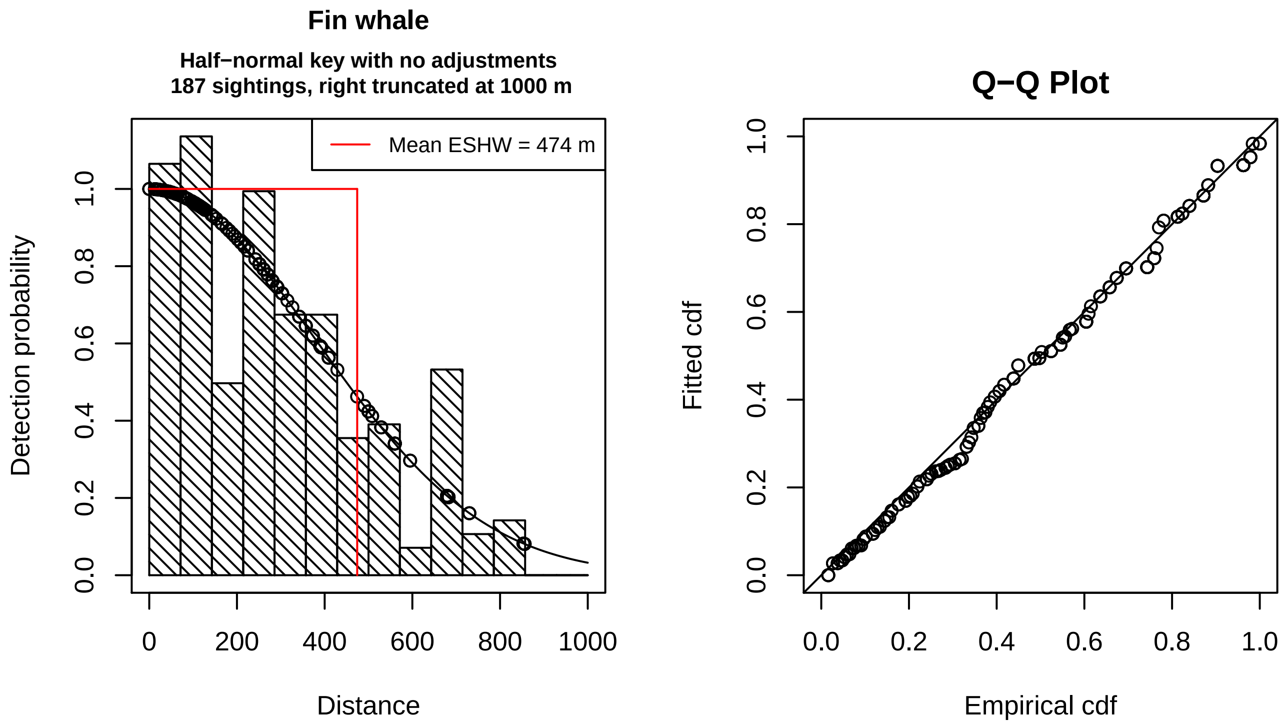

Figure 14: Detection function for With Belly Observers that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  187
Distance range         :  0  -  1000
AIC                    :  2480.693

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
            estimate         se
(Intercept) 5.944659 0.06291675

                       Estimate          SE         CV
Average p             0.4741924  0.02780043 0.05862690
N in covered region 394.3547098 31.17378165 0.07905011
```

Additional diagnostic plots:

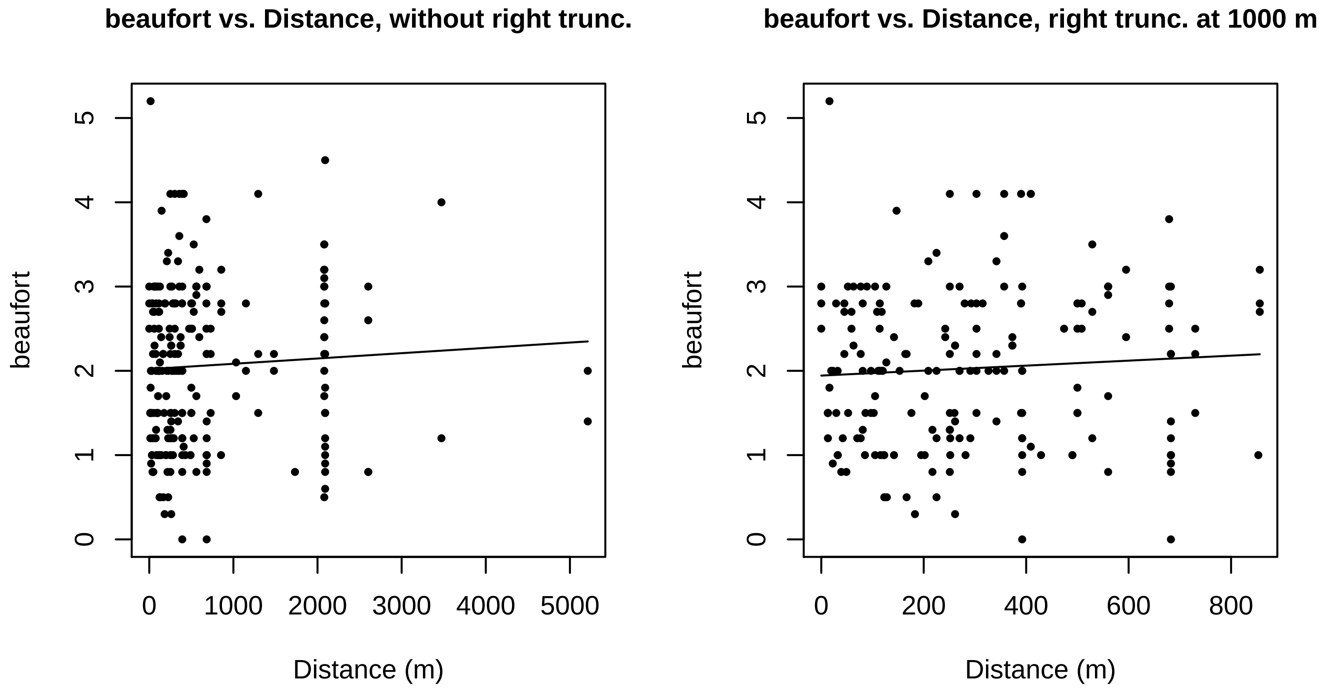

Figure 15: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

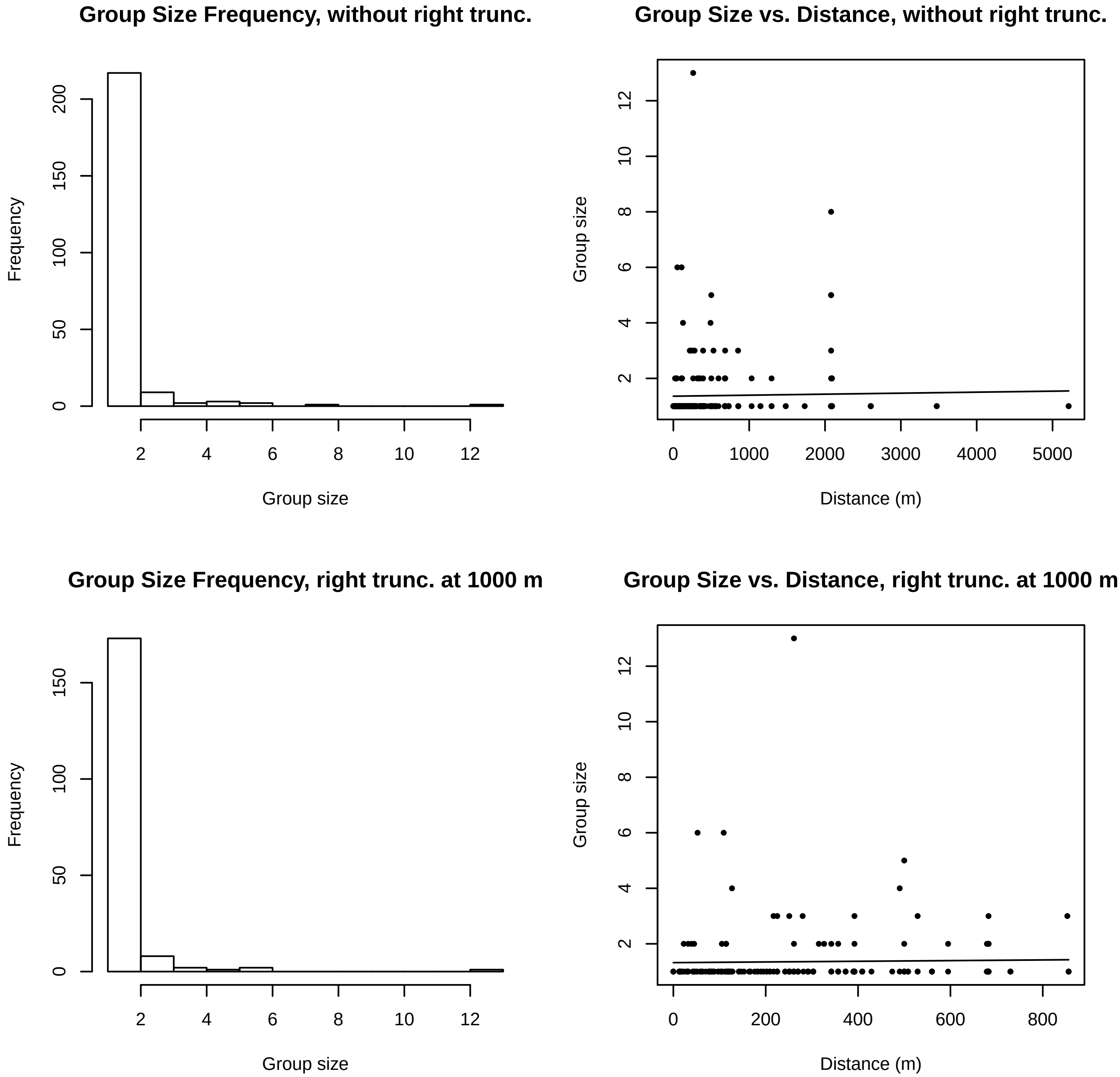

Figure 16: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Without Belly Observers - 750 ft

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	Balaenopterid sp.	1
Balaenoptera acutorostrata	Minke whale	0

Balaenoptera borealis	Sei whale	0
Balaenoptera borealis/edeni	Sei or Bryde's whale	2
Balaenoptera borealis/physalus	Fin or Sei whale	0
Balaenoptera edeni	Bryde's whale	3
Balaenoptera musculus	Blue whale	0
Balaenoptera physalus	Fin whale	2
Eubalaena glacialis	North Atlantic right whale	0
Eubalaena glacialis/Megaptera novaeangliae	Right or humpback whale	0
Megaptera novaeangliae	Humpback whale	6
Physeter macrocephalus	Sperm whale	37
Total		51

Table 10: Proxy species used to fit detection functions for Without Belly Observers - 750 ft. The number of sightings, n, is before truncation.

The sightings were right truncated at 600m. 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 40 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, so the candidate detection functions were fitted using linear bins scaled accordingly.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn	cos	2		Yes	0.00	216
hr				Yes	0.59	251
hn	cos	3		Yes	2.31	255
hn	herm	4		Yes	2.46	316
hr	poly	2		Yes	2.59	251
hr	poly	4		Yes	2.60	257
hn				No		

Table 11: Candidate detection functions for Without Belly Observers - 750 ft. The first one listed was selected for the density model.

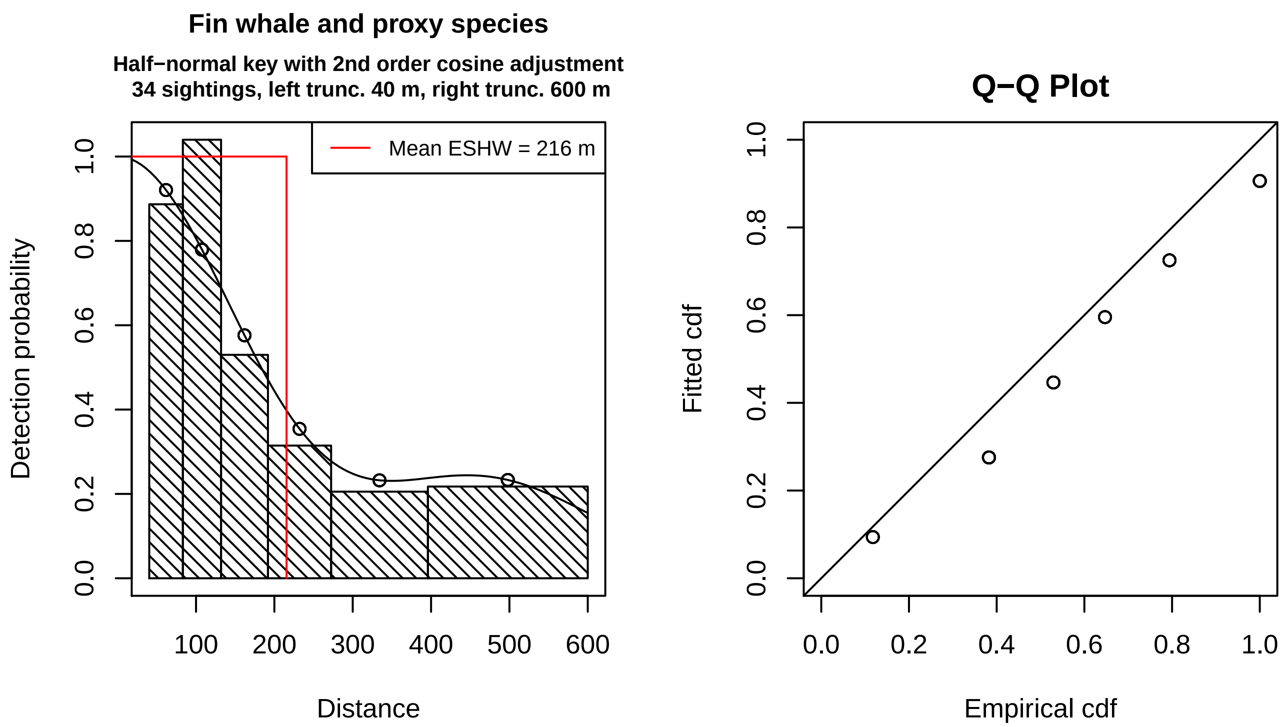

Figure 17: Detection function for Without Belly Observers - 750 ft that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  34
Distance range         :  40.30835  -  600
AIC                    :  124.984

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

Detection function parameters
Scale Coefficients:
            estimate        se
(Intercept) 5.738324 0.1838281

Adjustment term parameter(s):
              estimate       se
cos, order 2 0.4333816 0.242253


Monotonicity constraints were enforced.
                      Estimate         SE        CV
Average p            0.3592781  0.0870934 0.2424122
N in covered region 94.6341993 26.3634683 0.2785829

Monotonicity constraints were enforced.
```

Additional diagnostic plots:

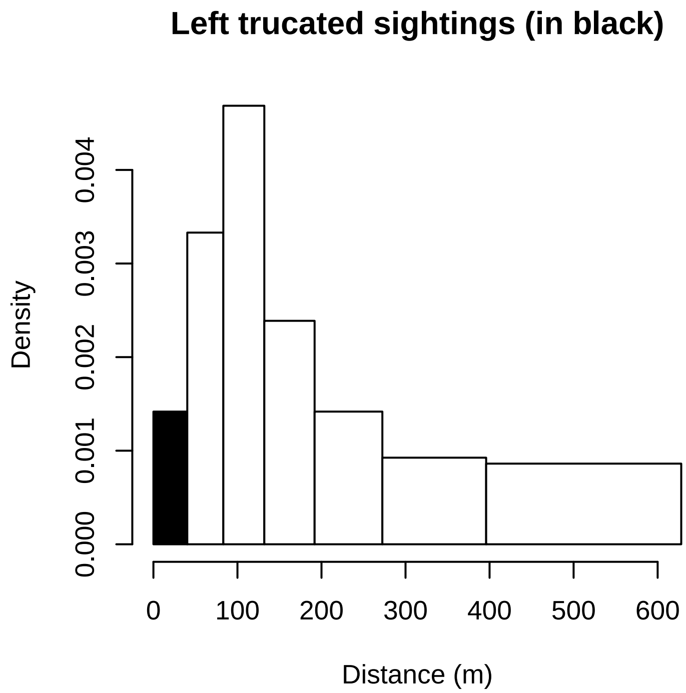

Figure 18: Density of sightings by perpendicular distance for Without Belly Observers - 750 ft. Black bars on the left show sightings that were left truncated.

g(0) Estimates

Platform	Surveys	Group Size	*g(0)*	Biases Addressed	Source
Shipboard	Binocular Surveys	Any	0.63	Perception	Palka (2006)
Aerial	All	Any	0.251	Availability	Lafortuna et al. (2003)

Table 12: Estimates of *g(0)* used in this density model.

Palka (2006) provided survey-specific g(0) estimates for fin and sei whales (pooled together) for two NOAA NEFSC shipboard surveys that used bigeye binoculars: the 1998 Abel-J survey (g(0)=0.32) and the 2004 Endeavor survey (g(0)=0.94). We used the estimates for the lower team, which was the primary team and the one for which we had sightings. These surveys occurred in the northwest Atlantic. All other binocular surveys, including all of those that occurred in the Gulf of Mexico, did not estimate g(0); for these we used the simple mean (g(0)=0.68) of Palka's two estimates. This estimate accounted for perception bias but not availability bias (Palka 2005b), but we do not believe availability to be a major factor affecting detectability of fin whales from shipboard surveys, as they are not a particularly long-diving species.

We found no species-specific g(0) estimate for fin whales observed from aerial surveys in the literature. Utilizing equation (3) of Carretta et al. (2000) (which follows Barlow et al. 1988), we computed the availability bias component of g(0) from the mean surface and dive intervals (62 s and 225 s) for fin whales reported by Lafortuna et al. (2003). We preferred this approach to the generic large whale g(0) estimate reported by Palka (2006), as the availability bias component we estimated here was substantially lower than Palka's g(0) estimate (0.53) that accounted for both availability and perception biases. We did not obtain an estimate of perception bias, but perception bias for whales is expected to be negligible (Carretta et al. 2000).

Density Model

Only one definitive sighting was reported by NOAA during the entire series of surveys from 1992-2009 utilized here. As part of our analysis, we located and reexamined the original sighting record and confirmed that the evidence was sufficient to confidently identify the sighting as a fin whale. It is likely that this sighting is extralimital (Jefferson and Schiro 1997), but to account for the non-zero abundance, we fit a stratified model using this single sighting.

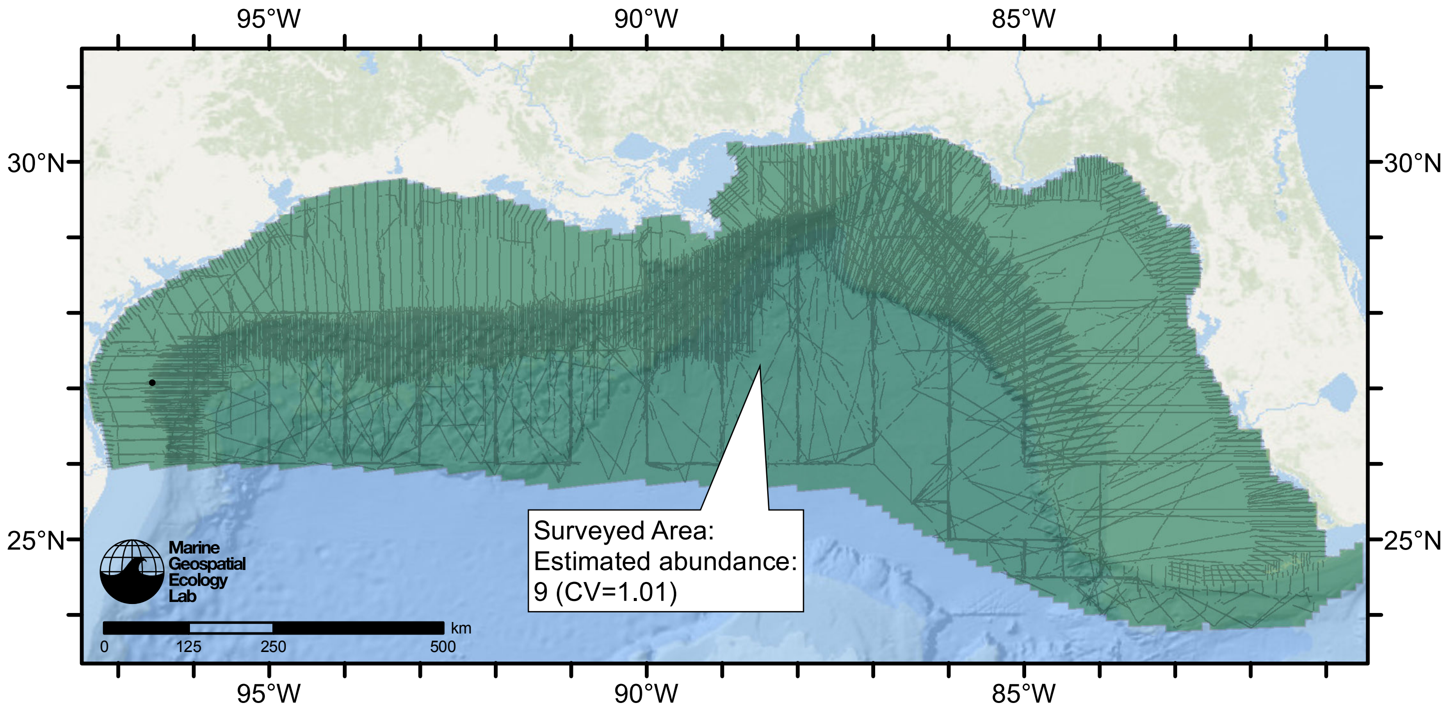

Figure 19: Fin whale density model schematic. All sightings are shown, including those that were truncated when detection functions were fitted. The coefficient of variation (CV) underestimates the true uncertainty of our estimate, as it only incorporated the uncertainty of the GAM stage of our model. 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.

Discussion

The single sighting utilized in this model is probably extralimital (Jefferson and Schiro 1997). Fin whales do not regularly occupy the Gulf of Mexico. Nonetheless, ocean users concerned about possible impacts to fin whale populations should consider that the probability of a chance encounter is not zero.

References

Barlow J, Oliver CW, Jackson TD, Taylor BL (1988) Harbor Porpoise, Phocoena phocoena, Abundance Estimation for California, Oregon, and Washington: II. Aerial Surveys. Fishery Bulletin 86: 433-444.

Carretta JV, Lowry MS, Stinchcomb CE, Lynn MS, Cosgrove RE (2000) Distribution and abundance of marine mammals at San Clemente Island and surrounding offshore waters: results from aerial and ground surveys in 1998 and 1999. Administrative Report LJ-00-02, available from Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA USA 92038. 44 p.

Jefferson TA, Schiro AJ (1997) Distribution of cetaceans in the offshore Gulf of Mexico. Mammal Rev. 27(1): 27-50.

Lafortuna CL, Jahoda M, Azzellino A, Saibene F, Colombini A (2003) Locomotor behaviours and respiratory pattern of the Mediterranean fin whale (Balenoptera physalus). Eur. J. Appl. Physiol. 90, 387-395.

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