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Cetacean Abundance in the U.S. Northwestern Atlantic Ocean, Summer 2021

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ABSTRACT

From June 27-September 15, 2021, as part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS) project, the Northeast Fisheries Science Center (NEFSC) and Southeast Fisheries Science Center (SEFSC) of the National Oceanic and Atmospheric Administration Fisheries Service conducted non-overlapping, line transect, aerial and shipboard abundance surveys. The goal was to estimate abundance of as many marine mammals and sea turtles in the northwestern Atlantic Ocean as the data allowed. This document focuses on abundance estimates of cetaceans detected only during the NEFSC surveys that covered waters from North Carolina to Maine, from the shore to the Gulf Stream, which is about 370 km (200 nm) offshore. In a study area of 464,492 km^2, the NEFSC's ship and plane surveyed 17,332 km of on-effort tracklines. To estimate abundance, we collected data following the two-independent-team procedure which we then analyzed using mark-recapture distance sampling analysis methods—to account for perception bias—and by using dive time patterns—to account for availability bias. Overall, we estimated 338,364 cetaceans (CV = 0.24) of 23 species or species groups to be present in the NEFSC study area during the summer of 2021. The abundance estimates by species are 26 (CV = 1.02) blue whales (*Balaenoptera musculus*); 34 (CV = 0.99) sei whales (*Balaenoptera borealis*); 213 (CV = 0.69) pygmy sperm whales (*Kogia breviceps*); 492 (CV = 0.46) Sowerby's beaked whales (*Mesoplodon bidens*); 753 (CV = 1.13) false killer whales (*Pseudorca crassidens*); 863 (CV = 0.36) humpback whales (*Megaptera novaeangliae*); 1,742 (CV = 0.39) Cuvier's beaked whales (*Ziphius cavirostris*); 2,240 (CV = 0.39) fin whales (*Balaenoptera physalus*); 2,268 (CV=0.50) Clymene dolphins (*Stenella clymene*); 3,181 (CV=0.65) spinner dolphins (*Stenella longirostris*); 3,746 (CV = 0.68) short-finned pilot whales (*Globicephala macrorhynchus*); 3,789 (CV = 0.38) sperm whales (*Physeter macrocephalus*); 3,799 (CV = 0.56) dwarf sperm whales (*Kogia simus*); 4,480 (CV = 0.34) True's beaked whales (*Mesoplodon mirus*); 4,632 (CV = 0.55) Atlantic white-sided dolphins (*Lagenorhynchus acutus*); 5,630 (CV = 0.58) minke whales (*B. acutorostrata*); 5,710 (CV = 0.62) long-finned pilot whales (*Globicephala melas*); 8,112 (CV = 0.22) Atlantic spotted dolphins (*Stenella attenuata*); 37,721 (CV = 0.34) bottlenose dolphins (*Tursiops truncatus*); 38,522 (CV = 0.34) striped dolphins (*Stenella coeruleoalba*); 39,612 (CV = 0.50) Risso's dolphins (*Grampus griseus*); 85,035 (CV = 0.61) common dolphins (*Delphinus delphis*); and 85,765 (CV = 0.53) harbor porpoises (*Phocoena phocoena*). We will report these abundance estimates in the Atlantic Stock Assessment Report. For stocks that also reside south of the NEFSC survey area, we will add the corresponding SEFSC abundance estimate to the NEFSC's estimate.

INTRODUCTION

The U.S. Marine Mammal Protection Act requires the status of marine mammal stocks in U.S. waters to be evaluated on a regular basis. To meet this mandate, the NOAA Fisheries Service conducts research to define marine mammal stock structure and estimate the stock's abundance and human-caused mortalities. In response to the need for updated abundance estimates, the Northeast Fisheries Science Center (NEFSC) and Southeast Fisheries Science Center (SEFSC) of the NOAA Fisheries Service conducted abundance surveys in the summer of 2021. We conducted these line transect abundance surveys using aerial and shipboard platforms and targeted marine mammals and sea turtles in the northwestern Atlantic from Nova Scotia, Canada, to Florida, United States. We will then update species assessments in the U.S. Marine Mammal Stock Assessments using our resulting abundance estimates. Previous assessments for most species used abundance data collected during the summers of 2011 and 2016 (Garrison 2016, 2020; Palka 2012, 2020).

The abundance data also support environmental assessments of ocean activities. Previous examples of marine mammal abundance data tailored to this usage include Roberts et al. (2016), Palka et al. (2017, 2021), and Chavez-Rosales et al. (2019). In addition, we used these data to investigate the spatial-temporal trends in the distribution and abundance of these species that could be changing due to changes in the physical and biological characteristics of the U.S. North Atlantic waters, as discussed in Chavez-Rosales et al. (2022).

The 2021 surveys are part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS) project, which is a multiagency, multiyear initiative to provide comprehensive assessments of marine mammal, sea turtle, and seabird abundance and spatial distributions in U.S. waters of the western North Atlantic Ocean. The major funding partners of AMAPPS are the NOAA Fisheries Service, the Bureau of Ocean Energy Management (BOEM) Environmental Studies program, the U.S. Navy, and the U.S. Fish and Wildlife Service (USFWS).

This manuscript focuses on cetacean abundance estimates from the shipboard and aerial line transect surveys conducted by the NEFSC from June 27-September 15, 2021, in waters north of North Carolina. Garrison and Aichinger Dias (2023) estimated abundance of cetaceans that reside south of the NEFSC survey area in U.S. waters using data collected during the summer of 2021.

We designed the NEFSC and SEFSC studies to use data collection procedures and analysis methods that account for 2 types of visibility bias which relate to visual line transect data collected from ships and planes (McLaren 1961). Availability bias is due to missing animals that were submerged and thus not available to visual observers on ships and planes. Perception bias is due to missing animals that were available to the observers, but the observers missed them for some reason. This oversight could be due to a variety of reasons, such as too far from the observation platform, cryptic animal behavior, or poor sighting conditions due to sun glare or sea state. To address perception bias, we designed the shipboard and aerial line transect surveys to collect simultaneously sightings data from 2 independent teams, and we analyzed these data using mark-recapture distance sampling (MRDS) methods. To address availability bias, we used externally collected animal dive patterns to inform a correction factor that we then applied to the perception bias corrected abundance estimates.

MATERIAL AND METHODS

Study area

The primary spatial strata surveyed by the NEFSC covered 3 habitats (Figure 1; Table 1A):

- *Gulf of Maine (GOM)*: a stratum ranging in U.S. and Canadian waters from Jersey to Maine (about 39˚N to 45˚N latitude) and from the shores of the U.S. to Nova Scotia, Canada. The NOAA Twin Otter airplane surveyed this stratum.
- *Shelfbreak*: a stratum ranging from Virginia to the southern tip of Nova Scotia (about 38˚N to 42˚N latitude) and in waters between the 100 m and 2000 m depth

contours. The NOAA Twin Otter airplane and the NOAA ship *Henry B. Bigelow* surveyed this stratum.

- *Offshore*: a stratum ranging from North Carolina to waters south of the southern tip of Nova Scotia (about 36˚N to 42˚N latitude) and in waters offshore of the 2000 m depth contour to beyond the U.S. exclusive economic zone and the Gulf Stream's northern wall. The NOAA ship *Henry B. Bigelow* also surveyed this stratum.

In addition, we highlighted 2 small additional strata that are part of a habitat-ecosystem study in prospective locations for wind energy projects (Table 1B):

- *Wind-MA*: a stratum south of Massachusetts on the continental shelf in waters about 30-60 m deep (around 41˚N latitude).
- *Wind-MidAtl*: 2 regions off the coasts of New Jersey and Delaware that are on the continental shelf in waters of about 20-30 m deep (between 38˚N and 40˚N latitude).

Both the NOAA Twin Otter plane and NOAA ship *Henry B. Bigelow* surveyed the 2 wind additional strata.

In this analysis, the shipboard data from the 2 wind energy additional strata augmented the shipboard data within the primary strata only to improve the definition of the detection function. In a separate future document, we will report the abundance estimates limited to these wind energy areas.

We defined primary tracklines as those designed before the survey to have approximate even coverage within a stratum. We defined "extra" tracklines as non-primary tracklines that occurred in 3 situations. The first situation was when we transited to primary tracklines. The second situation was the overlap of aerial shelfbreak tracklines with the primary shipboard shelfbreak tracklines; we will use the data from these overlapping shipboard and aerial lines in a future comparison analysis. The final situation was when we re-surveyed a trackline in better sighting conditions that we originally surveyed in poor sighting conditions (above Beaufort 4). In all the cases of extra tracklines, the data collection methods were identical to the normal on-effort procedures conducted on the primary tracklines. We used the extra trackline data in the analysis to improve the detection function estimation but not to estimate the encounter rate.

Aerial field procedures

The 2021 NEFSC aerial abundance line transect survey covered the primary GOM stratum (including the Wind-MA stratum) and the extra shelfbreak stratum with a NOAA Twin Otter airplane from August 1-September 15, 2021 (Figure 1). The NEFSC conducted the survey along primary tracklines oriented either perpendicular to the coast or at an angle aligned to cut across the expected spatial onshore-offshore animal density gradients. The survey plane flew at an altitude of 183 m (600 ft) above the water surface, at a speed of approximately 200 kph (110 kts), and when surface wind speeds were less than about 20 kts (approximately sea state 4 or less on the Beaufort scale).

The data entry program recorded Global Positioning System (GPS) locations automatically every 2 seconds. Whenever conditions changed, the observer team entered environmental conditions, effort, and sighting information into the data entry program.

We defined on-effort time periods as when the plane flew level at survey altitude and speed over the tracklines. During these periods, observers concentrated their visual search for animals within the region bound by straight down to the trackline (0˚ inclination angle) to approximately 300 m from the trackline (about 60˚ above vertical) and from as far forward as possible to slightly behind the plane, although time was also spent searching farther from the trackline. When an observer detected a group of animals, the observer waited until the group was perpendicular to the plane, then measured the angle (to the nearest degree) from vertically straight down to the center of the group by using a digital inclinometer or markings on the windows.

Two teams independently and simultaneously collected line transect data to estimate perception bias. The front team consisted of 3 scientists: 2 observers looking through forward bubble windows located at either side of the front of the plane and a dedicated data recorder collecting data from only the front team. The front bubble windows allowed downward visibility to the trackline and unobstructed views to the horizon forward, to the side, and toward the rear of the plane. The back team consisted of 3 scientists: 1 observer looking straight down through a belly window, another observer looking through a rear bubble window on the right side of the plane, and a dedicated data recorder collecting data from only the back team. The belly window observer had visibility of approximately 110 m (30˚) on either side of the trackline. The observer viewing through the back bubble window had the same viewing area as the observer viewing through the front right bubble-window. The 2 observation teams operated on independent intercom channels and were not able to alert each other. Observers rotated between the 4 sighting positions about every 30 minutes, while recorders stayed at the same positions for the entire flight.

Data collected included information on sightings, effort, and environmental characteristics. For each marine mammal and sea turtle group detected, the observers recorded the following data:

- time of detection when sighting was perpendicular to the observer;
- observer who detected the group;
- plane’s latitude and longitude;
- angle of declination from the trackline to the center of the group;
- species identification;
- level of certainty of the species identification (certain, probable, not sure);
- best estimate of group size;
- compass direction the group was swimming toward;
- initial cue that caught the observer’s eye (animal, splash, blow, footprint, birds, vessel or gear, windrows, disturbance, bubbles, or other);
- initial behavior (swimming, milling, breaching, charging, feeding, logging, diving or other); and
- comments, if any.

Effort and environmental data collected included:

- time and location when starting or ending a trackline or when another effort variable was updated;
- observers’ positions;
- Beaufort sea state condition (0-6 in 1 decimal increments);
- percent cloud cover (0-100% in 10 degree increments);

- location of the glare swath;
- severity of the glare within that swath (none, slight, moderate, or severe);
- overall quality of sighting conditions for each observer (excellent, good, moderate, fair, or poor); and
- comments, if any.

We determined, either in the plane or after the survey, duplicate sightings (groups seen by both teams) based upon the times, locations, and positions of the sightings recorded by both teams.

At times, the observers requested the plane to circle a group to verify species identification and group sizes. Circling time was off-effort and not included in the abundance estimate. If the front team made the initial sighting within about 300 m (60°) of the trackline and they were unable to identify the species, they waited until the sighting was aft of the plane to allow the back team an opportunity to detect the sighting. Then the observers asked the pilots to break effort and circle the sighting. We classified additional animal groups detected during off-effort periods as off-effort, and we did not use them in the analysis.

Shipboard field procedures

The 2021 NEFSC shipboard abundance line transect survey covered the primary shelfbreak and offshore strata, in addition to the extra Wind-MA and Wind-MidAtl strata. This survey was on the NOAA ship *Henry B. Bigelow* from June 27-August 23, 2021 (Figure 1).

Two teams independently and simultaneously collected visual line transect data to estimate perception bias. Each team consisted of 3 on-duty observers and 1 observer at rest. The upper team was located on the flying bridge, 15.1 m above the sea surface, and the lower team was on the roll tank platform that was in front of the bridge and was 11.8 m above the sea surface. Within each team, 2 observers searched with 25x150 powered binoculars, and 1 observer recorded the team's data while searching with the naked eye, concentrating on waters close to the ship where the observers searching with high-powered binoculars might miss a group. Observers changed positions within their team every 30 minutes. During daylight hours, when weather permitted (i.e., at least 3.7 km visibility and Beaufort <6), observers searched the waters in front of the ship within a region bound by 90° on both sides of the transect line and from the ship to the horizon. The entire teams switched platforms about every other survey data because the lower team platform was subject to more sun and weather; thus, the 2 teams shared these less desirable conditions.

Data collected included information on sightings, effort, and environmental characteristics. For each cetacean group detected, sightings data included:

- time of initial detection;
- ship's latitude and longitude;
- bearing between the transect line and line of sight to the location of the group;
- radial distance between the ship and center of the group;
- species composition;
- level of certainty of the species identification (certain, probable, not sure);
- best estimate of group size;
- initial behavior of the group (swimming, porpoising, charging, aerobatics, bow riding, breaching, diving, feeding, fluking, logging, milling, motionless, unknown, or other);

- initial sighting cue that attracted the observer to the group (body, splash, blow, footprint, birds, vessel or gear, windrow, or other); and
- comments, if any.

Observers measured the bearings by using angle rings around the tripod-mounted binoculars or angle boards mounted on the recorder's desk. They measured radial distances with reticles in the eyepiece of the binoculars. All team members jointly determined the best estimate of the group size, where the team assessed the size of the group as often as possible as the group passed by the ship. Effort and environmental data included:

- time of the data entry event;
- observers' positions;
- swell height and direction;
- Beaufort sea state condition (0-6 in 1 decimal increments);
- magnitude of the sun glare (none, slight, moderate, or severe);
- percent cloud cover (0-100% in 10 degree increments);
- presence of rain or fog; and
- approximate visibility distance.

The ship's instruments collected other environmental characteristics and recorded the following every second:

- ship's location;
- ship's speed and course;
- true wind speed and direction;
- water depth;
- water surface temperature;
- air temperature; and
- water current direction and speed.

When it was not possible to confirm the species identification or group size and the group was within a couple miles from the ship, the ship went off-effort and approached the group to a distance where it was possible to confirm the identification and/or group size. The observers initiated the approach procedure only after it was nearly 90° abeam or after both teams detected the group. Since both teams were off-effort when approaching a group, we classified any additional sightings as off-effort, and we did not use them in the analysis.

Aerial and shipboard field procedures

For both the shipboard and aerial surveys, in addition to recording marine mammals and sea turtles, observers also recorded groups of fish species, especially large sharks because they could be confused with a marine mammal. Observers did not record all fish sightings, particularly if this interfered with searching for marine mammals. Observers identified species to the lowest taxonomic level possible. When the observers could not distinguish the animals to the species level, they recorded a higher level of species identification. For example, the observers would record a group as "pilot whale spp." because they could not distinguish confidently between short-finned (*Globicephala macrorhynchus*) and long-finned (*G. melas*) pilot whales. They used species groupings such as "unidentified dolphin" when it was only possible to determine the animals as dolphins of some species. The abundance analyses did not use data from most groups identified to a level with the word "unidentified." This is because using the data from these very general groupings could result in negatively biased abundance estimates because an unknown proportion of the unidentified groups may have included individuals of any particular species. Many of the unidentified groups were far from the trackline and thus beyond the analysis truncation distance.

Analytical methods

In summary, analyses of both shipboard and aerial data resulted in abundance estimates accounting for perception bias using mark-recapture distance sampling (MRDS; Buckland et al. 2004), which were then multiplied by a species-specific dive time correction factor to account for perception bias.

Abundance Estimates

Because it is harder to detect animals from a plane than from a ship, especially smaller animals, in the analysis we used aerial data collected in Beaufort sea states of 4 or less for all species except harbor porpoises, where we used data collected in Beaufort sea states of 2 or less. In contrast, we used shipboard data collected in Beaufort sea state 6 or less to estimate the shipboard abundance estimates, although 92.2% of the primary shipboard tracklines were surveyed in Beaufort 5 or less conditions.

We based the abundance estimates accounting for perception bias on the independent observer approach assuming point independence (Laake and Borchers 2004) by using the MRDS packages (Laake et al. 2022) within R (R Core Team 2022). This analysis method based on the abundance of groups and expected size of the groups is an extension of standard line transect distance analysis. In MRDS, the sighting probability on the trackline implicitly includes the estimation of *g(0)*, which is the probability of detection of a group on the trackline. The probability of sighting a particular group is the product of 2 components. The first probability component is the distance sampling (DS) component that corresponds to the standard unconditional detection function. This component is the probability of 1 or more observer teams detecting the group of animals when accounting for the perpendicular distance and, if included covariate values. The probability of detection declines with increasing distance from the trackline following a known functional form (half-normal or hazard function). The second probability component is the mark-recapture (MR) component that is a conditional detection function. This component is the probability of a team detecting the animal group, when the other team has also detected it, and when accounting for the perpendicular distance and, if included covariate values. The MR component results in a probability likelihood of detection on the trackline, which is modeled by a logistic regression approach and the "capture histories" of each sighting (i.e., seen by one or both teams). Laake and Borchers (2004) detailed the derivation, assumptions, and implementation of this estimation approach.

Because of the physical limitations within the plane, the front and back teams could not search the exact same patch of water. The front team had full viewing coverage: from the horizon on the right side of the plane (90°), down to directly under the plane (on the track line; 0°), then over to the horizon on the left side of the plane (90°). The back team had limited viewing coverage: from the horizon on the right side of the plane, down under the plane through the trackline, then over to about 30-35° from the trackline on the left side of the plane. To account for this asymmetry, a 2-step procedure estimated the perception-bias corrected density for the aerial data. The first step was to estimate the average probability of the primary team detecting a group at the trackline, when accounting for the perpendicular distances and covariates (*p(0)*) in a 2-team MRDS analysis using only data collected from the area both teams could search. The second step used data only from the primary team in a standard single team multiple covariate distance sampling (MCDS) analysis to estimate densities that were then expanded by the estimate of *p(0)* for the primary team (as estimated in the first step). The primary team was the team that collected data resulting in the typically shaped detection function declining monotonically from the trackline. In most cases, the primary team was the front team.

We right truncated the perpendicular distances following guidance in Buckland et al. (2001), thereby accounting for differences in species, observers, observers' searching behavior, surveying conditions, and so on. The tests we used to determine the best-fitting models with the appropriate significant covariates included the Akaike Information Criterion (AIC), the Cramér-von Mises test, quantile-quantile plot fits, and visual inspection of the fitted models (Marques and Buckland 2003). Possible model forms of the DS models were the half-normal and hazard key functions. For the MR model, we also investigated interactions between covariates, particularly interactions with the team, thereby allowing the shape of the fitted curve to differ by team. To account for possible multi-collinearity between covariates in the detection function, following the conclusions of Dormann et al. (2013), we used only 1 covariate of pairs of covariates that had a correlation coefficient of $|r|>0.7$. However, Dormann et al. (2013) also pointed out that collinearity is a severe problem when we predict a model based on data from one region or time to another with a different or unknown structure of collinearity. This situation was not applicable in this analysis.

In some cases, we pooled data from similar looking species for the analysis to ensure a sufficient sample size to estimate the model parameters. For example, a global MRDS analysis used data from all beaked whale (Ziphiidae) sightings. Then, individual covariate values from each species applied to the global function resulted in species-specific detection functions. Finally, we estimated a species-specific abundance by using the species-specific detection functions, expected group sizes, and encounter rates.

Ambiguously identified groups

In some cases, observers were only able to identify the animals as 1 of 2 (or more) species. For example, sometimes observers were only able to identify the animals as either a fin whale (*Balaenoptera physalus*) or sei whale (*Balaenoptera borealis*). For other groups, observers were only able to identify the animals as some sort of Mesoplodont beaked whale, or perhaps as one of the *Kogia* whales. We used both the positively identified and ambiguous sightings in the estimation process. For example, we calculated the abundance of fin whales ($abun_{all.fin}$) as the sum of the abundance of positively identified fin whales ($abun_{pos.fin}$) and a portion of the abundance estimate of animals identified as either a fin or sei whales ($abun_{fin/sei} * g$):

$$abun_{all.fin} = abun_{pos.fin} + (abun_{fin/sei} * g) \qquad Eq.1$$

where

$$g = \frac{abun_{pos.fin}}{abun_{joint}}$$

$$abun_{joint} = abun_{pos.fin} + abun_{pos.sei}$$

and

$$var(abun_{fin/sei} * g) = \left(\frac{g*(1-g)}{abun_{joint}-1}\right).$$

The same process prorated the strata-specific abundance estimates of the following:

- unidentified Mesoplodonts to Sowerby's (*Mesoplodon bidens*) and True's beaked (*Mesoplodon mirus*) whales;
- unidentified Ziphiidae to Cuvier's (*Ziphius cavirostris*), Sowerby's, and True's beaked whales;
- *Kogia* spp. to dwarf sperm (*Kogia simus*) and pygmy sperm (*Kogia breviceps*) whales;
- aerial common/Atlantic white-sided dolphins to aerial common (*Delphinus delphis*) and aerial Atlantic white-sided dolphins (Lagenorhynchus acutus);
- shipboard *Stenella* sp. to shipboard Atlantic spotted (*Stenella attenuata*), spinner (*Stenella longirostris*), striped (*Stenella coeruleoalba*), and Clymene (*Stenella clymene*) dolphins; and
- shipboard *Delphinis*/*Stenella* to shipboard Atlantic spotted, striped, and common dolphins.

We did not add abundance estimates from ambiguous sightings labeled as unidentified dolphin or unidentified whale to any abundance estimates of positively identified species because it was not clear if the strategy used in Equation 1 was the appropriate approach for such general groupings.

Partitioning between short-finned and long-finned pilot whales

The vessel-based portion of the NEFSC abundance survey corresponded to the region where there is overlap between short-finned and long-finned pilot whales, particularly in the shelfbreak stratum. Garrison and Palka (2018) identified water temperature, water depth, and time of year as predictors of the proportion of each species at a particular location to assign sightings recorded as unidentified pilot whales to species. For each unidentified pilot whale sightings detected in the shipboard shelfbreak and offshore strata, we used the model developed in Garrison and Palka (2018) to predict the likelihood that the group was short-finned pilot whales based on the water temperature and depth at the time of observation. If the predicted probability was greater than 0.5, we assigned the group as a short-finned pilot whale. We summarized by stratum the proportion of individuals predicted to be short-finned (or long-finned) pilot whales. We then resampled the model parameters to develop a bootstrap distribution of the predicted proportion to account for uncertainty in the model predictions.

Availability correction

We calculated the abundance estimate accounting for both perception and availability bias by the product of the perception-bias corrected abundance and an availability biased correction factor. The perception-bias corrected abundance estimate is that described above by using mark-recapture distance sampling methods. We derived the availability bias correction factor is from Palka et al. (2017). In this analysis, we used the inverse of the correction factors presented in Palka et al. (2017). The reason is simply that the interpretation of a correction factor is easier to understand when we multiply a factor to the perception-bias correction abundance estimate as presented in this paper, in contrast to dividing the perception-bias correction abundance estimate by the inverse of the correction factor, as presented in Palka et al. (2017).

Laake et al. (1997, equation 7) defined the availability correction factor as the probability that an animal group at a perpendicular distance (x) was at the surface and within the observer's field of view. He modeled this factor as a 2-state continuous-time Markov process, requiring the average time a group was at the surface (representing time available to be seen by the observers), average time at depth (representing time unavailable to be seen), and amount of time a group at perpendicular distance x from the trackline remained in view of the observers. Since we estimated the average surface and dive times from individual animals and the correction factor needs to represent a correction for groups (which was the unit used in the abundance estimate accounting for perception bias), the group sizes as observed during the surveys were also accounted for. A full description of this calculation is in Palka et al. (2017).

Coefficient of variation estimation

We estimated the coefficient of variation (CV) of the abundance estimates by using the delta method and empirical variance in encounter rate between samples (Buckland et al. 2001; Fewster et al. 2009). The CV of the abundance estimates that included a portion of ambiguous groups included the variance of this portion.

RESULTS

General

Within 2 legs, the ship surveyed in the shelfbreak, offshore, Wind-MA, and Wind-MidAtl strata (Figure 1). Leg 1 was from June 16–July 11, 2021 (26 days), and leg 2 was from July 27–August 23, 2021 (28 days). In total, we surveyed on the ship for 230 on-effort hours during 38 good weather survey days, out of the total 50 days available to survey. We surveyed an additional 90.0 hours in less ideal conditions, Beaufort 4 or more, termed extra tracklines.

The plane surveyed on primary tracklines in the GOM stratum on August 1 and September 15, 2021, where 31.3 hours of on-effort surveying were during 17 good weather flight days (Figure 1). We surveyed an additional 25.2 hours on extra tracklines in the GOM and shelfbreak strata. We used the extra trackline data in the estimation of the detection function but not the encounter rate (as explained in more detail in the methods section).

Within the primary strata using both platforms, we surveyed 8,696.2 km of tracklines within a study area of 464,492 km^2 (Table 1). We surveyed about 75% of these tracklines in Beaufort Sea states of 3 or less (Table 1A; Figure 2). On the extra aerial and shipboard tracklines, we surveyed 6,247.7 and 1,697.6 km, respectively (Table 1B).

On the shipboard survey, we detected and positively identified 23 cetacean and 2 sea turtle species, along with several fish species (Tables 2-5). On the aerial survey, we detected and positively identified 10 cetacean, 4 sea turtle, and 2 seal species, along with several fish species (Tables 2-5). The locations of the cetacean and sea turtle sightings detected on the 2 platforms are in Figures 3-20. A general description of the distribution of the cetacean species is as follows:

- Species located either completely or nearly all within the GOM stratum included Atlantic white-sided dolphins, and harbor porpoises (*Phocoena phocoena)*.
- Species found in the GOM and on the shelfbreak included fin whales, humpback whales (*Megaptera novaeangliae*), sei whales, minke whales (*Balaenoptera acutorostrata)*, and common dolphins.
- Species found on the shelfbreak and in deeper waters included Atlantic spotted dolphins, beaked whales, sperm whales (*Physeter macrocephalus*), and striped dolphins.
- Species found mostly in waters deeper than the shelfbreak included dwarf sperm whales, false killer whales (*Pseudorca crassidens*), pygmy sperm whales, and spinner dolphins.
- Species found throughout the study area included bottlenose dolphins (*Tursiops truncatus*), Risso's dolphins (*Grampus griseus)*, and pilot whales.

Abundance estimates

Potential covariates that could be included the abundance models (Table 6) include variables describing the sighting conditions (Beaufort sea state, cloud cover, glare, sighting time, swell height, turbidity, visibility description, and a subjective evaluation of the overall quality of sighting conditions) and animal group characteristics (behavior, cue, group size, log of group size, species identification, and swim direction). Diagnostic plots from the distance sampling analyses for the species groupings from the aerial and shipboard surveys are in Appendices A and B, respectively. The diagnostics include scaled histograms of each team's detections, conditional mark-recapture detection functions for each team assuming detections from the other team, and quantile-quintile plots showing goodness of fits.

The average group sizes from the aerial (Table 7) and ships surveys (Tables 8 and 9) of large whales and *Kogia* spp. were the smallest: fewer than 2 animals per group per species. Harbor porpoises and beaked whales had slightly larger average group sizes: fewer than 4 animals per group per species. Average group sizes of bottlenose dolphins, Atlantic white-sided dolphins, false killer whales, and pilot whales were fewer than 12 animals per group per species. Average group sizes of the other dolphin species (common dolphins, Atlantic spotted dolphins, spinner dolphins, Clymene dolphins, and striped dolphins) were the largest, averaging 11-140 animals per group per species. Of the dolphin species found spread out throughout the study area (common dolphins, Risso's dolphins, bottlenose dolphins, and pilot whales), the average group sizes in the GOM were larger or about the same as the groups detected farther offshore on the shelfbreak and in deeper water. This is in contrast to that observed in the 2016 survey (Palka 2021).

The covariates that most commonly contributed significantly to the DS detection function models were group size and some descriptor of the sighting condition (such as quantified by subjective quality or Beaufort sea state), while group size (or log of group size) was the most common covariate in the MR models (Tables 10 and11). For the MR models, observer team was commonly significant for the shipboard data and large groups of animals detected from the plane.

The estimated effective strip half-width of the primary team ranged from about 150-300 m for groups detected from the plane to about 2000-4000 m or more for large whales as detected from the ship (Tables 10 and 11).

Availability bias correction factors included in the analysis (Table 12) were the inverse of those developed in Palka et al. (2017).

Intermediate abundance estimates used as input into Equation 1 to derive the strata-specific abundances of species that include some sightings that had ambiguous identifications are in Table 10. For example, in the shelfbreak stratum, we estimated 39 (CV = 0.75) ambiguously identified fin or sei whales (Table 13). Using Equation 1 for the shelfbreak animals, the estimated 39 ambiguously identified animals were prorated and added to the abundance estimates of positively identified fin whales (1,252 CV = 0.50) and positively identified sei whales (33 CV = 1.02; Table 10). This resulted in the shelfbreak strata-specific abundance estimates reported in Table 12: 1,290 (CV = 0.48) fin whales and 34 (CV = 0.99) sei whales.

We used the predicted proportions of short-finned and long-finned pilot whales for each shipboard stratum to partition the stratum-specific estimated abundance of all pilot whales (Table 14). For the offshore stratum, we predicted 99.5% (CV = 0.025) of the sightings to be short-finned pilot whales while this proportion for the shelfbreak stratum was 33.3% (CV = 0.22).

Total abundance of the 23 species observed in the surveyed area was 338,365 animals (CV = 0.24; Table 15). Abundance estimates range from less than 100 animals per species that were rarely seen in U.S. waters during the summer (for example, blue and sei whales), to over 80,000 animals per species of harbor porpoises and common dolphins.

DISCUSSION

The goal of this effort was to incorporate visibility biases in the abundance estimates of cetaceans detected during the NEFSC summer 2021 surveys. To accomplish this goal, we used visual 2-team line transect data collected from shipboard and aerial observation platforms in MRDS analysis methods to estimate abundance that incorporates perception bias. We then multiplied this estimate by a species-specific availability bias correction factor derived from species-specific dive patterns. In total, we calculated abundance estimates for 23 species (or species groups). These estimates represent the most recent available for the U.S. northern Atlantic waters. Thus, the combined estimates reported here and the abundance estimates from the U.S. southern Atlantic waters (Garrison and Dias 2023) collected at the same time are appropriate to update the U.S. Atlantic stock assessment reports.

We did not explicitly account for process error in this analysis. Process error can be due to interannual variability in the number of animals truly present within the study area. This variability could be due to random animal movement patterns both within the study area or between inside and outside of the study area. The variability could be due to an individual animal moving in response to changing physical and biological ocean conditions. Because of interannual variability, it is feasible that environmental factors incorporated in spatially explicit habitat-density models may help explain the variability in the encounter rates and group sizes and thus produce more precise abundance estimates. Examples of environmental factors include water temperature, bottom depth, presence/intensity of temperature or salinity fronts, and magnitude of chlorophyll and fish biomass. Chavez-Rosales et al. (2022) reported northeasterly seasonal distribution shifts between 2010 and 2017 for most cetacean species off U.S. Atlantic waters. To follow up, future work plans include standardizing all available summer 1992-2021 abundance estimates in a trend analysis that uses multivariate autoregressive state-space modeling techniques that incorporate environmental factors to explain process and observation error.

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TABLES AND FIGURES

Table 1. General description of strata covered by the aerial and shipboard surveys. Description includes the area (in km^2), platform used, and length of tracklines (in km) covered during Beaufort sea state levels (Beauf). A = Description of primary tracklines by strata. B = Description of extra tracklines and extra shipboard strata used to augment the estimation of the detection functions. Strata include Shelfbreak, Offshore, Gulf of Maine (GOM), wind energy area off Massachusetts (Wind-MA) and wind energy area off the Mid-Atlantic States (Wind-MidAtl).

A. Primary tracklines	Area (km^2)	Platform	Beauf 0	Beauf 1	Beauf 2	Beauf 3	Beauf 4	Beauf 5	Beauf 6	TOTAL
Shelfbreak	55,209	Ship	53.0	71.6	286.1	534.1	349.4	113.2	33.8	1,441.2
Offshore	194,036	Ship	8.2	146.8	586.8	613.4	434.0	161.0	87.5	2,037.7
GOM	215,247	Plane	24.8	240.4	2,072.5	1,900.6	923.5	55.5	0	5,217.3
TOTAL	464,492	Ship + Plane	86.0	458.8	2,945.4	3,048.1	1,706.9	329.7	121.3	8,696.2
Percent of total			0.01	0.05	0.34	0.35	0.20	0.04	0.01	1.0
Cumulative percent of total			0.01	0.06	0.40	0.75	0.95	0.99	1.00	
B. Extra tracklines	**Area (km^2)**	**Platform**	**Beauf 0**	**Beauf 1**	**Beauf 2**	**Beauf 3**	**Beauf 4**	**Beauf 5**	**Beauf 6**	**TOTAL**
Shelfbreak-extra tracks	-	Ship	0	0	74.1	301.2	502.7	526.6	39.2	1,443.8
Offshore-extra tracks	-	Ship	0	26.8	12.6	29.5	23.6	122.1	39.2	253.8
GOM-extra tracks	-	Plane	52.8	417.1	1,380.2	1,725.3	1,097.4	149.7	0	4,822.5
Shelfbreak-extra tracks	-	Plane	0	47.5	251.9	497.0	547.2	81.6	0	1,425.2
Wind-MA	2,563	Ship	0	0	0	174.7	43.5	0	0	218.2
Wind-MidAtl	8,672	Ship	0	43.8	111.4	123.5	167.3	26.4	0	472.4
GRAND TOTAL	464,492	Ship + Plane	138.8	994.0	4,775.6	5,899.3	4,088.6	1,236.1	199.7	17,332.1

Table 2. Number of dolphin groups detected by species, team (Upper, Lower, Front, Back), platform (Ship, Plane), and trackline type (Primary, Extra).

Species, Common Name	Species, Scientific Name	Primary Ship Lower	Primary Ship Upper	Extra Ship Lower	Extra Ship Upper	Primary Plane Back	Primary Plane Front	Extra Plane Back	Extra Plane Front	TOTAL Primary	TOTAL Extra
Atlantic spotted dolphin	*Stenella attenuata*	15	18	6	6	0	0	0	0	33	12
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	0	3	0	0	6	9	4	5	18	9
Bottlenose dolphin	*Tursiops truncatus*	84	83	24	20	5	19	18	32	191	94
Clymene dolphin	*Stenella clymene*	1	1	0	0	0	0	0	0	2	0
Common dolphin	*Delphinus delphis*	38	46	9	11	0	0	0	0	84	20
Common/Whitesided dolphin	*Delphinus/Lagenorhynchus*	0	0	0	0	0	5	4	4	5	8
Delphinus/Stenella	*Delphinus/Stenella*	6	9	3	3	0	0	0	0	15	6
Harbor porpoise	*Phocoena phocoena*	0	0	0	0	46	47	8	12	93	20
Pilot whale, Long-finned	*Globicephala melas*	3	5	1	0	0	0	0	0	8	1
Pilot whale, Short-finned	*Globicephala macrorhynchus*	4	5	2	5	0	0	0	0	9	7
Pilot whale, Unid	*Globicephala sp.*	11	14	17	10	8	15	1	11	48	39
Right whale	*Eubalaena glacialis*	0	0	0	0	0	0	0	2	0	2
Risso's dolphin	*Grampus griseus*	62	66	15	25	8	12	16	28	148	84
Risso's/Bottlenose	*Grampus/Tursiops*	5	0	5	1	0	0	0	0	5	6
Spinner dolphin	*Stenella longirostris*	2	2	0	0	0	0	0	0	4	0
Stenella sp.	*Stenella spp.*	23	21	3	4	0	0	0	0	44	7
Striped dolphin	*Stenella coeruleoalba*	37	39	4	4	0	0	0	0	76	8

Table 3. Number of whale groups detected by species, team (Upper, Lower, Front, Back), platform (Ship, Plane), and trackline type (Primary, Extra).

Species, Common Name	Species, Scientific Name	Primary Ship Lower	Primary Ship Upper	Extra Ship Lower	Extra Ship Upper	Primary Plane Back	Primary Plane Front	Extra Plane Back	Extra Plane Front	TOTAL Primary	TOTAL Extra
Cuvier's beaked whale	*Ziphius cavirostris*	8	6	1	2	1	1	0	0	16	3
Sowerby's beaked whale	*Mesoplodon bidens*	4	3	1	1	0	0	0	0	7	2
True's beaked whale	*Mesoplodon mirus*	5	7	1	0	0	0	0	0	12	1
Unidentified Mesoplodon	*Mesoplodon*	7	7	0	0	0	0	0	0	14	0
Unidentified Ziphiidae	*Ziphiid*	19	24	1	0	0	0	0	0	43	1
Blue whale	*Balaenoptera musculus*	1	1	1	0	0	0	0	0	2	1
False killer whale	*Pseudorca crassidens*	3	7	0	0	0	0	0	0	10	0
Fin whale	*Balaenoptera physalus*	52	66	29	40	1	7	1	8	126	78
Fin or Sei whale	*B. physalus or B. borealis*	4	1	0	0	0	0	0	0	5	0
Humpback whale	*Megaptera novaeangliae*	12	13	16	11	1	0	7	10	26	44
Killer whale	*Orcinus orca*	0	1	0	0	0	0	0	0	1	0
Dwarf sperm whale	*Kogia simus*	18	13	1	0	0	0	0	0	31	1
Pygmy sperm whale	*Kogia breviceps*	0	3	0	1	0	0	0	0	3	1
Dwarf or Pygmy sperm whale	*Kogia sp.*	1	7	2	1	0	0	0	0	8	3
Minke whale	*B acutorostrata*	0	0	3	1	9	14	13	32	23	49
Right whale	*Eubalaena glacialis*	0	0	0	0	0	0	0	2	0	2
Sei whale	*Balaenoptera borealis*	1	2	1	0	0	0	0	0	3	1
Sperm whale	*Physeter macrocephalus*	80	81	31	19	0	0	1	2	161	53

Table 4. Number of unidentified groups detected by species and all cetaceans, team (Upper, Lower, Front, Back), platform (Ship, Plane), and trackline type (Primary, Extra).

Species, Common Name	Species, Scientific Name	Primary Ship Lower	Primary Ship Upper	Extra Ship Lower	Extra Ship Upper	Primary Plane Back	Primary Plane Front	Extra Plane Back	Extra Plane Front	TOTAL Primary	TOTAL Extra
Unid. Baleen whale	*Mysticeti*	1	2	0	1	0	0	0	0	3	1
Unid. Balaenoptera	*Balaenoptera*	11	4	6	4	0	0	0	0	15	10
Unid. Cetacean	*Cetacea*	1	2	1	2	0	0	0	0	3	3
Unid. Dolphin	*Delphinidae*	55	65	13	12	1	5	5	9	126	39
Unid. Large dolphin	*Delphinidae*	4	1	1	1	0	0	0	0	5	2
Unid. Large whale	*Mysticeti*	10	19	7	7	0	1	3	5	30	22
Unid. Medium whale	*Mysticeti*	0	1	0	0	0	0	0	0	1	0
TOTAL CETACEANS		588	648	205	192	86	135	81	160	1457	638

Table 5. Number of groups of other species detected by species, team (Upper, Lower, Front, Back), platform (Ship, Plane), and trackline type (Primary, Extra).

Species, Common Name	Species, Scientific Name	Primary Ship Lower	Primary Ship Upper	Extra Ship Lower	Extra Ship Upper	Primary Plane Back	Primary Plane Front	Extra Plane Back	Extra Plane Front	TOTAL Primary	TOTAL Extra
Manta, Chilean devil ray	*Mobula tarapacana*	1	1	1	0	8	11	13	22	21	36
Manta, Spinetail devil ray	*Mobula mobular*	2	3	0	0	0	0	0	0	5	0
Manta, Unid	*Mobula sp.*	6	4	3	1	4	4	1	0	18	5
Manta, Unid black and white	*Mobula sp.*	0	2	1	3	0	0	0	0	2	4
Mola, Unid	*Mola sp.*	6	4	3	5	143	216	45	80	369	133
Ray, Cownose	*Rhinoptera bonasus*	0	0	0	0	17	22	1	0	39	1
Ray, Unid	*Rhinoptera*	0	2	0	0	4	0	3	2	6	5
School of fish	-	8	5	0	2	0	0	0	0	13	2
Tuna sp.	*Thunnini sp.*	8	6	1	4	3	0	4	3	17	12
Shark, Basking	*Cetorhinus maximus*	0	1	0	0	10	12	5	10	23	15
Shark, Blue	*Prionace glauca*	0	0	0	0	29	30	47	47	59	94
Shark, Great white	*Carcharodon carcharias*	0	0	0	0	8	3	13	13	11	26
Shark, Hammerhead	*Sphyrnidae sp.*	0	0	0	0	30	31	7	10	61	17
Shark, Mako, sp.	*Isurus sp.*	0	0	0	0	0	1	0	0	1	0
Shark, Thresher, sp.	*Alopias sp.*	0	0	0	0	1	1	0	0	2	0
Shark, Tiger	*Galeocerdo cuvier*	0	0	0	0	1	2	1	1	3	2
Shark, Whale	*Rhincodon typus*	0	0	0	0	2	2	5	4	4	9
Shark, Unid.	-	11	13	2	4	95	81	171	180	200	357
Turtle, Hardshell	*Chelonioidea*	6	1	0	0	29	56	5	8	92	13
Turtle, Leatherback	*Dermochelys coriacea*	4	4	2	0	9	13	11	13	30	26
Turtle, Loggerhead	*Caretta caretta*	20	17	0	1	85	109	10	6	231	17
Turtle, Green	*Chelonia mydas*	0	0	0	0	9	13	0	0	22	0
Turtle, Kemp's ridley's	*Lepidochelys kempii*	0	0	0	0	0	1	1	0	1	1
Seal, Gray	*Halichoerus grypus*	0	0	0	0	1	3	2	5	4	7
Seal, Harbor	*Phoca vitulina*	0	0	0	0	8	2	0	4	10	4
Seal, Unid	*Pinniped*	0	0	0	0	20	14	2	3	34	5

Table 6. Description of covariates used in abundance analyses of the aerial and shipboard data.

Abbreviation	Description	Platform	Type	Values
Beaufort	Beaufort sea state	Both	Continuous	0-6, in increments of 0.1
Behav	Group activity when initially detected	Both	Factor	Low profile (swimming, feeding, logging, milling, motionless); Medium profile (diving, bow riding, fluking, porpoising); High profile (aerobatics, charging, breaching)
CloudCov	Percent cloud cover	Both	Continuous	0-100, usually in increments of 5
Cue	Feature of sighting initially detected	Both	Factor	Low profile (body or footprint); Medium profile (splash, birds, water disturbance, bubbles); Higher profile (blow)
GlareC and GlareF	Severity of sun glare in the area where there is glare	Both	Continuous and Factor	0 = none; 1 = slight; 2 = moderate; 3 = severe
SightTime	Time of day of initial detected	Both	Continuous	0600-1900, in decimal format (e.g., 1530 = 15.5)
Size	Best estimate of the number of animals in the group	Both	Continuous	1-1000 (ship max = 365, plane max = 1000)
Logsize	Logarithm of the group size	Both	Continuous	
Species	Name of species	Both	Factor	Species name
Subj	Subjective overall quality of the sighting conditions as determined by the average of each observers' evaluation	Both	Continuous	0 = poor; 1 = fair; 2 = moderate; 3 = good; 4 = excellent
SwellHeight	Approximate height of the ocean's swell (m)	Ship	Continuous	0-2.0 m
SwimDir	Approximate direction the group is swimming towards relative to the track line	Ship	Continuous	0-359, in increments of 5. 0 = swimming in same direction that the ship is traveling; 45 = swimming to the right directly perpendicular to the track line; 180 = swimming in the opposite direction of the ship's travel; 275 = swimming to the left directly perpendicular to the track line.
Turb	Turbidity, subjective evaluation of the level of water clarity	Plane	Factor	1 = moderately clear; 2 = turbid; 3 = very turbid
VizC and VizF	Description of the general visibility at the horizon	Ship	Continuous and Factor	0 = clear horizon; 1 = good horizon; 2 = thin haze; 3 = thick haze; 4 = bad obscured horizon

Table 7. Description of aerial survey data for each species within the pooled species groups. Unshaded rows in italics are from the pooled species groups detected on the primary and extra tracklines within the chosen truncation perpendicular distance, in meters. Shaded rows are the individual species within the pooled species groups detected on only the primary tracklines within the truncation distance. Other descriptions include the number of groups detected by the front team (n-Front); the number of groups detected by the back team (n-Back); the number of duplicate sightings (n-Dups) detected by both teams; and the average group size with its associated coefficient of variation (CV(Average Group Size)).

Pooled Species Group Species	Species Scientific Name	Truncation Distance (m)	n-Front	n-Back	n-Dups	Average Group Size	CV(Average Group Size)
Harbor porpoise		*200*	*49*	*51*	*28*	*2.46*	*0.06*
Harbor porpoise	*Phocoena phocoena*		42	43	22	2.74	0.09
Small dolphins		*400*	*81*	*75*	*55*	*35.30*	*0.28*
Common dolphin	*Delphinus delphis*		38	19	15	27.29	0.09
Atlantic white-sided dolphin	Lagenorhynchus acutus		9	6	5	6.50	0.19
Common or Atlantic white-sided dolphin	*D. delphis* or *L. acutus*		1	0	0	2.00	0.00
Large dolphins		*500*	*79*	*56*	*42*	*7.13*	*0.16*
Bottlenose dolphin	*Tursiops truncatus*		13	4	2	7.47	0.18
Risso's dolphin	*Grampus griseus*		2	1	1	36.00	0.22
Pilot whale spp.	*Globicephala sp.*		2	0	0	10.00	0.35
Large whales		*600*	*36*	*31*	*25*	*1.02*	*0.02*
Fin whale	*Balaenoptera physalus*		8	2	2	1.38	0.13
Humpback whale	*Megaptera novaeangliae*		9	7	4	1.17	0.07
Minke whale	*Balaenoptera acutorostrata*		45	21	17	1.00	0.00
Sperm whale	*Physeter macrocephalus*		2	1	1	1.00	0.00

Table 8. Description of shipboard survey data for each species within the pooled whale species groups. Unshaded rows in italics are from the pooled species groups detected on the primary and extra tracklines within the chosen truncation perpendicular distance, in meters. Shaded rows are the individual species comprising the pooled species groups detected on only the primary tracklines within the truncation distance. Other descriptions include the number of groups detected by the front aerial team (n-Front); the number of groups detected by the back aerial team (n-Back); the number of duplicate sightings (n-Dups) detected by both teams; and the average group size with its associated coefficient of variation (CV(Average Group Size))

Pooled Species Group Species	Species Scientific Name	Truncation Distance (m)	n-Lower	n-Upper	n-Dups	Average Group Size	CV(Average Group Size)
Large whales		*4000*	*103*	*108*	*55*	*1.32*	*0.04*
Blue whale	*Balaenoptera musculus*		1	1	0	1.00	0.00
Fin whale	*Balaenoptera physalus*		45	53	28	1.36	0.04
Fin or Sei whale	*B. physalus or B. borealis*		3	0	0	1.00	0.00
Humpback whale	*Megaptera novaeangliae*		11	11	4	1.22	0.07
Sei whale	*Balaenoptera borealis*		1	2	1	1.50	0.19
Sperm whale		*6500*	*106*	*95*	*51*	*1.55*	*0.04*
Sperm whale	*Physeter macrocephalus*		75	77	41	1.53	0.03
Beaked whales and Kogia spp.		*2500*	56	61	24	2.09	0.06
Cuvier's beaked whale	*Ziphius cavirostris*		8	5	3	2.90	0.11
Sowerby's beaked whale	*Mesoplodon bidens*		4	3	2	3.00	0.12
True's beaked whale	*Mesoplodon mirus*		5	7	3	3.11	0.11
Unidentified Mesoplon	*Mesoplodon*		7	5	2	2.60	0.15
Unidentified Ziphiid	*Ziphiid*		9	16	3	1.82	0.08
Dwarf sperm whale	*Kogia simus*		17	12	9	1.50	0.09
Pygmy sperm whale	*Kogia breviceps*		0	2	0	1.50	0.19
Dwarf/pygmy sperm whale	*Kogia* sp.		0	7	0	1.29	0.10

Table 9. Description of shipboard survey data for each species within the pooled dolphin species groups. Unshaded rows in italics are from the pooled species groups detected on the primary and extra tracklines within the chosen truncation perpendicular distance, in meters. Shaded rows are the individual species comprising the pooled species groups detected on only the primary tracklines within the truncation distance. Other descriptions include the number of groups detected by the front aerial team (n-Front); the number of groups detected by the back aerial team (n-Back); the number of duplicate sightings (n-Dups) detected by both teams; and the average group size with its associated coefficient of variation (CV(Average Group Size))

Pooled Species Group Species	Species Scientific Name	Truncation Distance (m)	n-Lower	n-Upper	n-Dups	Average Group Size	CV(Average Group Size)
Bottlenose dolphin		*2500*	*97*	*83*	*65*	*12.09*	*0.10*
Bottlenose dolphin	*Tursiops truncatus*		63	58	43	12.19	0.07
Small dolphins		*4000*	*137*	*153*	*105*	*30.55*	*0.09*
Atlantic spotted dolphin	*Stenella attenuata*		15	18	15	28.50	0.13
Clymene dolphin	*Stenella clymene*		1	1	0	64.00	0.04
Common dolphin	*Delphinus delphis*		34	39	26	30.13	0.19
Delphinus/Stenella	*Delphinus* or *Stenella*		5	5	4	34.33	0.25
Spinner dolphin	*Stenella longirostris*		2	2	2	138.50	0.35
Stenella sp.	*Stenella* sp.		16	16	7	15.76	0.12
Striped dolphin	*Stenella coeruleoalba*		35	37	31	40.80	0.07
Large dolphins		*3000*	*112*	*122*	*67*	*6.47*	*0.08*
False killer whale	*Pseudorca crassidens*		2	3	2	5.00	0.44
Pilot whales sp.	*Globicephala sp.*		15	20	13	7.45	0.10
Risso's dolphin	*Grampus griseus*		60	61	34	6.46	0.09

Table 10. Aerial survey results from the distance sampling analyses. Step 1 of analysis is from the independent observer (IO) configuration assuming point independence by using data from both teams in area of overlap. Step 2 is a multiple covariate distance sampling analysis using only the primary team (the front team). The following results are reported: key model; significant covariates for the distance sampling (DS) and mark-recapture (MR) models; Cramer-von Mises goodness-of-fit test p-value (C-vM p-value);); Akaike Information Criteria (AIC); effective half strip width (Eshw) and its coefficient of variation [cv(Eshw)], measured in meters; and average probability of detecting an animal group on the track line by the primary team [p(0)] and its coefficient of variation [cv(p(0))].

Pooled Species Group[1]	Team	Trunc Dist (m)	Key Model[2]	Covariates for Detection Function (DS)[3]	Covariates for Mark-Recapture (MR) [3]	C-vM Test p-value	AIC	Eshw (m)	CV (Eshw)	Ave p(0) Primary Team	CV(p)
Harbor porpoise	IO	200	HR	Distance + Subj + Size	Distance + Size + Turb	0.76	904.1	-	-	0.62	0.18
	Front	200	HN	Distance + Cloudcov	NA	0.86	445.6	148	0.17	-	-
Atlantic white-sided dolphin, Common dolphin, Common/Atlantic white-sided dolphin	IO	400	HN	Distance + GlareF	(Team * Distance) + Size + Subj	0.82	1376.3	-	-	0.79	0.10
	Front	400	HN	Distance + Logsize + Beaufort	NA	0.74	665.4	273	0.14	-	-
Fin whale, Sperm whale, Humpback whale, Minke whale	IO	600	HR	Distance + Turb + Subj	Distance + Swmdir + Cloudcov	0.99	583.9	200	0.19	0.78	0.16
Bottlenose dolphin, Risso's dolphin, Pilot whale	IO	500	HN	Distance + Subj + Beaufort	Team*(Distance + Size + Beaufort)	0.90	1277	-	-	0.62	0.20
	Front	500	HN	Distance + Cloudcov + Subj	NA	0.61	555.8	252	0.15	-	-

[1] Species Scientific Names provided in Tables 2 and 3. [2]HR = hazard rate model. HN = half normal model.[3] Covariate abbreviations described in Table 6.

Table 11. Shipboard survey results from the distance sampling analyses. Analysis is from the independent observer (IO) configuration assuming point independence by using data from both teams. The following results are reported: key model; significant covariates for the distance sampling (DS) and mark-recapture (MR) models; Cramer-von Mises goodness-of-fit test p-value (C-vM p-value); Akaike Information Criteria (AIC); effective half strip width (Eshw) and its coefficient of variation [cv(Eshw)], measured in meters; and average probability of detecting an animal group on the track line by the primary team [p(0)] and its coefficient of variation [cv(p(0))].

Pooled Species Group[1]	Team	Truncation Distance (m)	Key Model[2]	Covariates for Detection Function (DS)[3]	Covariates for Mark-Recapture (MR)[3]	C-vM Test p-value	AIC	Eshw (m)	CV (Eshw)	Ave p(0) for Primary Team	Cv(p)
Fin, Sei, Fin/sei, Humpback, Minke, Blue whales	IO	4000	HR	Distance + Subj	(Team*Distance) + Size	0.81	2892.0	1907	0.20	0.62	0.12
Sperm whale	IO	6500	HR	Distance + CueF + SwmDir	(Team*Distance) + Logsize + Beaufort	0.77	2914.5	4222	0.08	0.60	0.13
Bottlenose dolphin spp.	IO	2500	HR	Distance + Beaufort + CueF	(Team*Distance) + Logsize + CueF	0.99	1957.0	1303	0.11	0.71	0.12
Atlantic spotted dolphin, Atlantic white-sided dolphin, Clymene dolphin, Common dolphin, Spinner dolphin, Striped dolphin, *Delphinus/Stenella*, *Stenella sp*.	IO	4000	HR	Distance + BehaviorF + Size	(Team*Distance) + Logsize + CueF	0.80	3345.0	2243	0.10	0.80	0.08
Pilot whales spp., Risso's dolphin, False killer whale	IO	3000	HR	Distance + Size + Beaufort	(Team*Distance) + Logsize + CueC	0.99	2922.0	919	0.20	0.71	0.12
Beaked whales, *Kogia* spp.	IO	2500	HR	Distance + Sighttime	Distance + Logsize	0.98	1639.4	1258	0.25	0.54	0.2

[1] Species Scientific Names provided in Tables 2 and 3. [2]HR = hazard rate model. HN = half normal model.[3] Covariate abbreviations described in Table 6.

Table 12. Availability bias correction factor for aerial and shipboard line transect data. Derived from Palka et al. (2017).

Species - Common Name	Species – Scientific Name	Aerial Factor	CV (Aerial Factor)	Shipboard Factor	CV (Shipboard Factor)
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	1.124	0.186	1	-
Bottlenose dolphin	*Tursiops truncatus*	1.274	0.364	1	-
Common dolphin	*Delphinus delphis*	1.075	0.138	1	-
Cuvier's beaked whale	*Ziphius cavirostris*	7.042	0.462	1.309	0.246
Fin whale	*Balaenoptera physalus*	2.674	0.336	1	-
Harbor porpoise	*Phocoena phocoena*	1.592	0.299	1	-
Humpback whale	*Megaptera novaeangliae*	1.541	0.185	1	-
Long/short finned pilot whale	*Globicephala melaena/ G. macrorhynchus*	1.473	0.241	1	-
Minke whale	*Balaenoptera acutorostrata*	3.257	0.397	1	-
Pygmy/dwarf sperm whale	*Kogia* sp.	-	-	1.855	0.307
Risso's dolphin	*Grampus griseus*	1.176	0.173	1	-
Right whale	*Eubalaena glacialis*	3.774	0.060	1	-
Sei whale	*Balaenoptera borealis*	2.398	0.517	1	-
Sperm whale	*Physeter macrocephalus*	6.897	0.005	1.631	0.247
Striped dolphin	*Stenella coeruleoalba*	1.000	0.000	1	-

Table 13. Intermediate abundance estimates (N) and coefficient of variation [CV(N)] for ambiguous identified sightings by stratum. Strata include the Gulf of Maine (GOM), Offshore, and Shelfbreak strata.

Species – Common Name	Species – Scientific Name	GOM N	GOM CV(N)	Offshore N	Offshore CV(N)	Shelfbreak N	Shelfbreak CV(N)	TOTAL N	TOTAL CV(N)
Fin whale	*Balaenoptera physalus*	924	0.67	26	0.93	1,252	0.50	2,202	0.40
Sei whale	*Balaenoptera borealis*	0	0	0	0	33	1.02	33	1.02
Fin or Sei whale	*B. physalus or B. borealis*	0	0	0	0	39	0.75	39	0.75
TOTAL FIN AND SEI WHALES		924	0.67	26	0.93	1,324	0.47	2,274	0.39
Cuvier's beaked whale	*Ziphius cavirostris*	0	0	882	0.59	250	0.56	1,132	0.48
Sowerby's beaked whale	*Mesoplodon bidens*	0	0	0	0	315	1	315	0.67
True's beaked whale	*Mesoplodon mirus*	0	0	912	0.48	165	0.67	1,077	0.42
Unidentified Mesoplodon	*Mesoplodon*	0	0	1,575	0.64	111	0.68	1,686	0.60
Unidentified Ziphiidae	*Ziphiid*	0	0	2,278	0.64	226	0.58	2,504	0.59
TOTAL BEAKED WHALES		0	0	5,647	0.34	1,067	0.30	6,714	0.29
Dwarf sperm whale	*Kogia simus*	0	0	2,952	0.71	107	0.80	3,059	0.68
Pygmy sperm whale	*Kogia breviceps*	0	0	139	1.02	30	1.10	169	0.86
Dwarf or Pygmy sperm whale	*Kogia sp.*	0	0	738	0.65	46	1.10	784	0.62
TOTAL KOGIA		0	0	3,829	0.56	183	0.57	4,012	0.54
Atlantic spotted dolphin	*Stenella attenuata*	0	0	4,986	0.25	1,901	0.60	6,887	0.25
Clymene dolphin	*Stenella clymene*	0	0	1,964	0.57	0	0	1,964	0.57
Delphinus/Stenella (ship) or Common/Atlantic white-sided dolphins (plane)	*Delphinus/Stenella* (ship) or *Delphinus/Lagenorhynchus* (plane)	144	1.10	0	0	1,579	0.60	1,723	0.56
Common dolphin	*Delphinus delphis*	74,591	0.69	0	0	9,198	0.34	83,789	0.62
Spinner dolphin	*Stenella longirostris*	0	0	2,706	0.76	0	0	2,706	0.76
Striped dolphin	*Stenella coeruleoalba*	0	0	29,811	0.40	1,839	0.55	31,650	0.37
Stenella sp.	*Stenella sp.*	0	0	8,276	0.35	131	0.83	8,407	0.35
Atlantic white-sided dolphin	Lagenorhynchus acutus	4,624	0.55	0	0	0	0	4,624	0.55
TOTAL SMALL DOLPHINS		79,359	0.65	47,743	0.26	14,648	0.25	141,750	0.37

Table 14. Abundance and coefficient of variation (CV) of short-finned (*Globicephala macrorhynchus*) and long-finned (*Globicephala melas*) pilot whales by shipboard stratum. Based on a logistic regression model of pilot whale habitat (Garrison and Palka 2018).

Stratum	Total Pilot Whale Abundance (CV)	Predicted Proportion Short-finned (CV)	Short-finned Pilot Whale Abundance (CV)	Long-finned Pilot Whale Abundance (CV)
Shelfbreak	4,509 (0.67)	0.333 (0.224)	1,501 (0.707)	3,008 (0.707)
Offshore	2,256 (1.02)	0.995 (0.025)	2,245 (1.020)	11 (1.020)

Table 15. Species abundance estimates (N) and coefficient of variation (CV) by stratum and in total. Strata include the Gulf of Maine (GOM), Offshore, and Shelfbreak strata.

Species - Common Name	Species – Scientific Name	GOM N	GOM CV(N)	Offshore N	Offshore CV(N)	Shelfbreak N	Shelfbreak CV(N)	TOTAL N	TOTAL CV(N)
Harbor porpoise	*Phocoena phocoena*	85,765	0.53	0	0.00	0	0	85,765	0.53
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	4,632	0.55	0	0.00	0	0	4,632	0.55
Fin whale	*Balaenoptera physalus*	924	0.67	26	0.93	1,290	0.48	2,240	0.39
Sei whale	*Balaenoptera borealis*	0	0.00	0	0.00	34	0.99	34	0.99
Minke whale	*Balaenoptera acutorostrata*	5,630	0.58	0	0.00	0	0	5,630	0.58
Blue whale	*Balaenoptera musculus*	0	0	0	0.00	26	1.02	26	1.02
Humpback whale	*Megaptera novaeangliae*	564	0.48	0	0.00	299	0.50	863	0.36
Sperm whale	*Physeter macrocephalus*	530	0.76	2,764	0.50	495	0.56	3,789	0.38
Bottlenose dolphin	*Tursiops truncatus*	17,870	0.67	12,000	0.30	7,851	0.24	37,721	0.34
Common dolphin	*Delphinus delphis*	74,726	0.69	0	0.00	10,309	0.31	85,035	0.61
Clymene dolphin	*Stenella clymene*	0	0.00	2,268	0.50	0	0.00	2,268	0.50
Atlantic spotted dolphin	*Stenella attenuata*	0	0	5,906	0.23	2,206	0.52	8,112	0.22
Spinner dolphin	*Stenella longirostris*	0	0	3,181	0.65	0	0	3,181	0.65
Risso's dolphin	*Grampus griseus*	13,813	0.76	4,115	0.59	21,684	0.76	39,612	0.50
Pilot whale, long-finned	*Globicephala melas*	2,691	1.04	11	1.02	3,008	0.71	5,710	0.62
Pilot whale, short-finned	*Globicephala macrorhynchus*	0	0	2,245	1.02	1,501	0.71	3,746	0.68
False killer whale	*Pseudorca crassidens*	0	0	753	1.13	0	0.00	753	1.13
Striped dolphin	*Stenella coeruleoalba*	0	0	36,388	0.36	2,134	0.48	38,522	0.34
Cuvier's beaked whale	*Ziphius cavirostris*	0	0	1,424	0.46	318	0.46	1,742	0.39
Sowerby's beaked whale	*Mesoplodon bidens*	0	0	0	0.00	492	0	492	0.46
True's beaked whale	*Mesoplodon mirus*	0	0	4,222	0.36	258	0.46	4,480	0.34
Dwarf sperm whale	*Kogia simus*	0	0	3,656	0.58	143	0.66	3,799	0.56
Pygmy sperm whale	*Kogia breviceps*	0	0	173	0.83	40	0.87	213	0.69
TOTAL		207,145	0.34	79,132	0.45	52,088	0.33	338,365	0.24

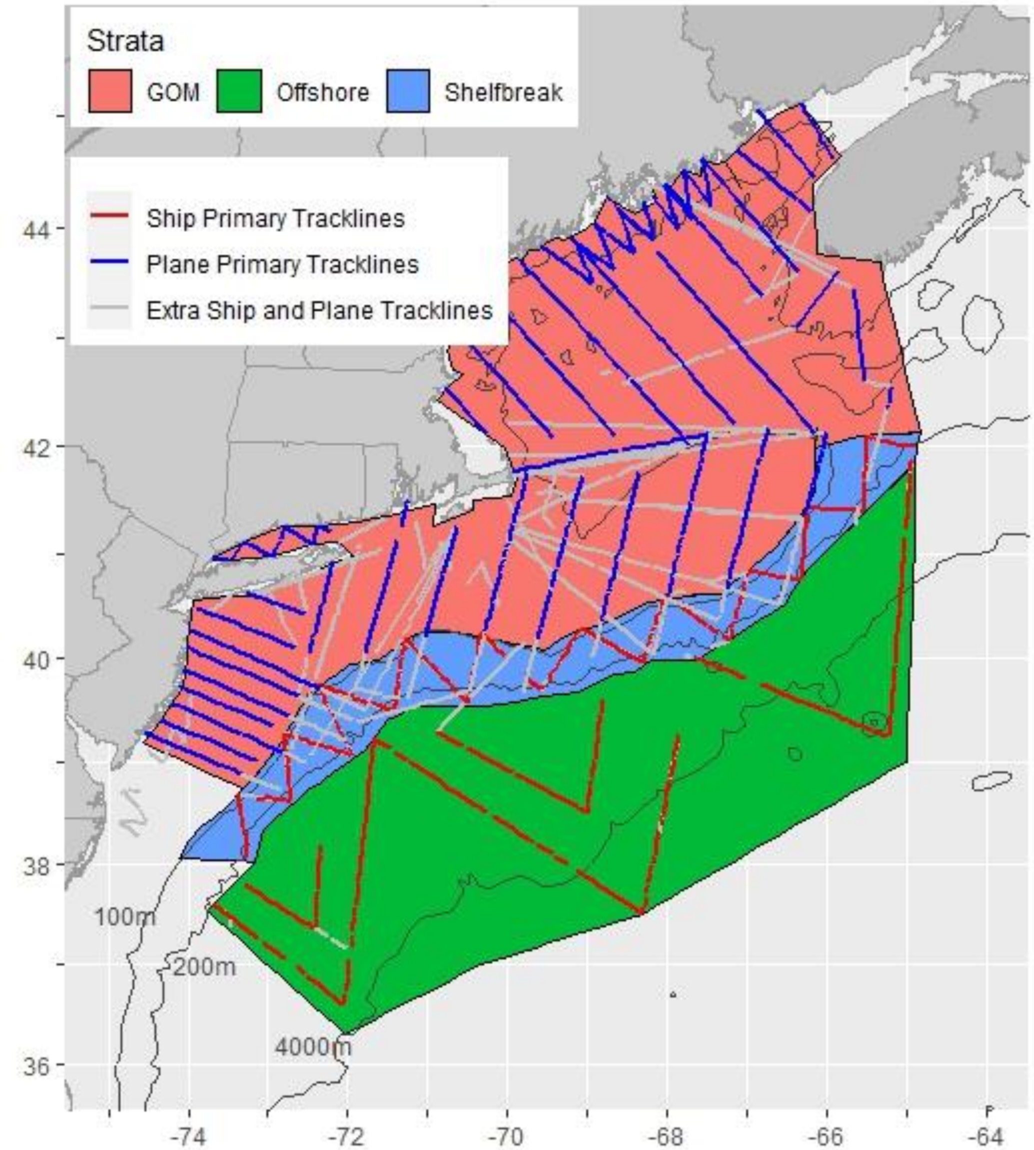

Figure 1. Strata and tracklines conducted during the 2021 northeast summer abundance survey. Surveys conducted by the Northeast Fisheries Science Center using ships and planes. Also displayed are the 100, 200, and 4000 m depth contours.

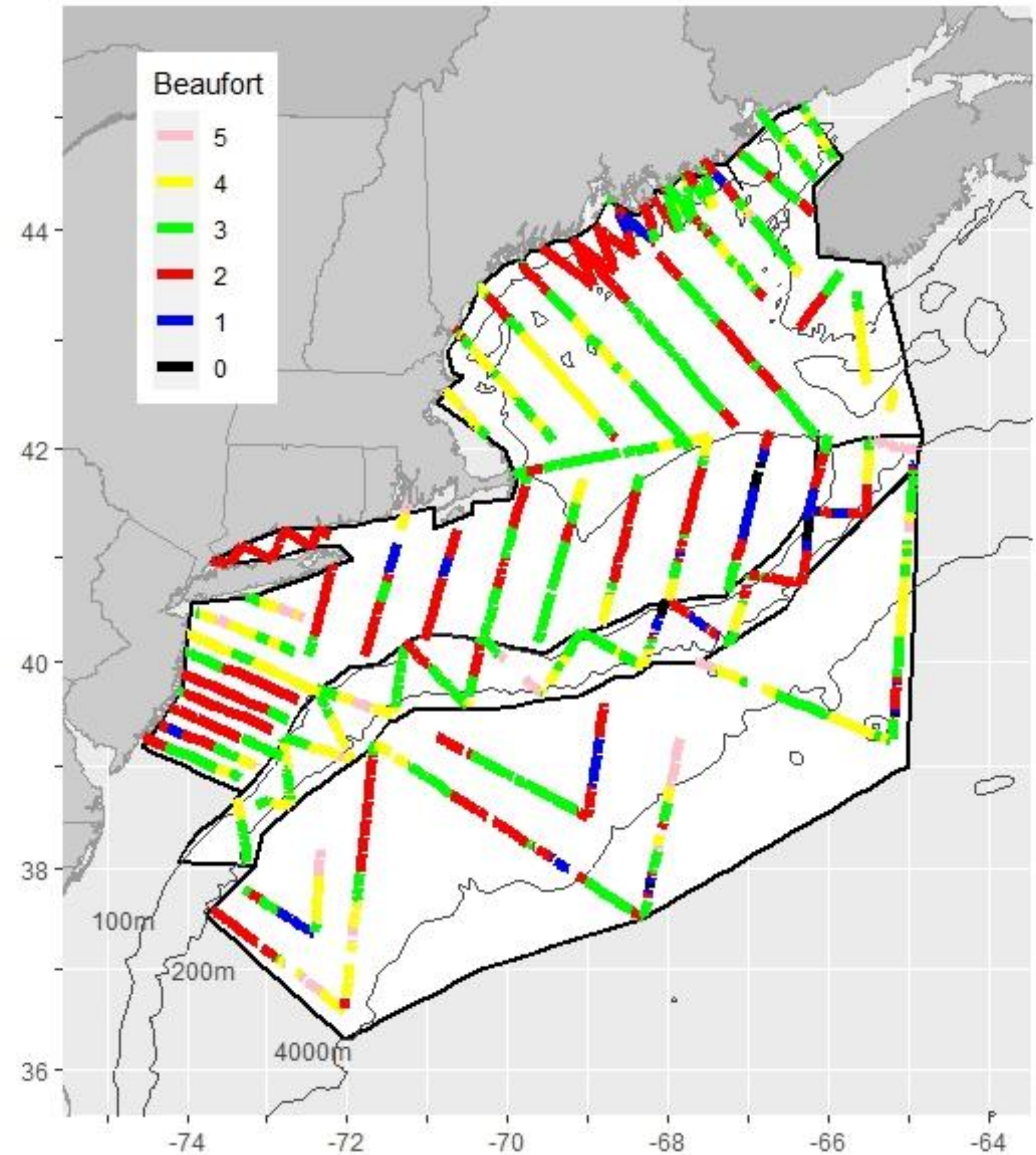

Figure 2. Beaufort sea state during survey. Also displayed are the survey strata and the 100, 200, and 4000 m depth contours.

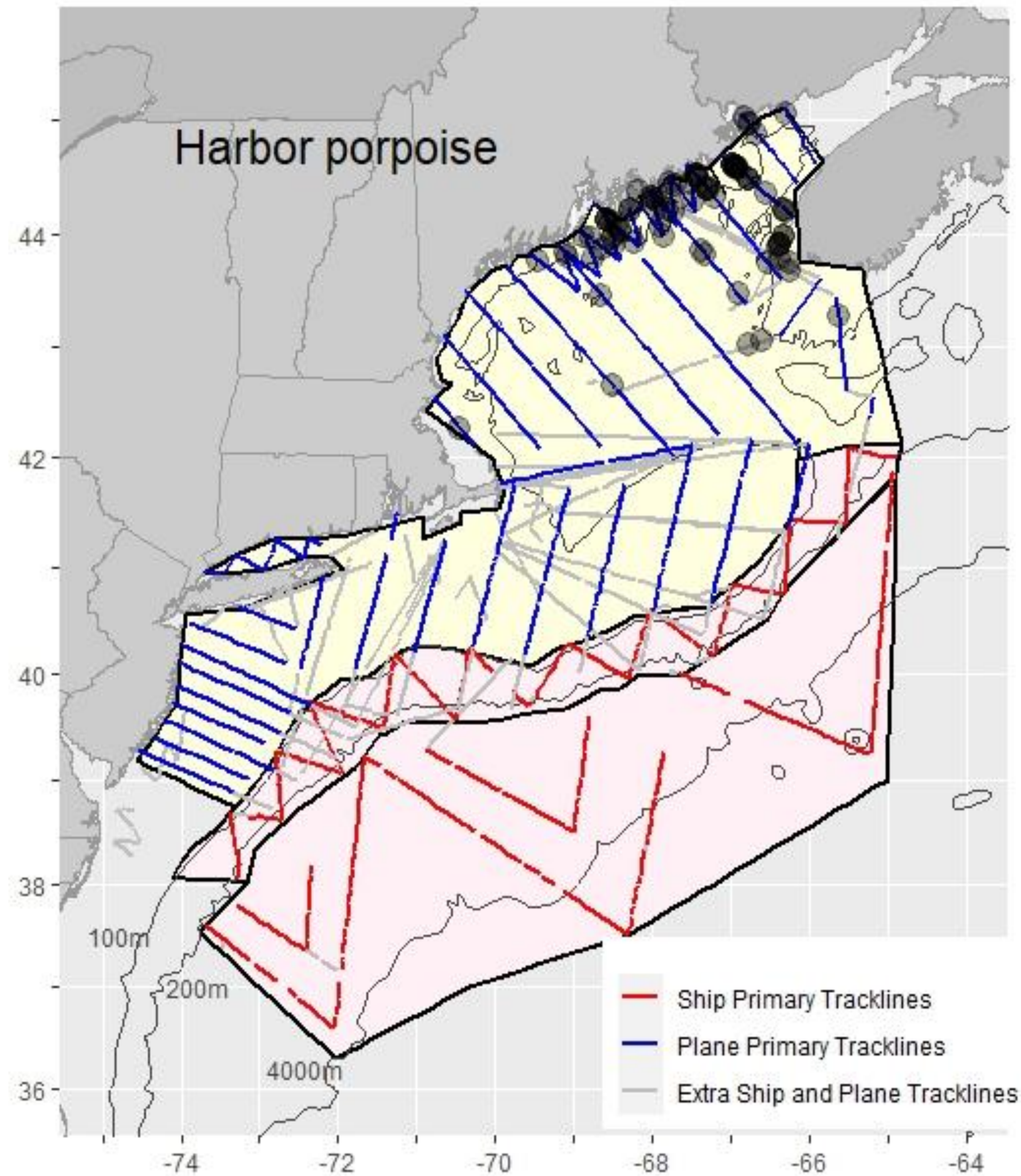

Figure 3. Harbor porpoise (*Phocoena phocoena*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

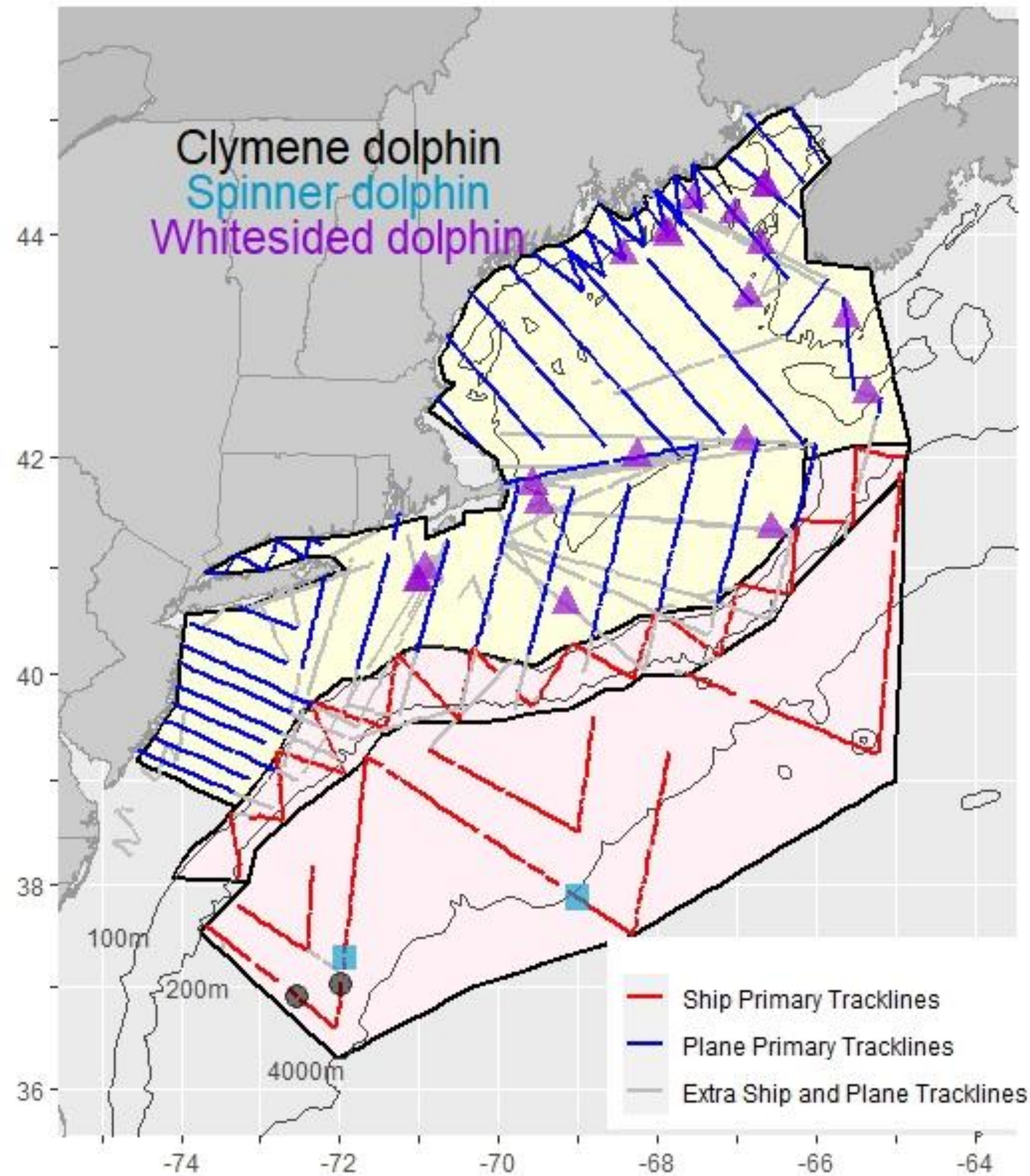

Figure 4. Clymene (*Stenella clymene*), spinner (*S. longirostris*) and Atlantic white-sided dolphin (*Lagenorhynchus acutus*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow),;and the shelf and offshore strata surveyed by the ship (pink).

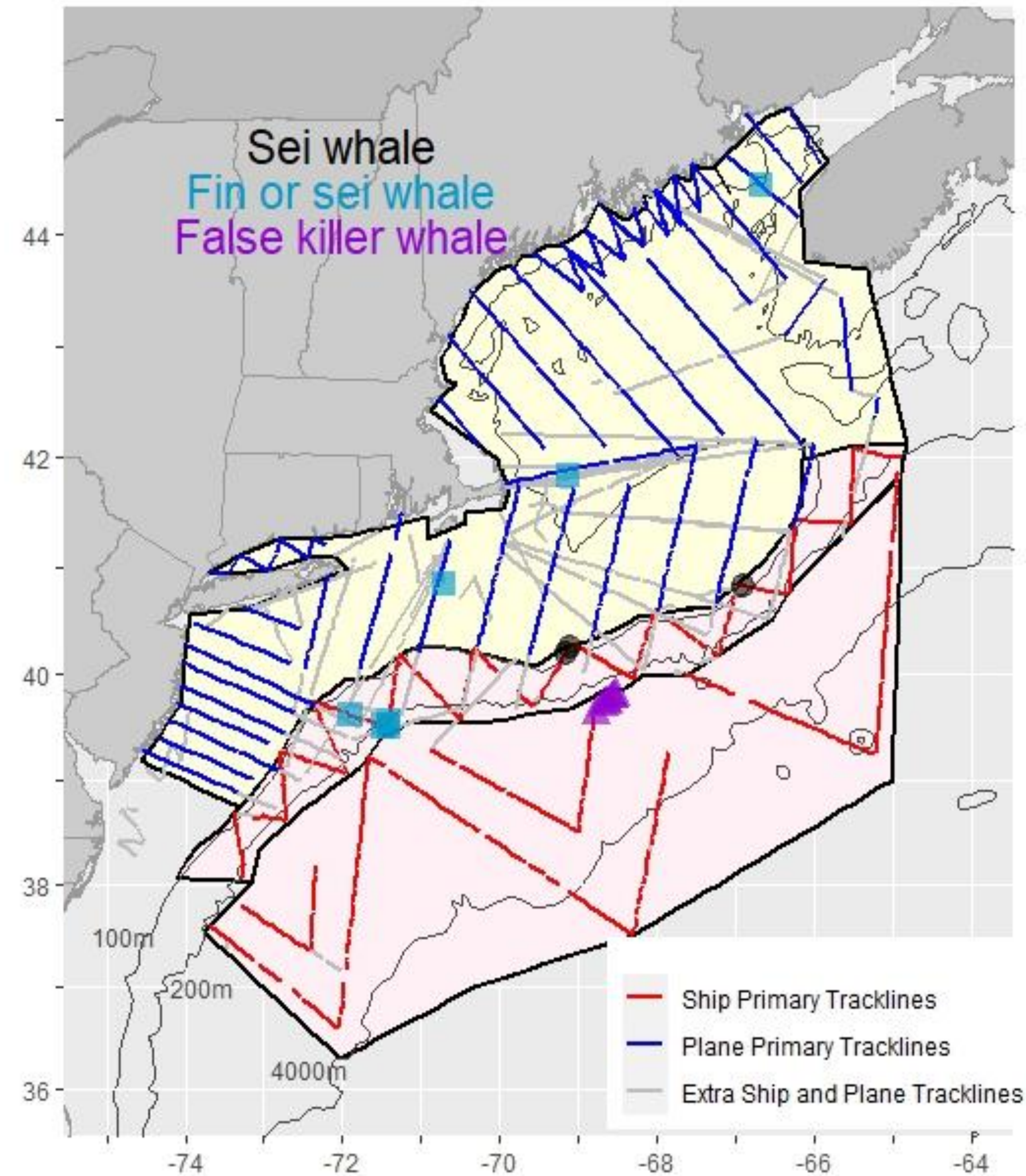

Figure 5. Sei (*Balaenoptera borealis*), fin (*B. physalus*) or sei, and false killer (*Pseudorca crassidens*) whale sightings during northeast summer 2021 survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

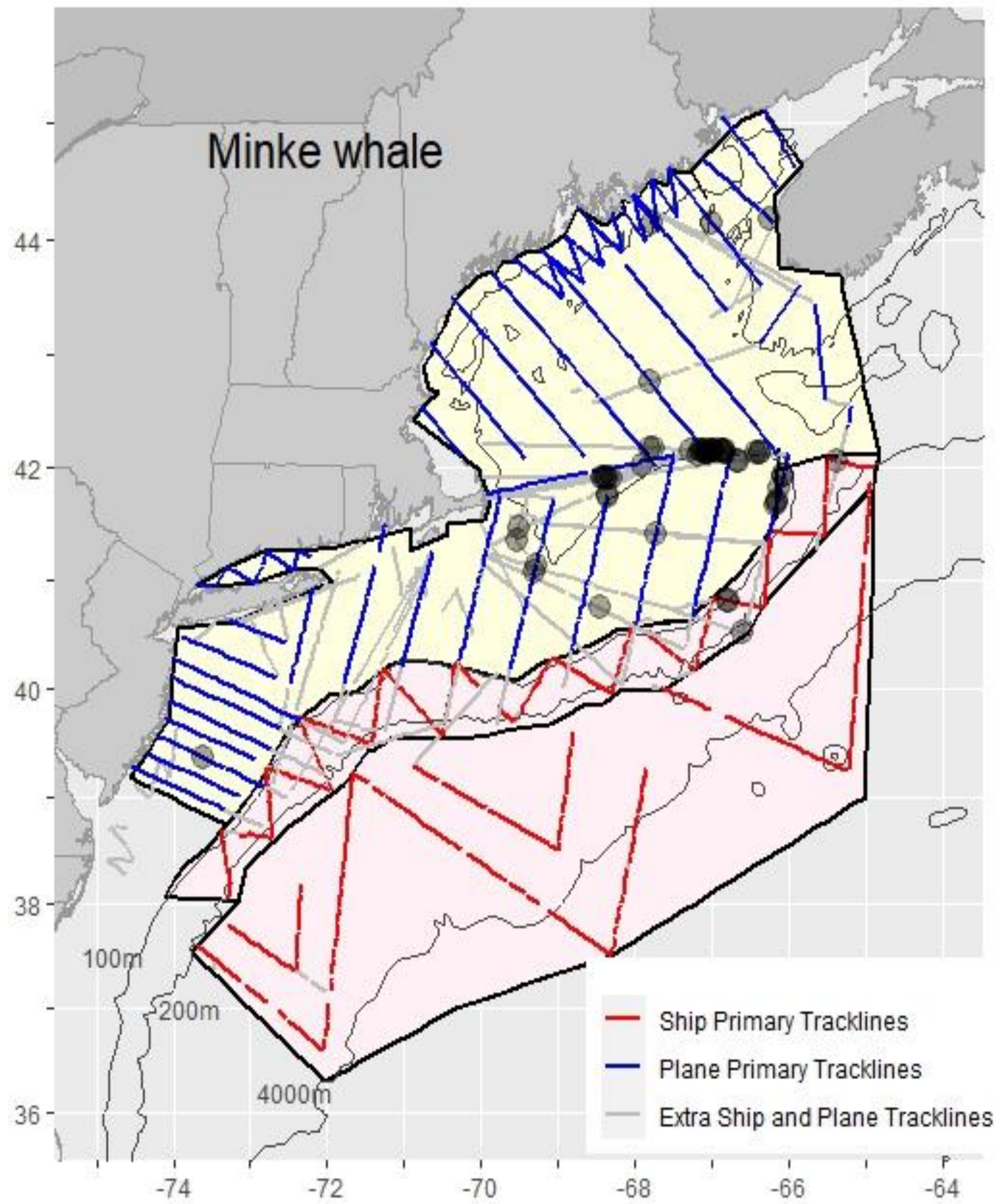

Figure 6. Minke whale (*Balaenoptera acutorostrata*) sightings during northeast summer 2021 survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

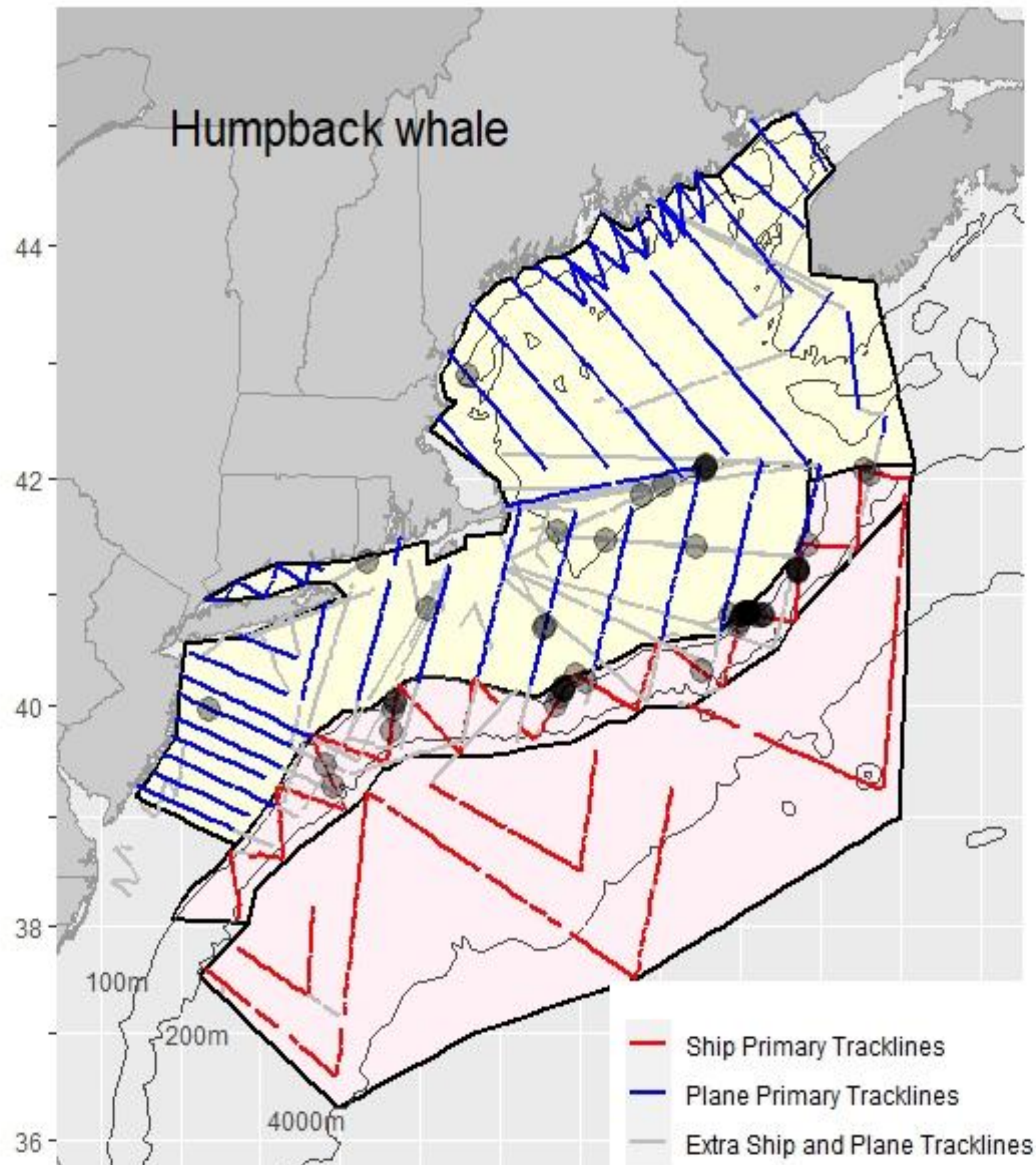

Figure 7. Humpback whale (*Megaptera novaeangliae*) sightings during summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

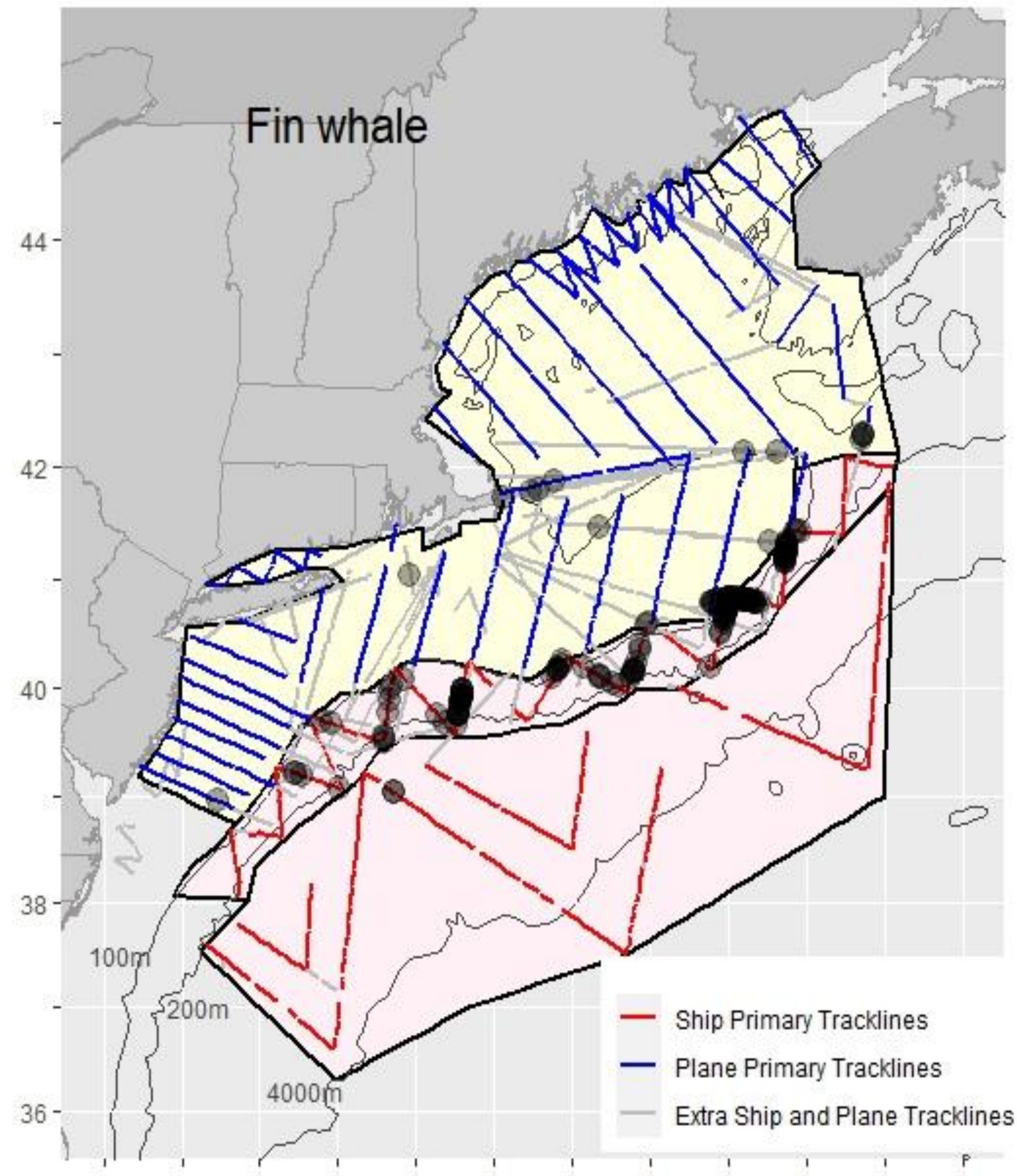

Figure 8. Fin whale (*Balaenoptera physalus*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

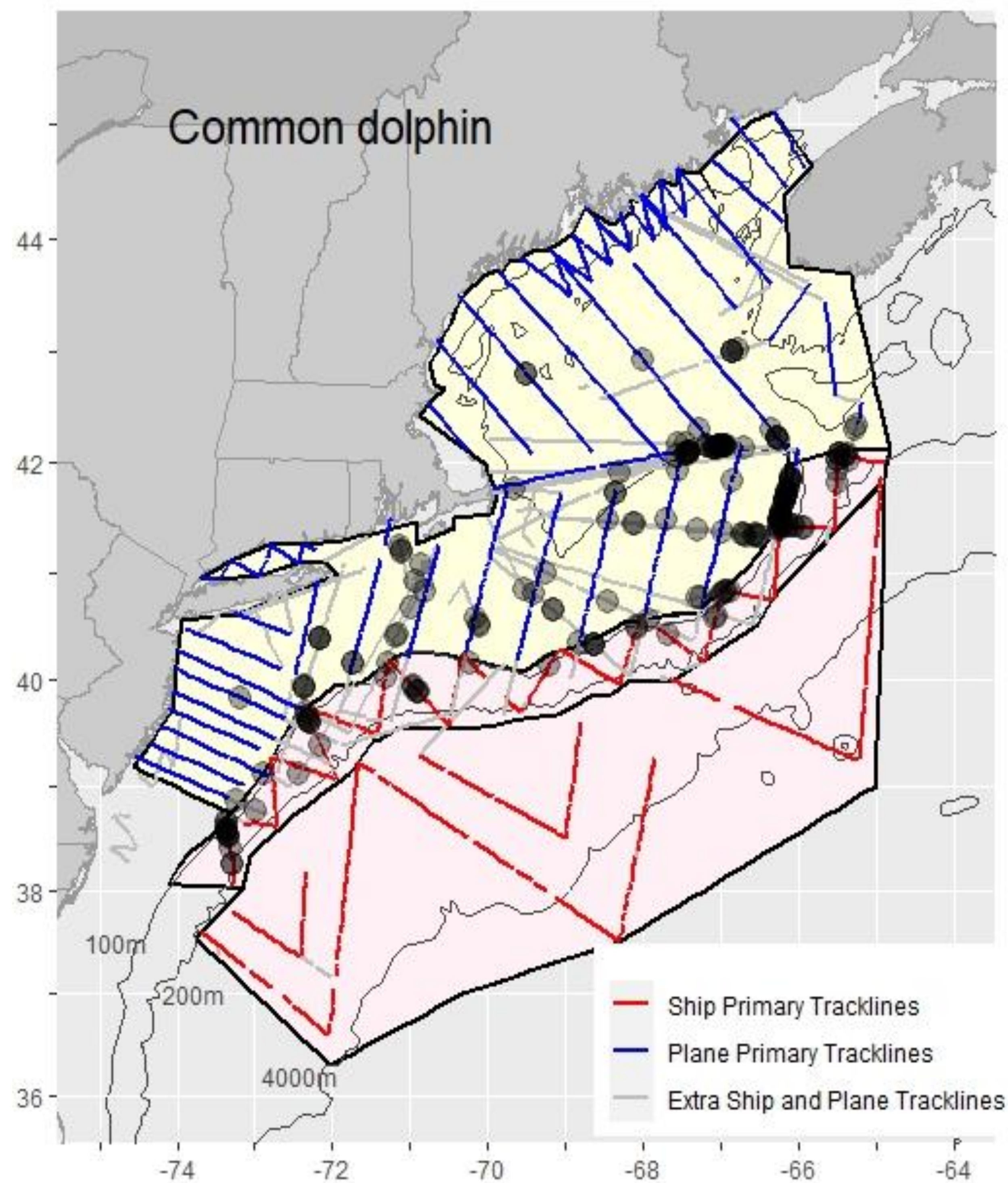

Figure 9. Common dolphin (*Delphinus delphis*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

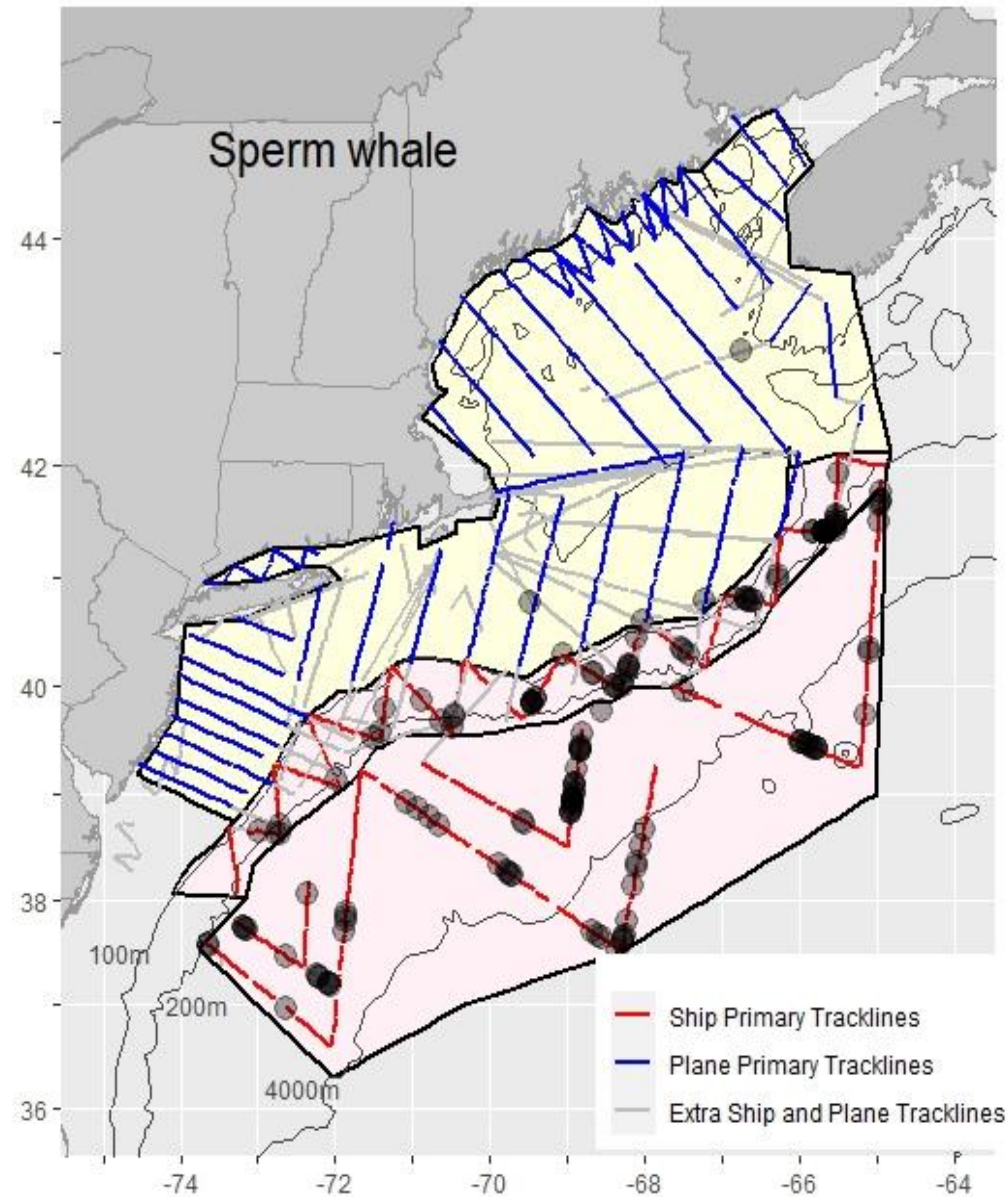

Figure 10. Sperm whale (*Physeter macrocephalus*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

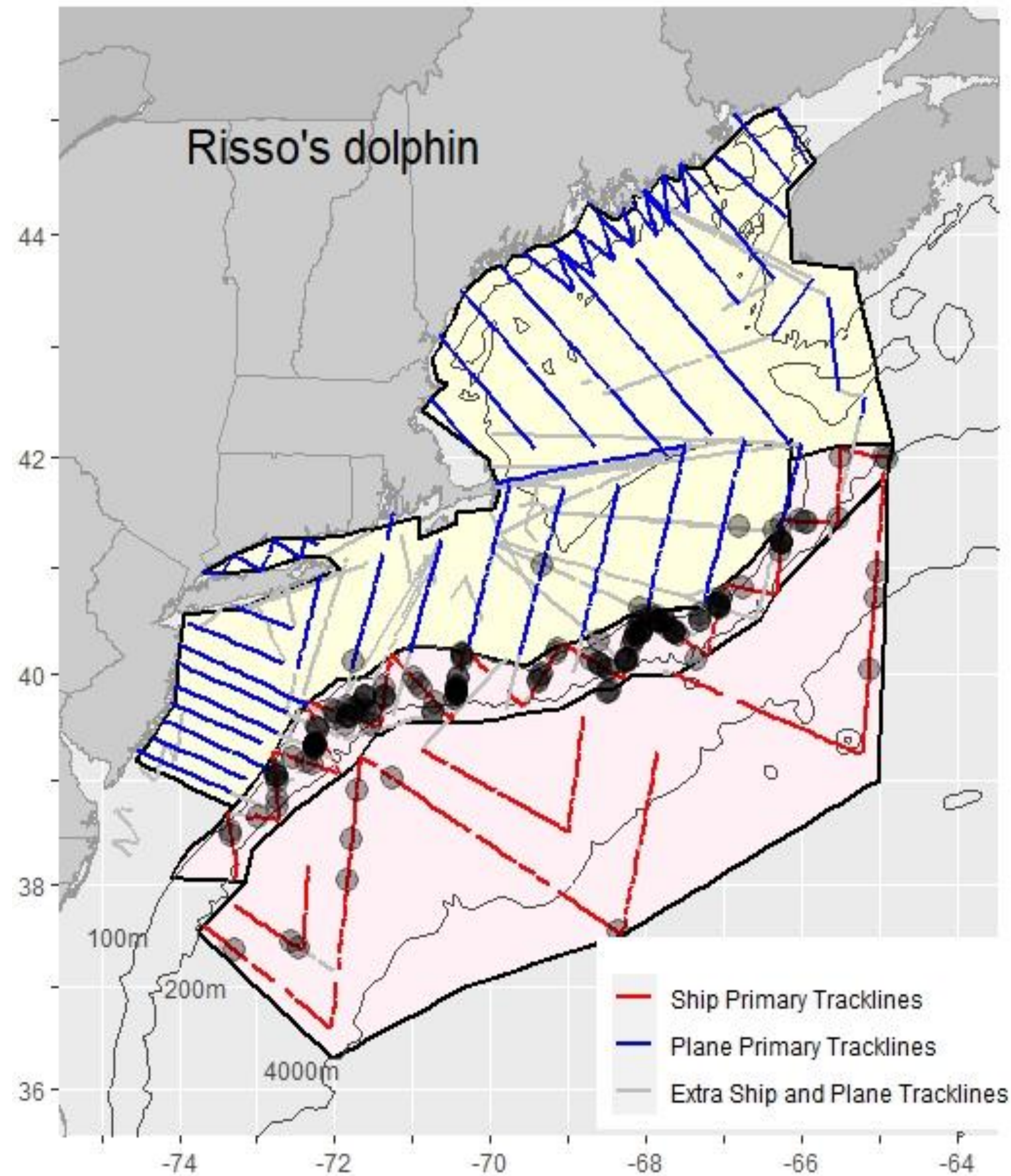

Figure 11. Risso's dolphin (*Grampus griseus*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

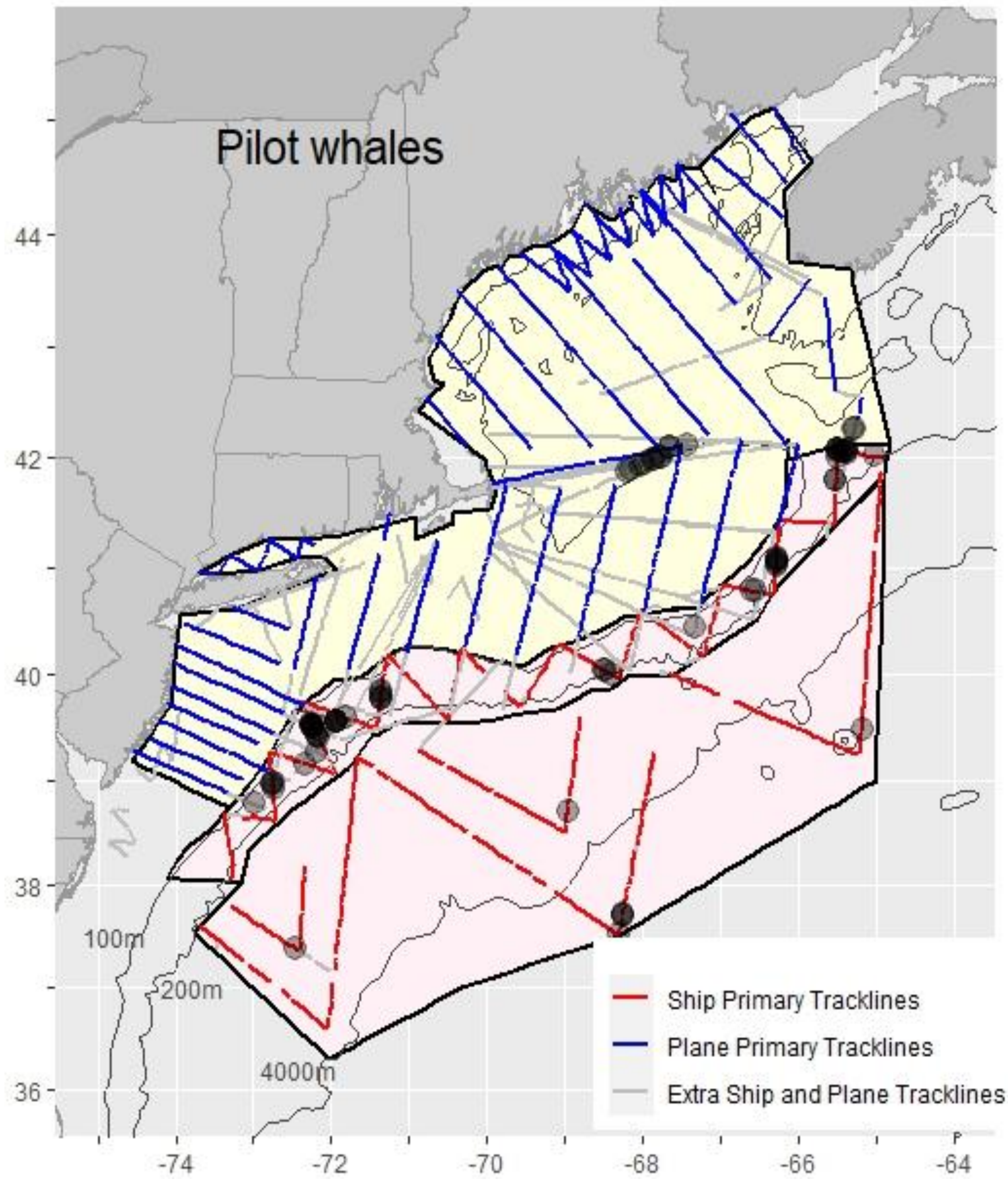

Figure 12. Pilot whales (*Globicephala* spp.) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

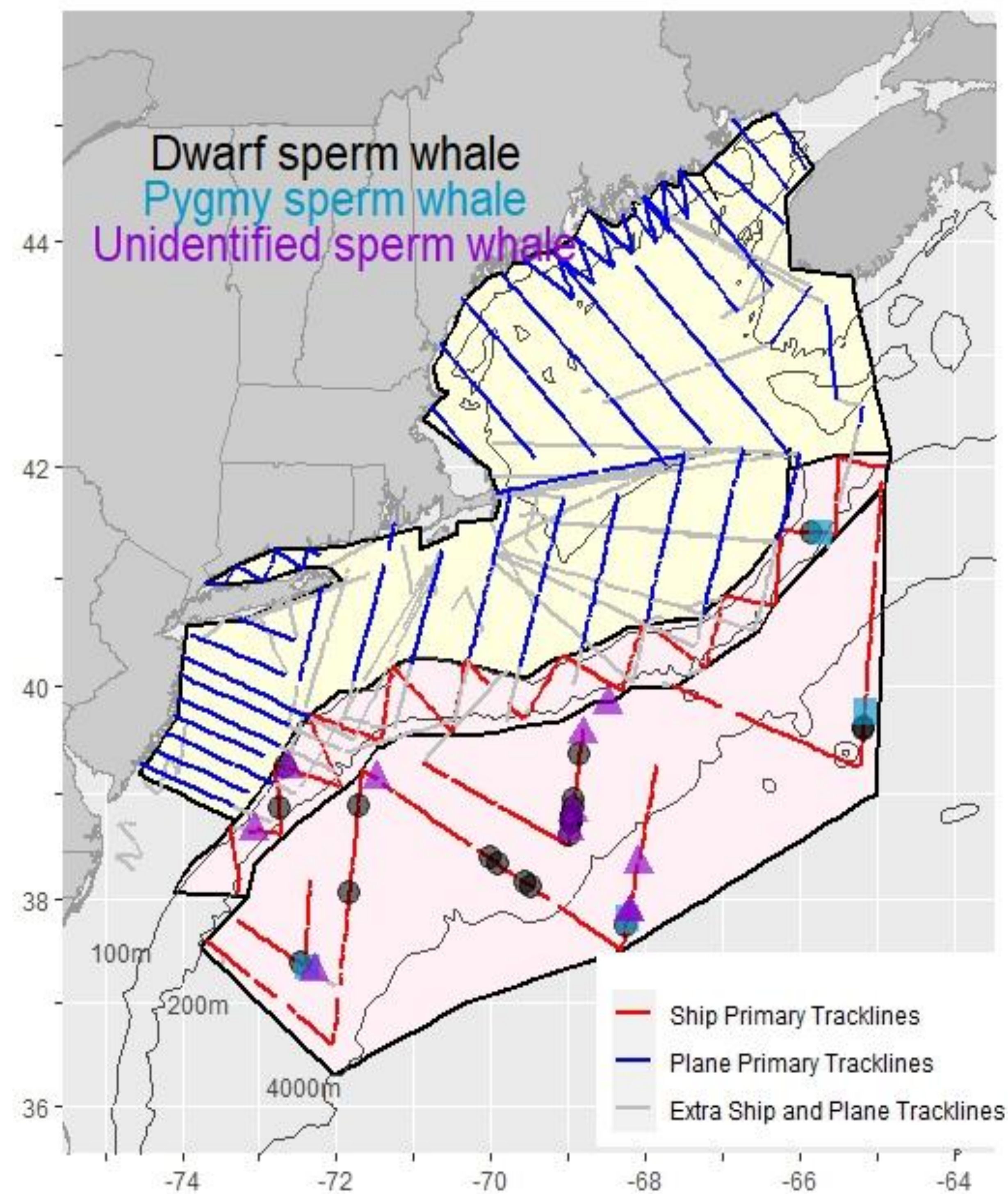

Figure 13. Dwarf sperm (*Kogia simus*), pygmy sperm (*K. breviceps*), and dwarf or pygmy sperm whales sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

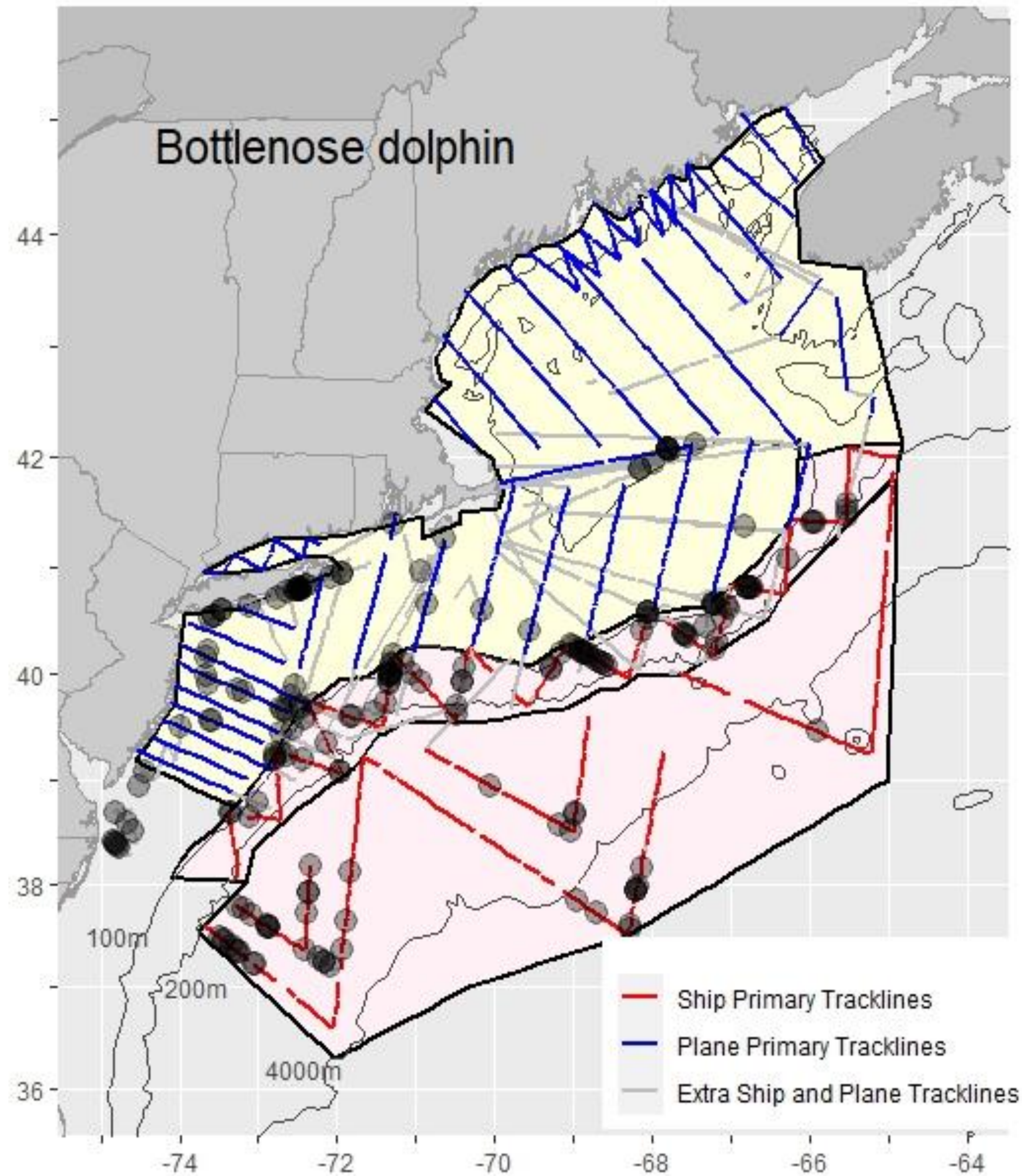

Figure 14. Bottlenose dolphin (*Tursiops truncatus*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

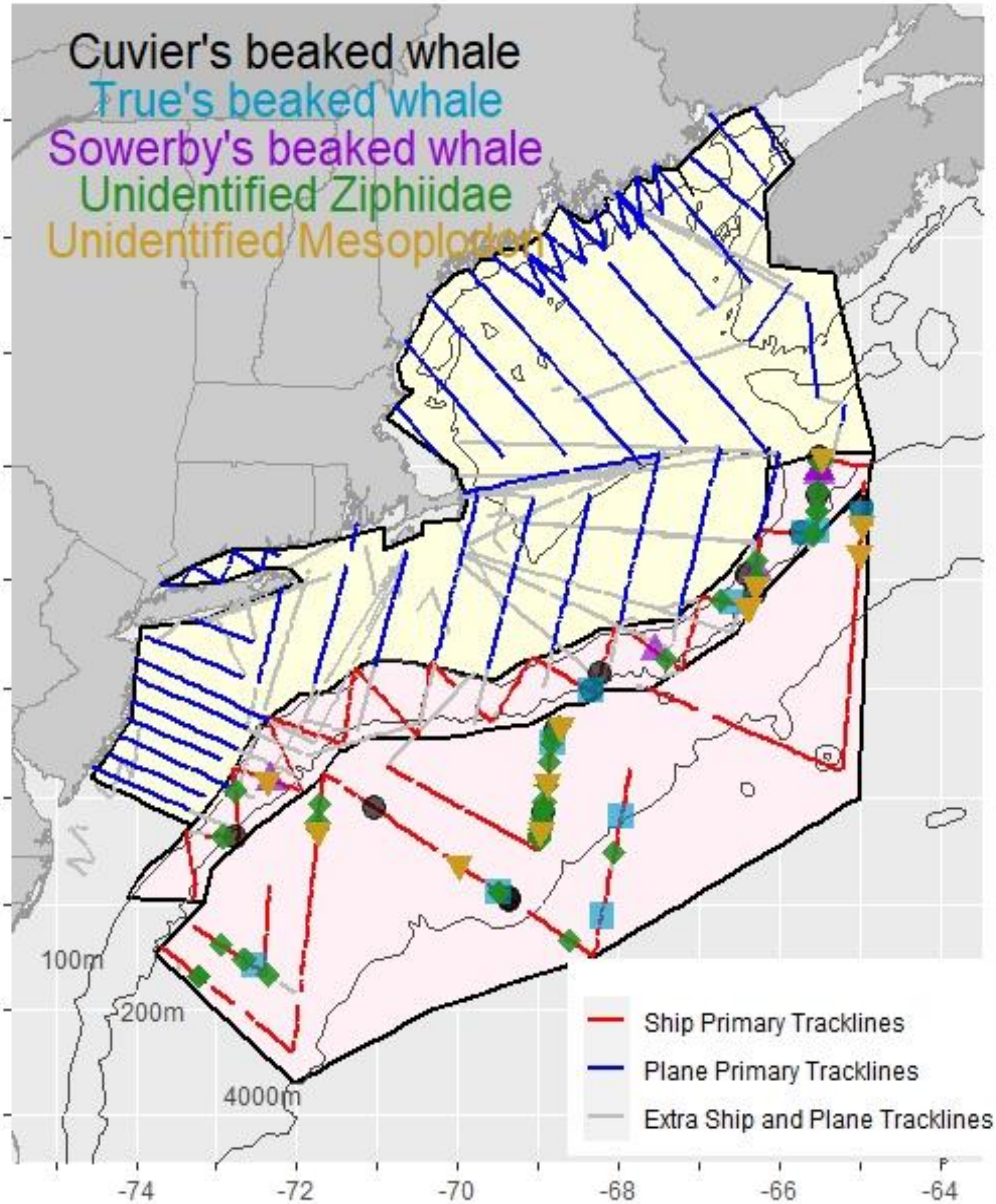

Figure 15. Beaked whale sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

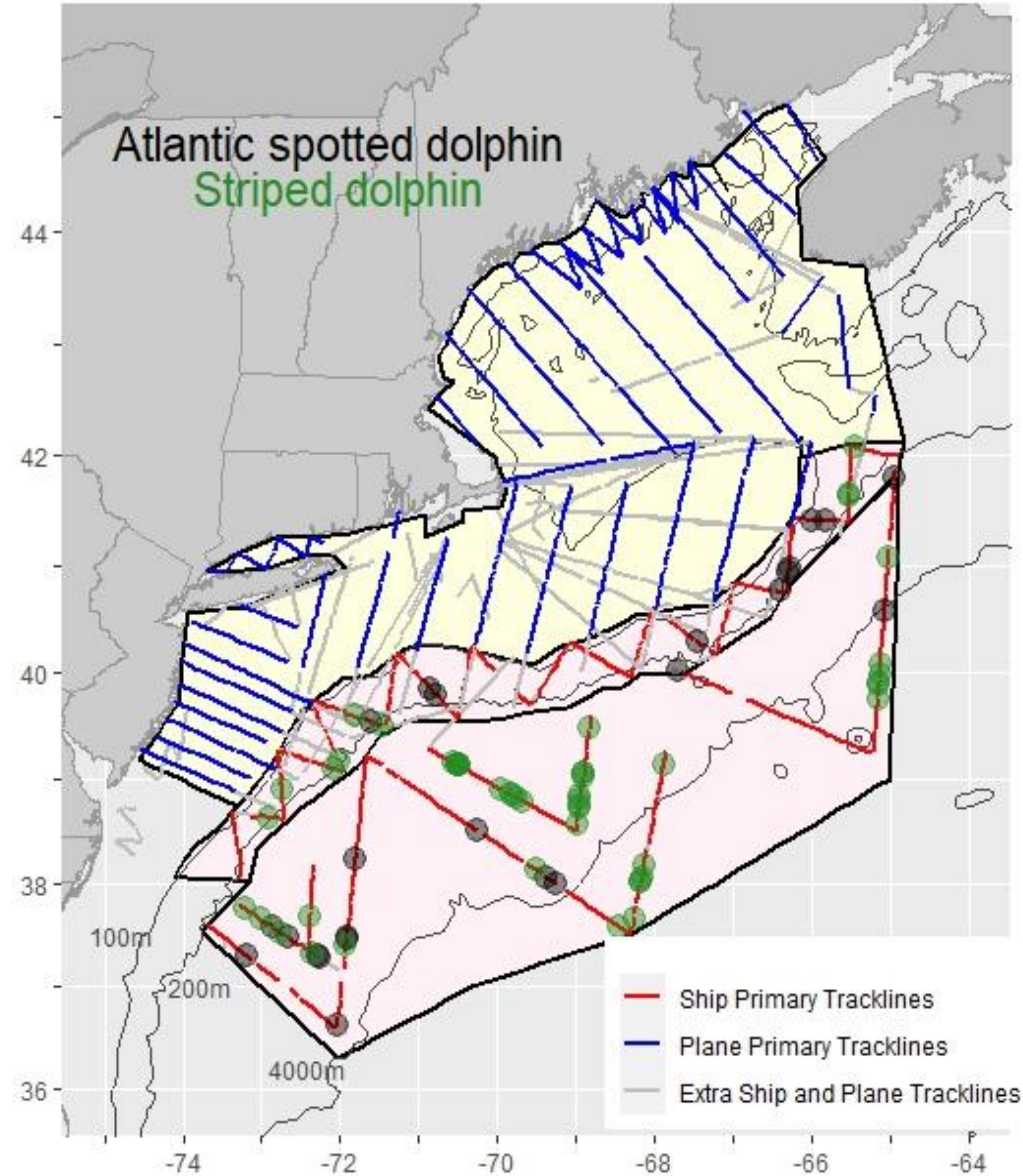

Figure 16. Atlantic spotted (*Stenella attenuata*) and striped (*Stenella coeruleoalba*) dolphin sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

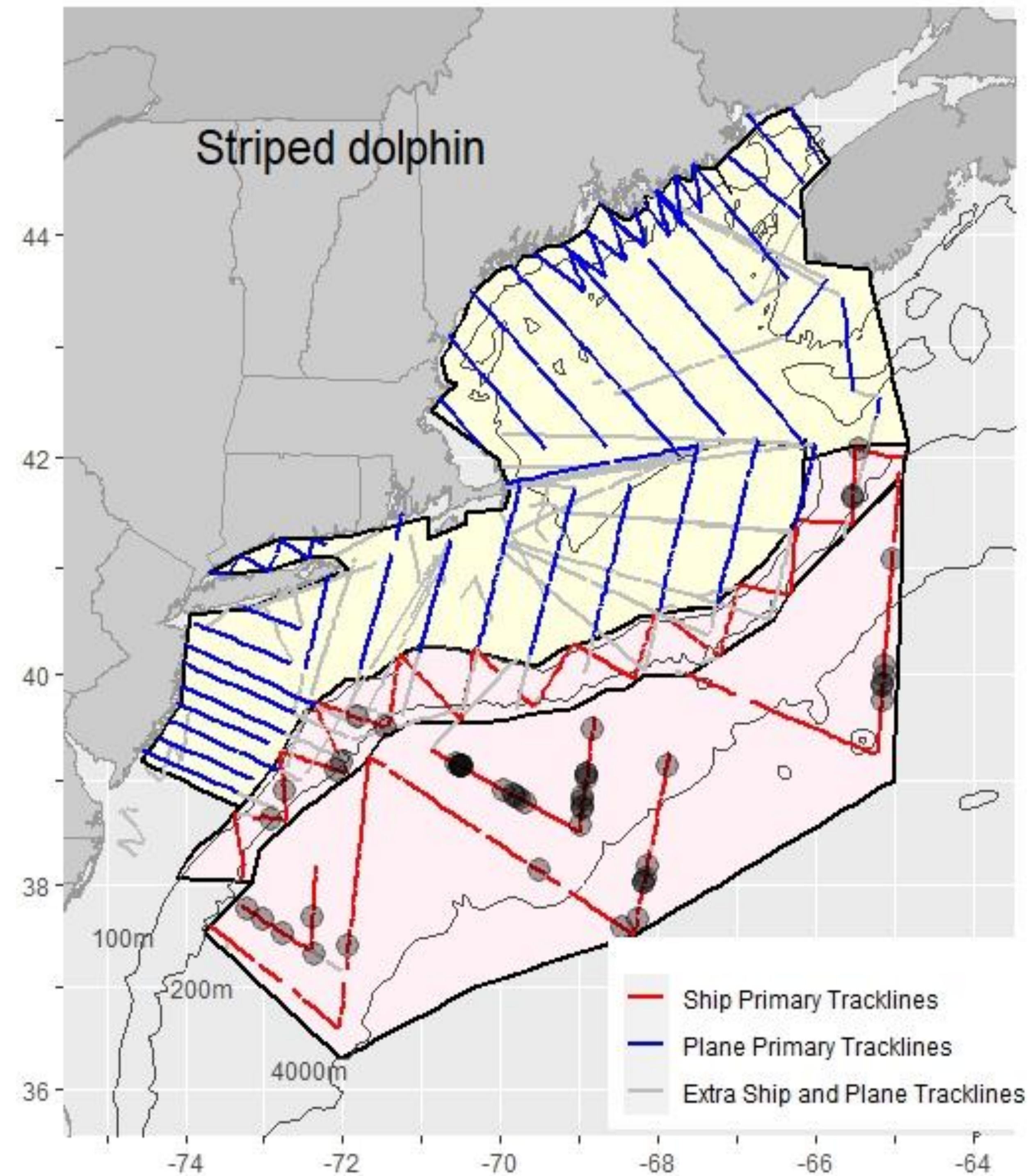

Figure 17. Striped dolphin (*Stenella coeruleoalba*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

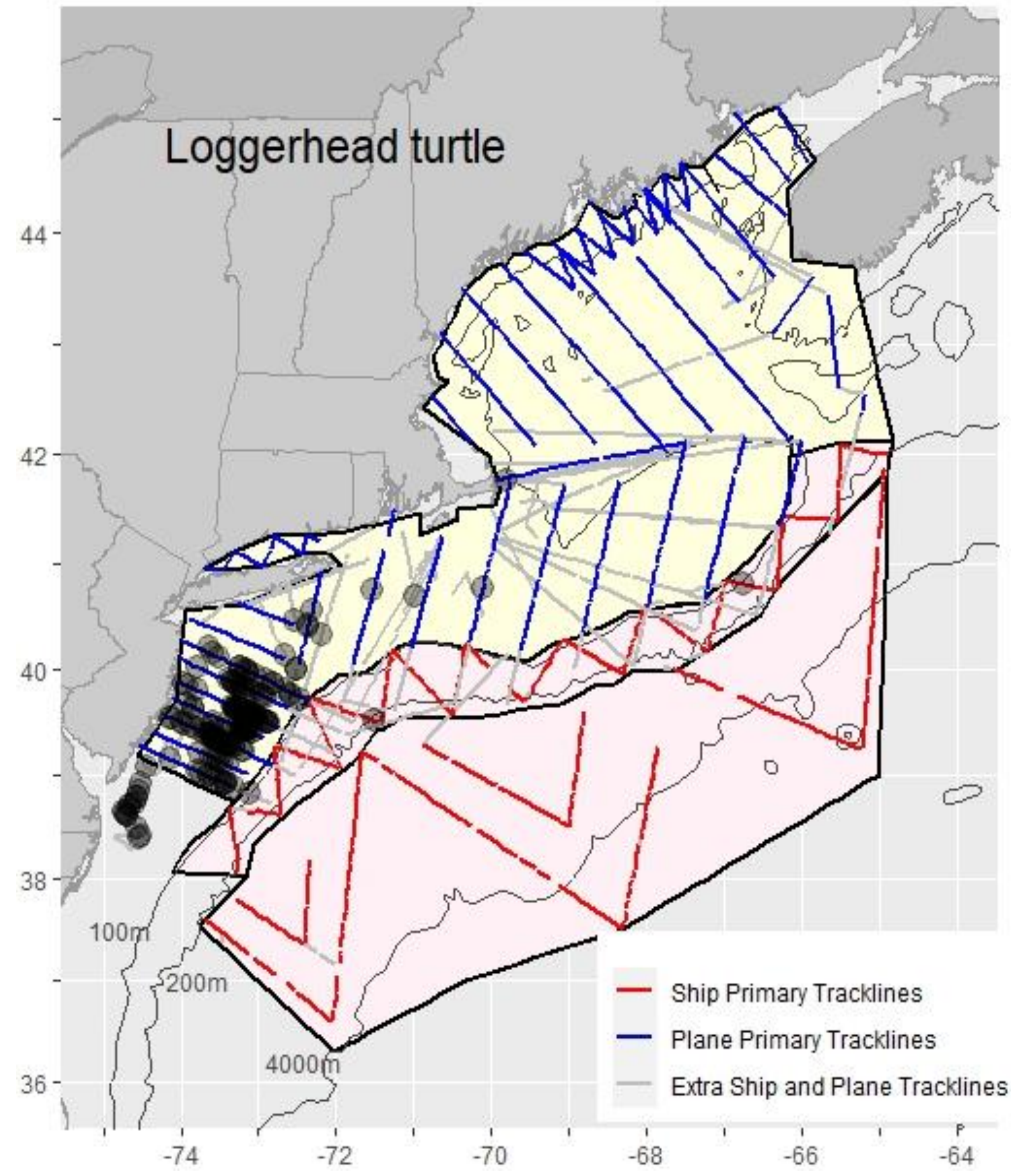

Figure 18. Loggerhead turtle (*Caretta caretta*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

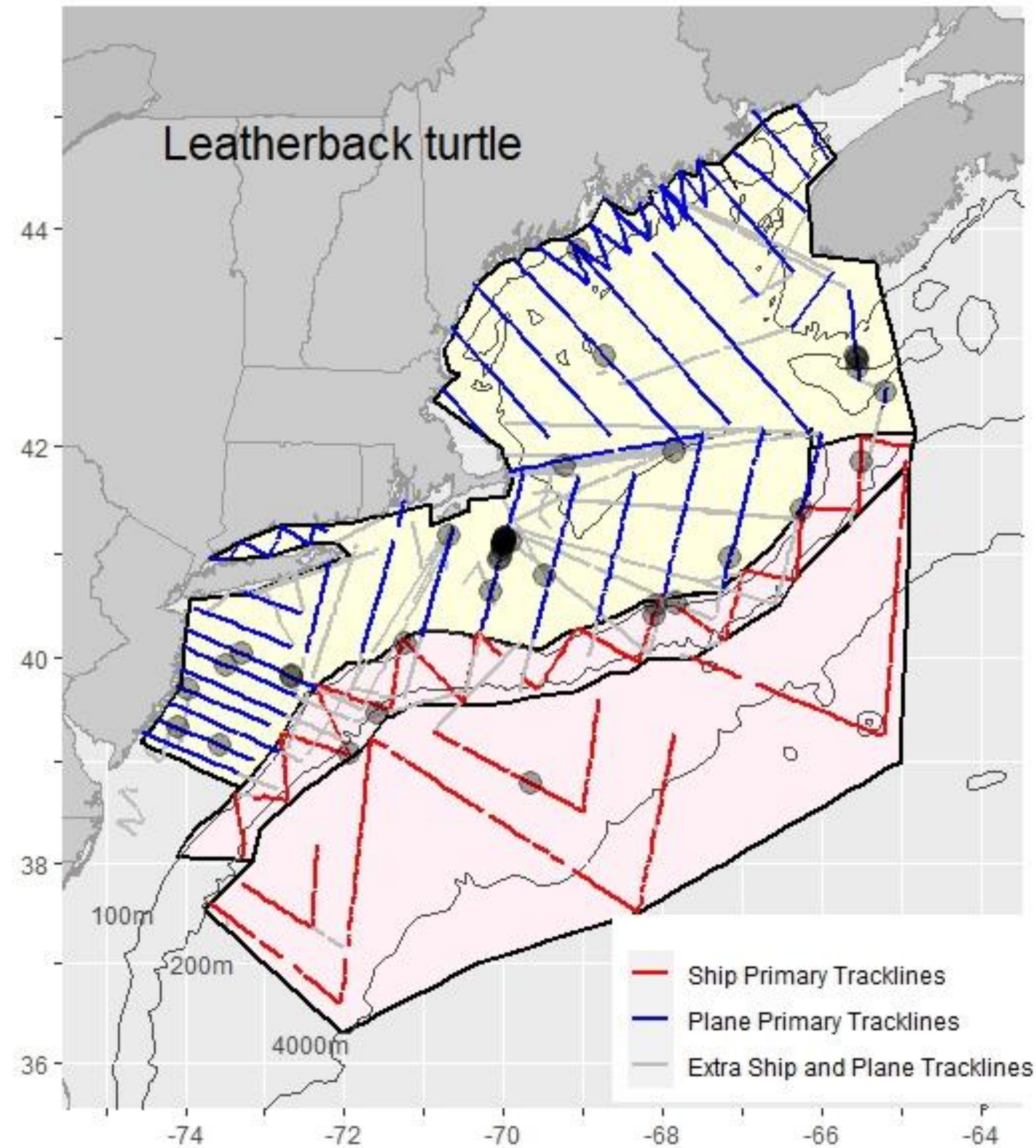

Figure 19. Leatherback turtle (*Dermochelys coriacea*) sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

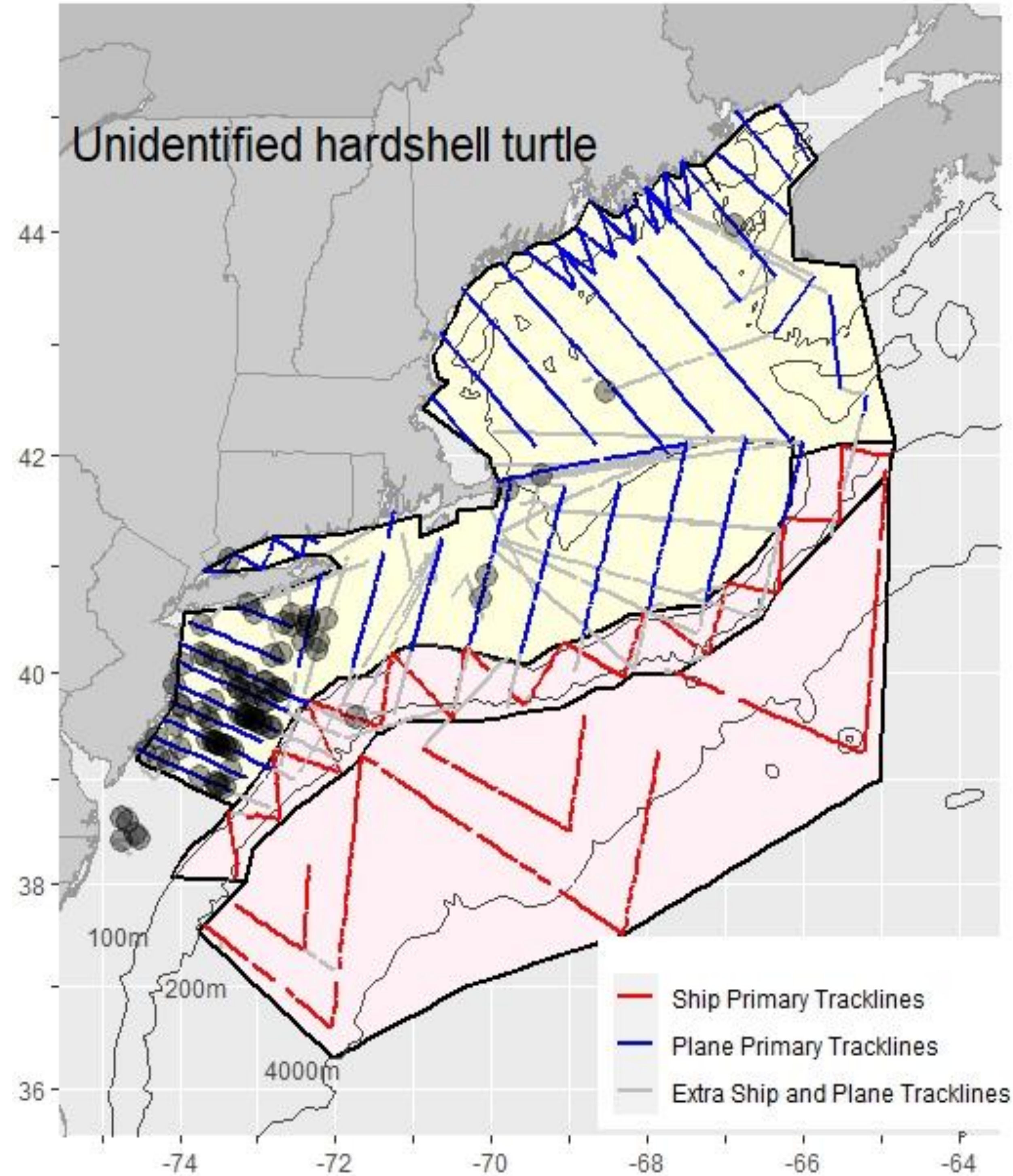

Figure 20. Unidentified hardshell turtle sightings during northeast summer 2021 abundance survey. Also displayed are the primary and extra shipboard and aerial on-effort tracklines; the 100, 200, and 4000 m depth contours; the Gulf of Maine stratum surveyed by the plane (yellow); and the shelf and offshore strata surveyed by the ship (pink).

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APPENDIX 1. AERIAL SURVEY DIAGNOSTIC PLOTS FOR EACH SPECIES GROUP

For each species grouping, the diagnostic plots include:

A. A scaled histogram of front team's detections from the area of overlap with the back team. The line is the average fitted distance sample (DS) model scaled by the mark-recapture (MR)-estimate of g(0), the probability of detecting a group on the trackline. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
B. A scaled histogram of back team's detections from the area of overlap with the front team. The line is the average fitted DS model scaled by the MR-estimated g(0). The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
C. A scaled histogram of the pooled front and back teams' detections from the area of overlap. The line is the average fitted DS model scaled by the MR-estimated g(0). The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
D. A scaled histogram of the duplicate detections from the area of overlap. The line is the average fitted DS model scaled by the MR-estimated g(0). The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
E. The conditional MR detection function for the front team's sightings that were also detected by the back team in the area of overlap. A histogram of the proportion of sightings detected by the front team when also detected by the back team. The line is the fitted MR model averaged over covariate values. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
F. The conditional MR detection function for the back team's sightings that were also detected by the front team in the area of overlap. A histogram of the proportion of sightings detected by the back team that were also detected by the front team. The line is the fitted MR model averaged over covariate values. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
G. A quantile-quantile (Qq) plot showing the goodness of fit of the independent observer MRDS fitted model for data in the area of overlap.
H. A scaled histogram of the detections from only the primary team. The line is the fitted detection function averaged over the estimated population levels of the covariate values. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
I. A Qq plot showing the goodness of fit of the multiple covariate distance sampling (MCDS) fitted model for data from only the primary team.

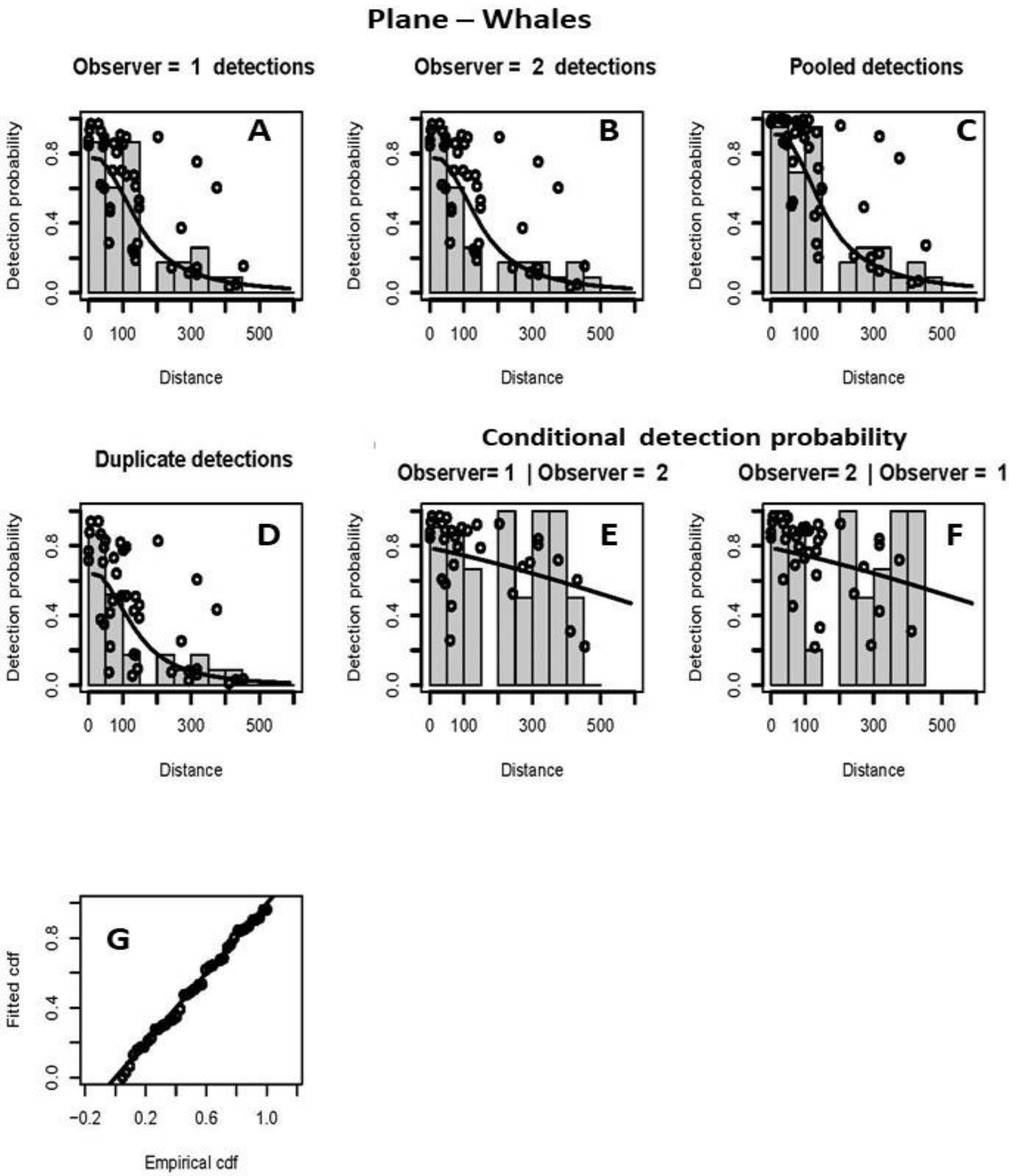

Figure A1 - 1. Aerial mark recapture and multiple covariate distance sampling diagnostic plots from whales. Whales include fin (*Balaenoptera physalus*), sperm (*Physeter macrocephalus*), humpback (*Megaptera novaeangliae*), and minke (*B. acutorostrata*) whales.

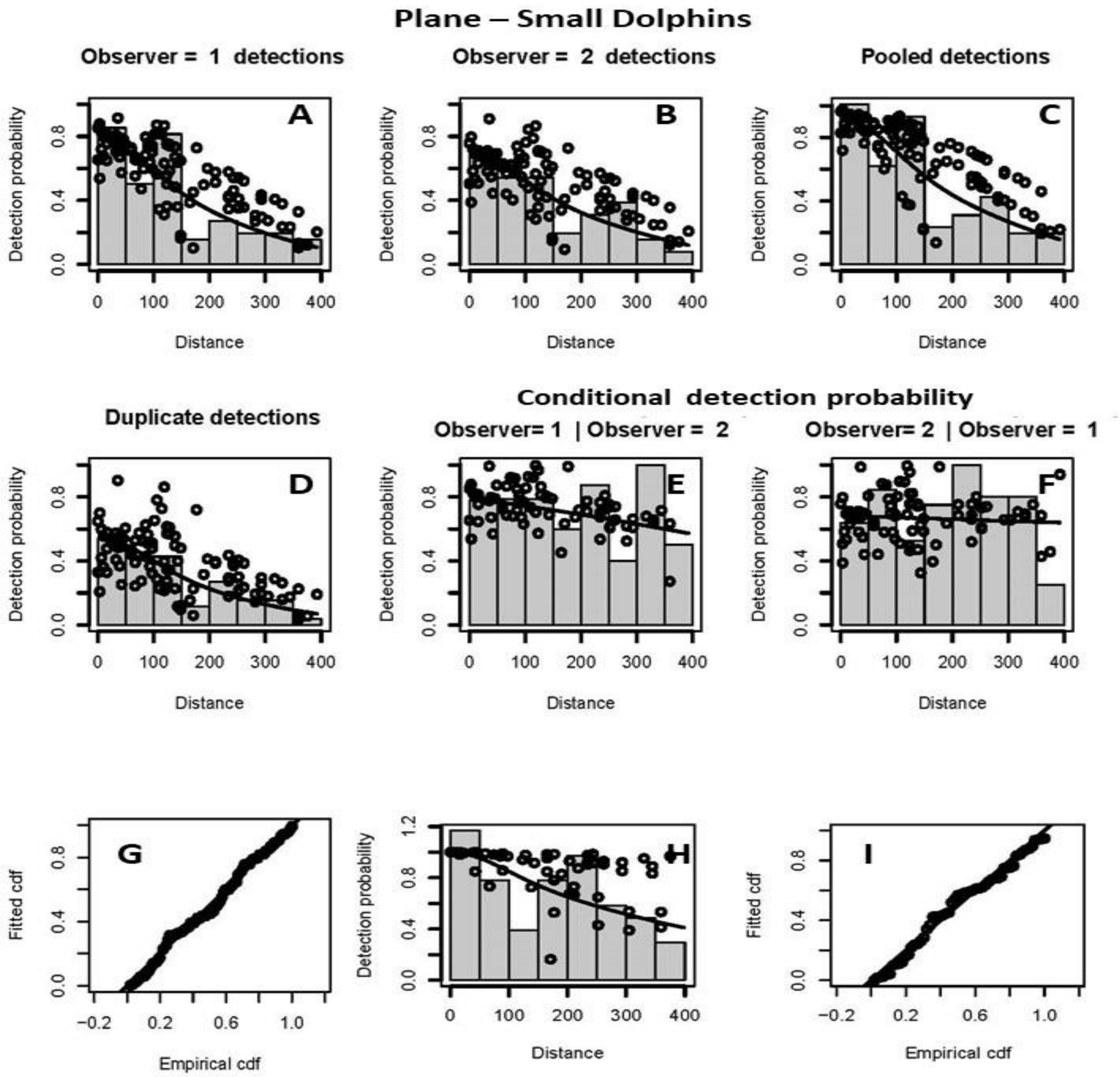

Figure A1 - 2. Aerial mark recapture and multiple covariate distance sampling diagnostic plots from small dolphins. Small dolphins include Atlantic white-sided (*Lagenorhynchus acutus*), common (*Delphinus delphis*), and common/Atlantic white-sided dolphins.

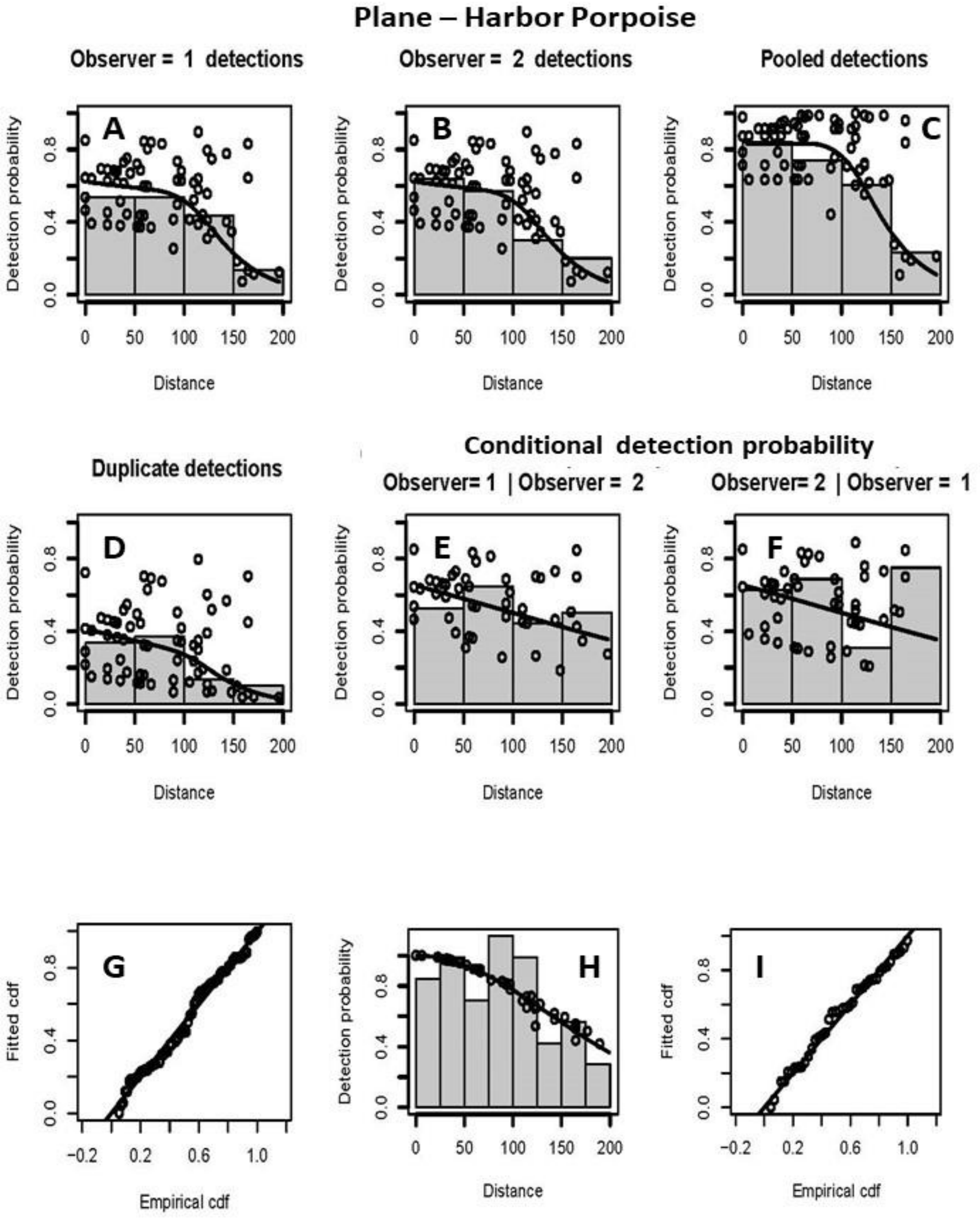

Figure A1 - 3. Aerial mark recapture and multiple covariate distance sampling diagnostic plots from harbor porpoises (*Phocoena phocoena*).

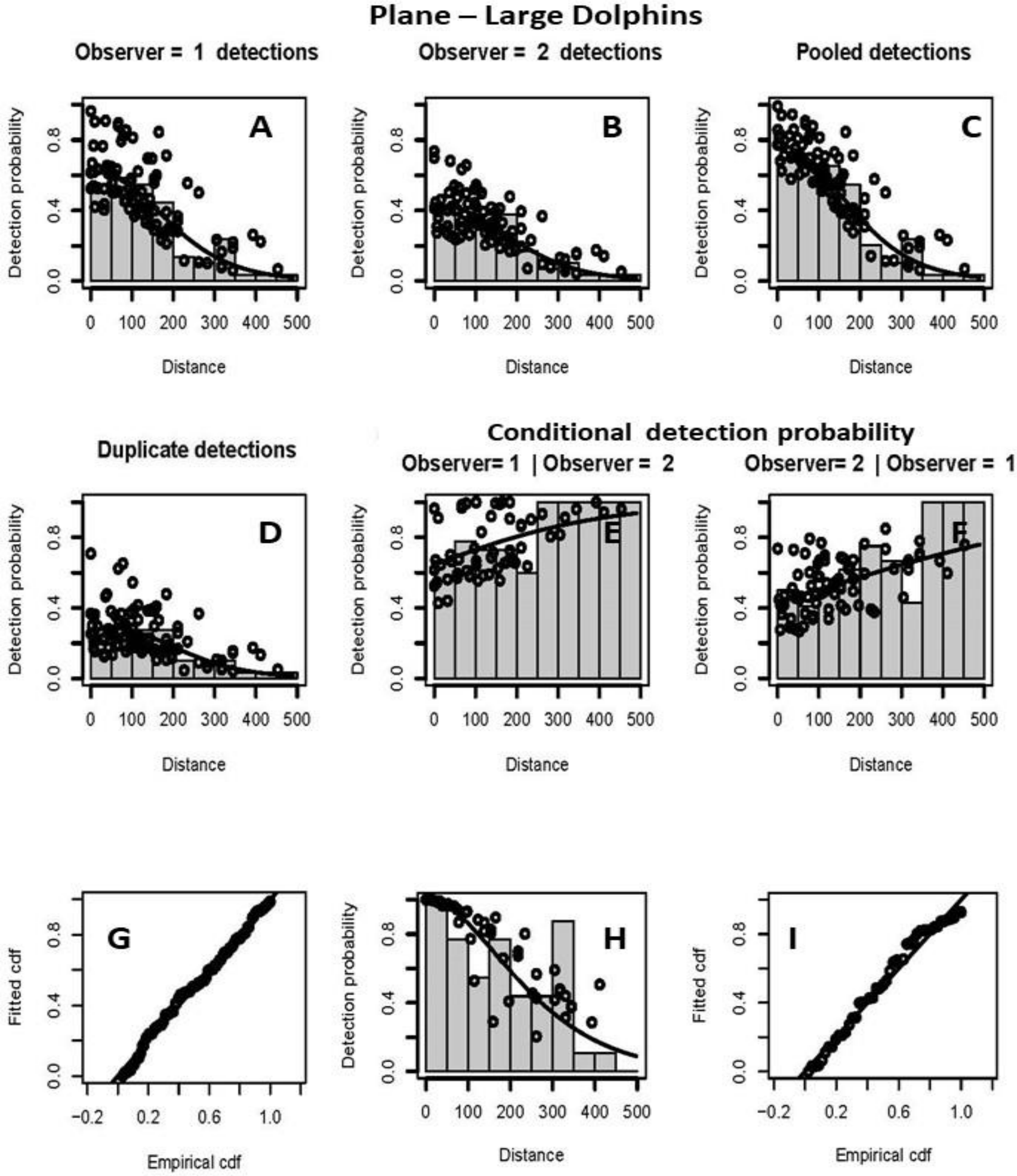

Figure A1 - 4. Aerial mark recapture and multiple covariate distance sampling diagnostics plots from large dolphins. Large dolphins include pilot whales (*Globicephala sp.*), Risso's dolphins (*Grampus griseus*), and bottlenose dolphins (*Tursiops truncatus*).

APPENDIX 2. SHIPBOARD DIAGNOSTIC PLOTS FOR EACH SPECIES GROUP

For each species grouping, the diagnostic plots include:

A. A scaled histogram of upper team's detections. The line is the average fitted distance sample (DS) model scaled by the mark-recapture (MR)-estimate of g(0), the probability of detecting a group on the trackline. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
B. A scaled histogram of lower team's detections. The line is the average fitted distance sample (DS) model scaled by the mark-recapture (MR)-estimate of g(0), the probability of detecting a group on the trackline. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
C. A scaled histogram of the pooled upper and lower teams' detections. The line is the average fitted DS model scaled by the MR-estimated g(0). The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
D. A scaled histogram of the duplicate detections. The line is the average fitted DS model scaled by the MR-estimated g(0). The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
E. The conditional MR detection function for the upper team that were also detected by the lower team. A histogram of the proportion of sightings detected by the upper team when also detected by the lower team. The line is the fitted MR model averaged over covariate values. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
F. The conditional MR detection function for the lower team's sightings that were also detected by the upper team. A histogram of the proportion of sightings detected by the lower team that were also detected by the upper team. The line is the fitted MR model averaged over covariate values. The points are the estimated detection probability of each observation that have accounted for its values of covariates and perpendicular distance.
G. A quantile-quantile (Qq) plot showing the goodness of fit of the independent observer MRDS fitted model for data.

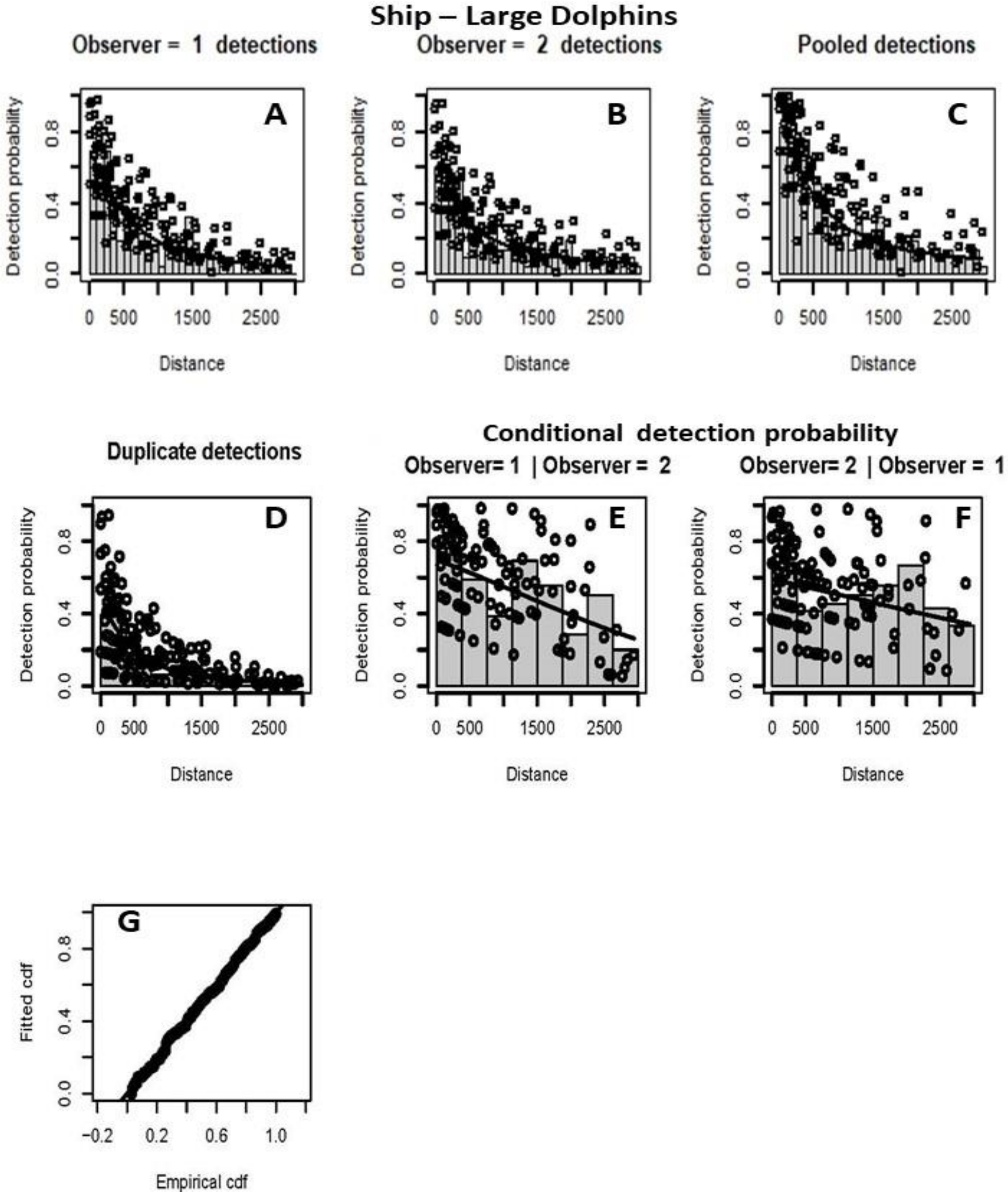

Figure A2 - 1. Shipboard mark recapture distance sampling diagnostic plots from large dolphins. Large dolphins include pilot whales (*Globicephala sp.*), Risso's dolphins (*Grampus griseus*), and false killer whales (*Pseudorca crassidens*).

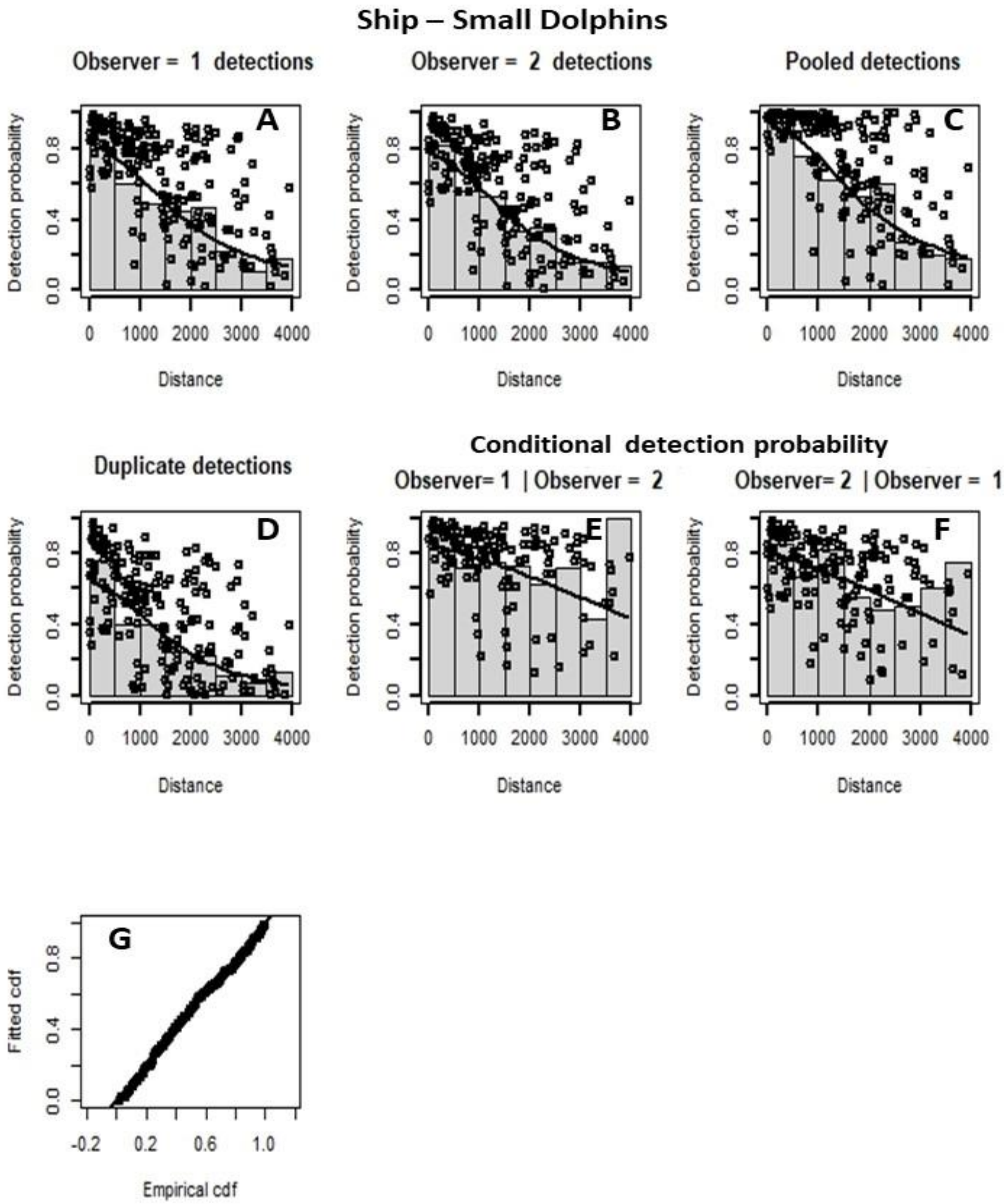

Figure A2 - 2. Shipboard mark recapture distance sampling diagnostic plots from small dolphins. Small dolphins include Atlantic spotted (*Stenella attenuata*), Atlantic white-sided (*Lagenorhynchus acutus*), Clymene (*S. clymene*), common (*Delphinus delphis*), spinner (*S. longirostris*), striped (*S. coeruleoalba*), *Delphinus/Stenella*, and *Stenella sp*.

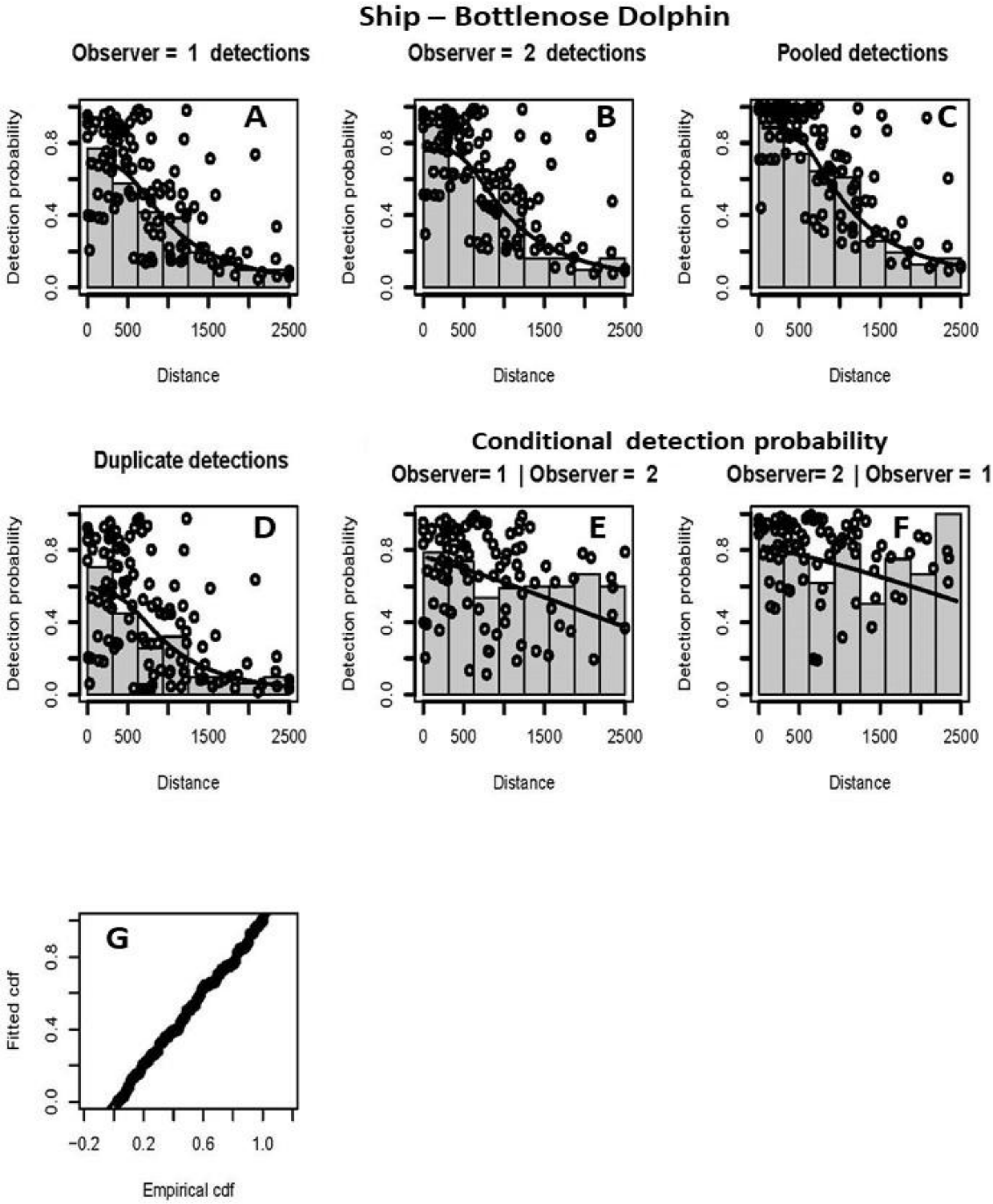

Figure A2 - 3. Shipboard mark recapture distance sampling diagnostic plots from bottlenose dolphins (*Tursiops truncatus*).

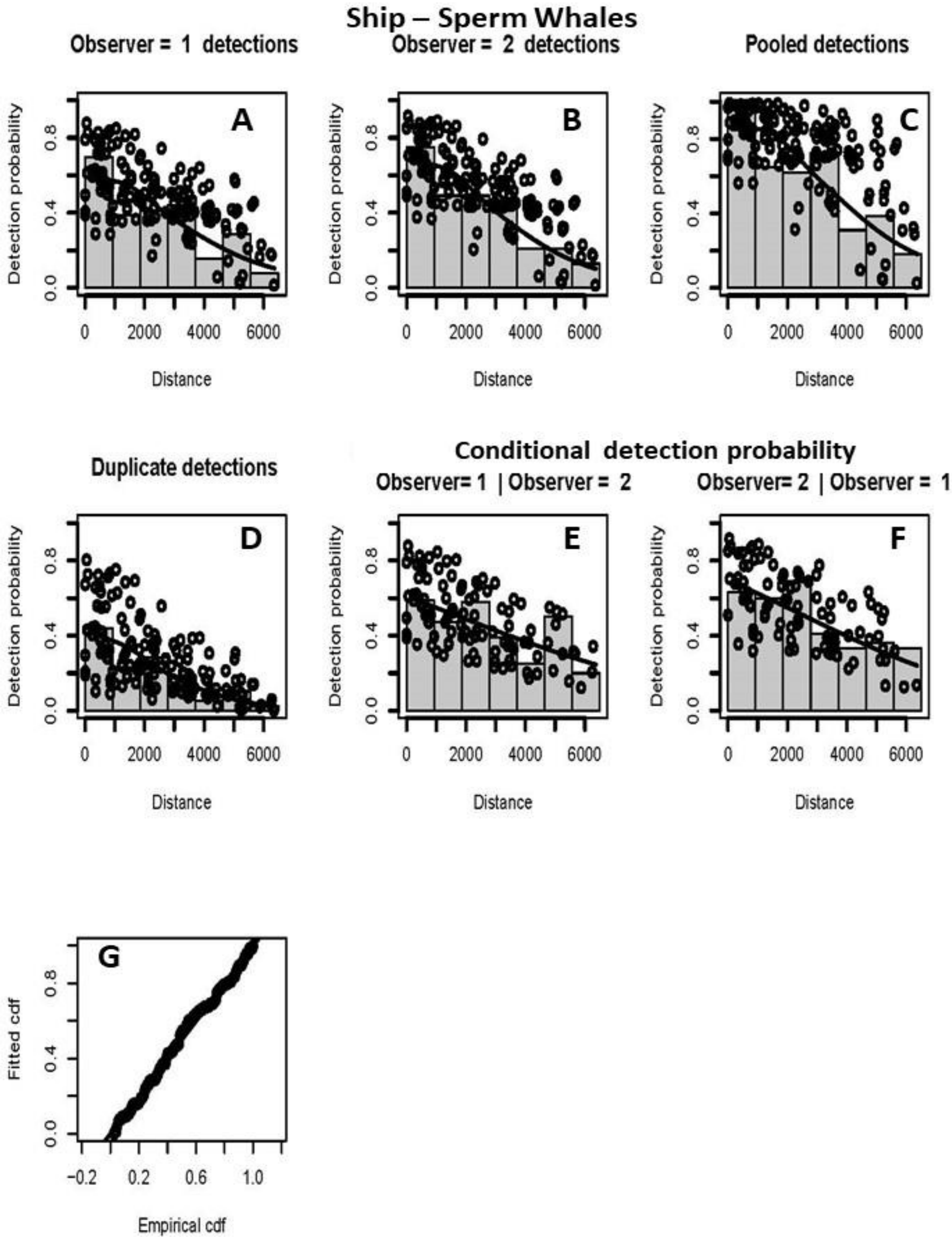

Figure A2 - 4. Shipboard mark recapture distance sampling diagnostic plots from sperm whales (*Physeter macrocephalus*).

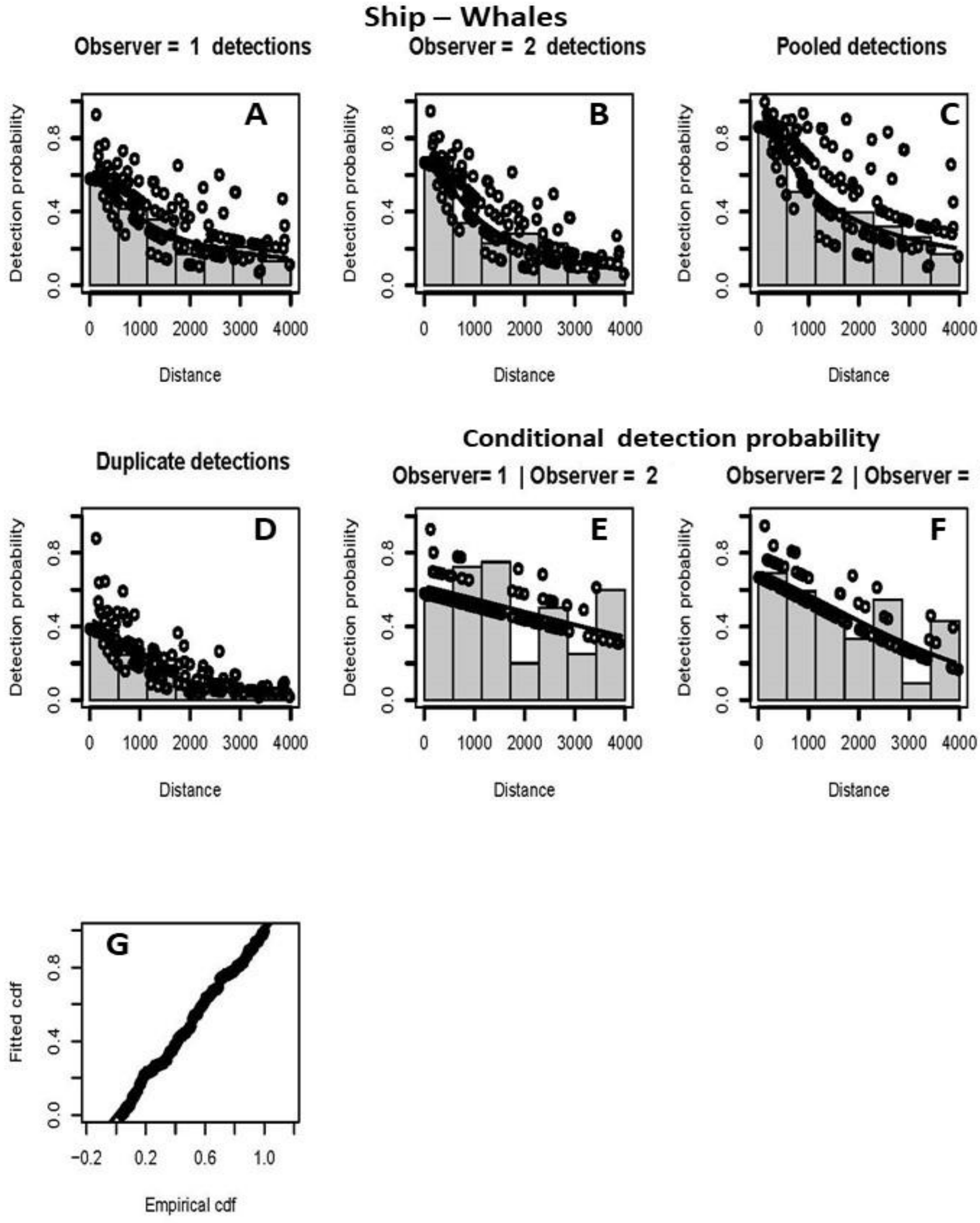

Figure A2 - 5. Shipboard mark recapture distance sampling diagnostic plots from whales. Whales include fin (*Balaenoptera physalus*), sei (*B. borealis*), fin/sei, humpback (*Megaptera novaeangliae*), minke (*B. acutorostrata*), and blue (*B. musculus*) whales.

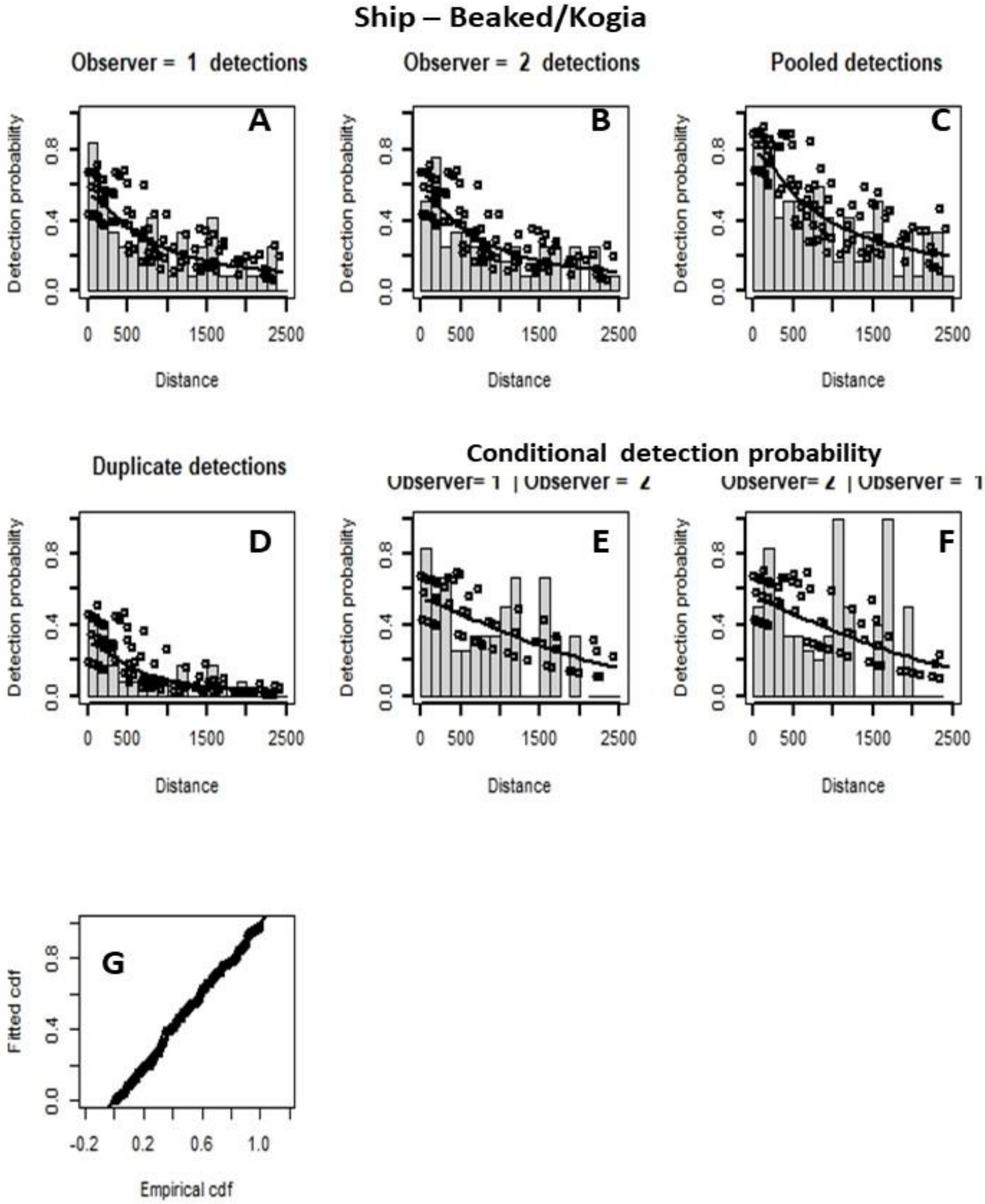

Figure A2 - 6. Shipboard mark recapture distance sampling diagnostic plots from beaked whales and *Kogia sp*.

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