Final

Spatial Use by Odontocetes Satellite Tagged off Cape Hatteras, North Carolina in 2016

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Prepared by

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Clymene dolphin (*Stenella clymene*) off Cape Hatteras. Photographed by Danielle Waples, Duke University, taken under NOAA Scientific Permit No. 14809 (Douglas Nowacek) and NOAA General Authorization Letter of Confirmation 19903 held by Duke University.

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Acronyms and Abbreviations

EEZ	Exclusive Economic Zone
hr	hour(s)
km	kilometer(s)
LIMPET	Low-Impact Minimally-Percutaneous External-electronics Transmitter
m	meter(s)
min	minute(s)
photo-ID	photo-identification
SD	standard deviation
SPOT	Smart Position and Temperature
U.S.	United States

1. Introduction

In 2014 a study was initiated off Cape Hatteras, North Carolina, to examine the spatial use and diving behavior of a number of species of odontocetes, with particular emphasis on Cuvier's beaked whales (*Ziphius cavirostris*) and short-finned pilot whales (*Globicephala macrorhynchus*). During 2014 and 2015, remotely deployed Low-Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) satellite tags were used to obtain movement data from 9 Cuvier's beaked whales, 35 short-finned pilot whales, 9 common bottlenose dolphins (*Tursiops truncatus*, hereafter bottlenose dolphins), 1 sperm whale (*Physeter microcephalus*) and 1 short-beaked common dolphin (*Delphinus delphis*), ranging over periods from 1.3 to 193.8 days (Baird et al. 2015, 2016; Foley et al. 2015a; Thorne et al. 2015). This report summarizes information obtained through additional field efforts undertaken in 2016, while incorporating results from the first two years of effort. The present work is intended to complement ongoing research by Duke University off Cape Hatteras (hereinafter referred to as the Duke program) by providing information on the movement and diving behavior of these species over the medium term (weeks to months). The Duke program is focusing on shorter-term dive behavior (i.e., hours to days) using Digital Acoustic Tags and longer-term movements (i.e., months to years) using photo-identification (photo-ID) techniques (Swaim et al. 2014). The photo-ID work has demonstrated a high degree of re-sightings, particularly of short-finned pilot whales, suggesting some residency in the Cape Hatteras Study Area. Attempts were made in the field to obtain digital images of all tagged animals to ensure that linkages could be drawn between the photo-ID and satellite tagging work. Photographic matches of tagged animals and their associates are presented in the annual report of the Duke program (Foley et al. 2015b, 2016, 2017a).

2. Methods

Four types of Argos-linked satellite tags were used in this study in 2016, two location-only Smart Position and Temperature tags (SPOT5 and SPOT6), a location-depth SPLASH10 tag, and a location-depth SPLASH10F prototype tag, which included a Fastloc-GPS (all produced by Wildlife Computers, Redmond, Washington), all in the LIMPET configuration (Andrews et al. 2008). The SPLASH10F prototype tag was deployed as a field test of this tag type and the Fastloc-GPS system to support development of the tag for Wildlife Computers and the Alaska SeaLife Center, and thus the tag was not set to record/transmit dive behavior information other than basic 24-hour histogram dive blocks. Tags were remotely deployed using a DAN-INJECT JM 25 pneumatic projector (DanWild LLC, Austin, Texas), and were attached with two surgical-grade titanium darts with backward-facing petals. Target area for all tags was the dorsal fin or the base of the fin. Two dart lengths were used depending on the species. Short darts (4.4-centimeter) were used on small cetaceans (e.g., bottlenose dolphins), and long darts (6.8-centimeter) were used on large cetaceans (i.e., short-finned pilot whales and Cuvier's beaked whales).

For each tag type (i.e., location-only or location-depth), there were different programming combinations depending on species, based on the average number of respirations per hour from previous tagging studies and taking into account the speed of surfacing and likelihood of

the tag remaining attached for longer than approximately 30 days, which varies by species (Cascadia Research Collective, unpublished).

- The number of hours (hr) transmitting per day for location-only tags by species was: short-finned pilot whales—10 hr, bottlenose, common, and Clymene dolphins (*Stenella clymene*)—14 hr, and Cuvier's beaked whales—18 hr. For location-depth tags, this was: short-finned pilot whales—17 hr and Cuvier's beaked whales—20 hr.
- Location-only tags programmed for deployment on small cetaceans transmitted daily through the lifespan of the tags (expected battery life of 34 days), and those deployed on short-finned pilot whales were also duty-cycled to transmit daily for the lifespan of the tags, but hours transmitting were reduced after 60 and 105 days. For deployments on Cuvier's beaked whales, duty-cycling was set for daily transmissions with the number of hours transmitting being reduced after 80 and 105 days.
- Location-depth tags on Cuvier's beaked whales were set to transmit every day for 25 days, then every other day for 4 transmission days (i.e., covering a span of 8 days), then every third day for the remainder of the tag life. For short-finned pilot whales, location-depth tags were programmed to transmit daily for the first 20 days, every third day for 4 transmission days, and every ninth day for the duration of tag attachment.
- The total number of possible tag transmissions per day was varied to reflect the number of hours transmitting per day and the average number of respirations per hour for each species. Given this, the theoretical battery life for location-only tags was 150 calendar days for short-finned pilot whales, 120 calendar days for Cuvier's beaked whales, and 49 calendar days for small cetaceans, while the theoretical battery life for location-depth tags was 41 calendar days for short-finned pilot whales and 63 calendar days for Cuvier's beaked whales.

Location-depth tags were programmed to provide dive statistics (e.g., start and end time, maximum depth, and duration) for any dives that exceeded the species-specific depth threshold. Thresholds were defined as: short-finned pilot whales—30 meters (m), and Cuvier's beaked whale—50 m. For the purposes of comparative analyses, dive statistics were only calculated for dives exceeding 50 m for all species. Prior to each field effort, satellite pass predictions were carried out using the Argos website to determine the best hours of the day for transmissions given satellite overpasses for the approximate 2-month period starting at the beginning of each deployment period.

Photographs were taken of target individuals prior to and at the time of tagging, and photos were used to confirm sex for some species based on external morphology and scarring patterns (in the case of Cuvier's beaked whales, see McSweeney et al. 2007).

Filtered location data were processed with R 3.2.2 (packages *sp* 1.2-2, *rgeos* 0.3-15, *raster* 2.5-2) to determine depth, distance from shore, and distance from the 200-m isobath. Depth values were generated from 3 arc-second data from the U.S. Coastal Relief Model for regions off the U.S. Atlantic coast (www.ngdc.noaa.gov/mgg/coastal/crm/data/netcdf/ne_atl_crm_v1.nc.gz and www.ngdc.noaa.gov/mgg/coastal/crm/data/netcdf/se_atl_crm_v1.nc.gz) where available, and

with 30 arc-second data from the General Bathymetric Chart of the Oceans 2014 (www.gebco.net/) in other areas. The 200-m isobath dataset used was from the "Data Basin" on-line mapping tool (databasin.org). Given the inherent lack of precision associated with Argos-derived locations, combined with the steep continental shelf-edge and slope topography, we report median and maximum depths of tagged animal locations. Maximum depths are less likely to be influenced by Argos location quality or the steep slope given that the deepest locations of most tagged individuals were well seaward of the continental shelf (see **Results**).

Probability-density maps were generated using all filtered satellite-tag data for all individuals of each of three species where multiple individuals were satellite tagged in 2014, 2015, and 2016, with data from all three years incorporated. Kernel-density polygons corresponding to the 50, 95, and 99 percent densities were generated using the R package *adehabitatHR* version 0.4.11[1]. Polygons were plotted in Google Earth Pro version 7.1.2.2041.

When more than one tag was deployed on the same species, we assessed whether individuals were acting in concert during the period of overlap by measuring the straight-line distance between pairs of individuals when locations were obtained during a single satellite overpass (approximately 10 minutes [min]). We used both the mean distances between pairs of individuals and the maximum distance between pairs to assess whether individuals were acting independently, following protocols described by Schorr et al. (2009) and Baird et al. (2010).

3. Results

Field efforts were undertaken for tagging in May, June, and August 2016. Thirty-three tags were available for deployment: 13 location-depth tags (SPLASH10), 19 location-only tags (SPOT5 and SPOT6) and 1 location-depth SPLASH10F prototype tag. Twenty tags were deployed, 15 off Hatteras (**Table 1**), and 5 off Jacksonville, Florida (as part of a related project; see Foley et al. 2017b). One location-only tag was lost during a deployment attempt. Of the 20 tags, 16 were deployed in the dorsal fin or at the base of the dorsal fin, and four were deployed below the base of the fin (all on Cuvier's beaked whales).

One location-only tag was deployed on a bottlenose dolphin, with an attachment duration of 13.1 days (**Table 1**). Cumulative distance moved was 1,016.4 kilometers (km), yet the mean distance from the tagging location was only 30.2 km, with the maximum distance moved from the tagging location of 79.1 km (**Table 2**; **Figures 1 and 2**). Median depth determined from locations of the tagged individual was 1,837 m, with a maximum depth at tagged animal locations of 2,538 m. Location data combined with the nine bottlenose dolphins tagged in 2014 (Baird et al. 2015) and 2015 (Baird et al. 2016) indicate that movements are limited (**Figure 3**). A kernel density utilization distribution including all 10 individuals indicates that the core of the habitat used by the tagged bottlenose dolphins is on the continental slope off Cape Hatteras (**Figure 4**).

A single location-only tag was deployed on a short-beaked common dolphin, and location data were obtained over an 11.34-day period (**Table 1**). The cumulative distance moved by this

[1] https://www.movebank.org/node/14620

individual was 678 km, yet the mean distance from the tagging location was 25.8 km, and it had moved a maximum of 69.5 km from the tagging location when the tag stopped transmitting (**Table 2**). Over the 11.34-day period, the dolphin primarily remained over the shelf break and continental slope (**Figures 5**), often returning to near the area where it was tagged (**Figure 6**). The median depth of the tagged animal locations over the 11.34-day span was 573.2 m (**Table 3**). Only a single short-beaked common dolphin had previously been tagged off Hatteras (in 2015) and showed considerably greater movements to the north (**Figure 7**).

One location-only tag was deployed on a Clymene dolphin, and location data were obtained over a 20.27-day period (**Table 1**). The cumulative distance moved by this individual was 1,684.5 km yet the mean distance from the tagging location was 152.4 km, and it had moved a maximum of 268 km from the tagging location when the tag stopped transmitting (**Table 2**). Although tagged on the continental slope, over the 20.27-day period the dolphin primarily remained offshore of the slope (**Figure 8**), with a median depth of tagged animal locations of 2,689 m (**Table 3**). During the time of the deployment the tagged animal moved away from and then returned to within 50 km of where it was tagged (**Figure 9**).

Another single location-only tag was deployed on a Risso's dolphin (*Grampus griseus*), and location data were obtained over a 17.55-day period (**Table 1; Figure 10**). The cumulative distance moved by this individual was 1,453.8 km. While its mean distance from the tagging location was 170.6 km, around seven days post-tagging the animal moved directionally away from the general area to the south (**Figure 11**), and was 470 km from where it was tagged when the tag stopped transmitting (**Table 2**). Over the 17.55-day period, the dolphin primarily remained over the continental slope (**Figure 10**), with a median depth of the tagged animal locations of 328 m (**Table 3**).

Six satellite tags were deployed on Cuvier's beaked whales, with one location-only tag and five location-depth tags (**Table 1**). Tags were deployed on two individuals in the same encounter on two different days, although assessment of distance between the two pairs of individuals during the period of tag overlap indicates that the individuals did not act in concert (**Table 4**). Other pairs of individuals with overlapping tag data, tagged on different days, also acted independently (**Table 4**).

Movement patterns of the six individuals varied, with most remaining relatively close to the location where they were tagged (**Table 2**). The individual (ZcTag051) tagged in the deepest water (1,774 m; **Table 1**) left the area where it was tagged in the first two days and moved over 180 km away, while another (ZcTag049) remained in the general area for over 80 days before moving 120 km away (**Figure 12**). Most of the tagged individuals remained in relatively small areas on the continental slope near the tagging locations (**Figures 13, 14, 15, 16, 17; Table 3**), with only occasional movements off the slope (e.g., **Figure 16**). Four of the tagged Cuvier's beaked whales had three or more satellite-derived locations on the continental shelf (i.e., in <200 m depth). An assessment of location classes for ZcTag047, the individual with the largest number of locations on the shelf (**Figure 14**) indicate that these shallow locations are likely artifacts of poor location classes combined with the individuals' spending considerable time in close proximity to the shelf break. For example, a combined 45 percent of locations of class B

and Z were in depths less than 200 m, in comparison to only 8 percent of locations of class 2 and 1.

The one individual that moved the farthest (ZcTag051; **Figure 18**) was the only individual primarily using waters off the continental slope (**Table 3**). In general, the individuals tagged in 2016 had similar ranges to those tagged in 2014 and 2015 (**Figure 19**). A probability-density distribution from tag data obtained in 2014 (Baird et al. 2015), 2015 (Baird et al. 2016) and 2016 (**Table 1**) suggests that the core range for individuals tagged off Cape Hatteras is relatively small (**Figure 20**) and broadly overlaps with the core range of tagged bottlenose dolphins (**Figure 4**).

One of the location-depth tags (ZcTag047) had a pressure transducer failure shortly after deployment. While dive data were obtained from the tag that could be used for documenting long dive durations, status messages from the tag indicated that dive depths were likely inaccurate. Dive data were obtained from the other four individuals tagged with location-depth tags, three of which remained primarily in slope waters and one of which spent its time seaward of the slope. Maximum dive depths and dive durations documented for the three individuals that primarily remained in slope waters ranged from 1,847 to 2,159 m and 68.7 to 152.5 min (**Table 4**). Median depths at locations of these tagged individuals ranged from 1,009 to 1,340 m (maximum from 2,004 to 2,300 m; **Table 3**), suggesting that many of the dives were likely to, or close to, the sea floor. A pseudotrack showing dive data relative to bottom depth is shown in **Figure 21**. The individual that spent almost all of its time seaward of the continental slope had one 78.5-min dive to 3,567.5 m (**Table 5**). Assuming this was a V-shape dive, the ascent and descent rates would have averaged 1.32 m/sec, within 1 standard deviation (SD) of the ascent/descent rates for other dives >1,000 m of this individual (mean=1.20 m/sec, SD=0.28 m/sec). Bottom depths for locations of this individual shortly before (3,451 m) and shortly after (3,326 m) the deepest dive suggest that it is technically possible the dive depth was accurate, particularly given the uncertainty associated with Argos locations. However, while status reports from the tag showed no failure of the pressure transducer, the pressure transducer for the location-depth tags has been tested to 3,000 m on only a few occasions, thus this dive depth should be treated with caution.

Five satellite tags were deployed on short-finned pilot whales. Four of these were location-only tags, and one was a prototype location-depth tag also obtaining Fastloc-GPS locations (**Table 1**). The attachment durations ranged from 24.3 to 156.7 days (median=131.8 days). The tags were deployed during five different encounters, and the distances between pairs of individuals suggested that all individuals generally acted independently (**Table 4**).

Mean and maximum distances moved varied considerably among individuals (**Table 2)**, as did the typical depths used (**Table 3**), suggesting considerable variability in movement patterns and habitat use among short-finned pilot whale groups off the U.S. Atlantic coast (**Figures 22, 23, 24, 25, 26**). Only one individual (GmTag159) spent the majority of its time seaward of slope waters (**Figure 24**), moving over 600 km from where it was tagged in less than 10 days, before returning back to the area it was tagged 10 days later. This tag recorded 727 Fastloc-GPS locations, in comparison to 206 Argos-derived locations. While the locations from the two

positioning systems were generally similar, the track derived from the Argos-derived locations did deviate at times from the Fastloc-GPS track.

A map showing combined track and location data from all short-finned pilot whales tagged in 2014 (*n*=17), 2015 (*n*=19), and 2016 (*n*=5) is shown in **Figure 26**, with a probability-density representation shown in **Figure 27.** As with Cuvier's beaked whales and bottlenose dolphins, the core range centers off Cape Hatteras, North Carolina, although movements represented by the 90 percent and 95 percent polygons cover a large proportion of U.S. waters from North Carolina to New York and extend offshore into both international and Canadian waters.

4. Discussion

This study provides information on the movements and habitat use of six different species of odontocetes along the eastern coast of the U.S. and builds upon work begun in 2014 (Baird et al. 2015) and 2015 (Baird et al. 2016). The combined efforts represent the first dedicated satellite tagging on free-ranging small and medium-sized odontocetes off the U.S. Atlantic Coast. Tag deployments have provided additional long-distance movement information for Cuvier's beaked whales off the U.S. Atlantic Coast, as well as long-term and long-distance movements of short-finned pilot whales in the area, information that prior to 2014 had only been obtained from previously stranded individuals released off Florida (Wells et al. 2013). The movement information obtained from the tag deployment on a Clymene dolphin (**Figures 8, 9**) is the first movement data available for this poorly-known species.

Six Cuvier's beaked whales were tagged in 2016. While most of the tagged animals remained in or near the core area of the 2014 and 2015 tagged animals, staying near the continental slope off Cape Hatteras (**Figures 13, 14, 15, 17**), two individuals did spend considerable time seaward of the slope (**Figures 16, 18**), one moving over 140 km from the area it was tagged within a few days of tagging (**Figure 12**). This may suggest the occasional occurrence of oceanic animals using the area of the apparently resident population. Results from individual photo-identification may help address longer-term site fidelity, for example whether either of those two individuals return in subsequent years. The dive-data records obtained from individuals in 2016, combined with the four individuals in 2015 and two individuals in 2014, will allow for a comparison of diving patterns of this species with data obtained elsewhere (i.e., Hawai'i, California, Italy; Baird et al. 2006, 2008; Schorr et al. 2014; Tyack et al. 2006). One dive was recorded to 3,567.5 m (**Table 5**), deeper than any dive that has been previously recorded for Cuvier's beaked whales (Schorr et al. 2014; Baird et al. 2015; Baird 2016), although as noted, this dive record should be treated with some caution. Given this recorded dive depth, further testing of pressure transducers on these tags is warranted. Future deployments of depth-transmitting tags on Cuvier's beaked whales using offshore waters will be informative on whether and how often this species may dive to such depths.

In 2016 we were able to field test a prototype tag that provided Fastloc-GPS locations in addition to Argos-derived locations, providing a much higher degree of resolution of movement data than for Argos tags (**Figure 24**), as well as providing more accurate locations. Once commercially available these tags will greatly increase the value of LIMPET satellite tags for addressing finer-scale questions that require the more accurate GPS locations. It should be

noted, however, that there are several limitations to using such tags. They are heavier than the currently available location-depth tags, and thus the range of circumstances when they can be deployed is narrower. For example, the tags may not fly as far or as straight when deployed with a pneumatic projector, thus increasing the likelihood of poor tag placement or potentially losing a tag. In addition, bandwidth limitations to transmitting both dive data and Fastloc-GPS locations through the Argos satellite system suggest there will be a tradeoff in the quantity of dive and surfacing data obtained in order to obtain the GPS locations. Thus while they may be the best choice of tag to deploy in some circumstances, they may not be so in all.

While the photo-ID work suggests that short-finned pilot whales display a high degree of site fidelity off Cape Hatteras, satellite tagging demonstrates that these animals cover a significant range up and down the continental slope, and occasionally into offshore waters (**Figures 24, 26**). The considerable variability in movement patterns and habitat use likely reflects patterns that vary by social group, and understanding site fidelity and association patterns determined through photo-ID will help in interpreting such variability.

Even though short-finned pilot whales cover a much larger range, their core range (**Figure 27**) appears to be centered in the same area as the bottlenose dolphins (**Figure 4**) and Cuvier's beaked whales (**Figure 20**), although it is a much larger area that extends north to offshore of Maryland. Unlike the other whales and dolphins, the 90 percent and 95 percent polygons extend much farther, along the continental slope all the way into Canadian waters, and out across the abyssal plain to the New England Seamount chain. Even though more study is necessary to determine the structure and habitat use of these stocks, the importance of the continental slope to the east of Cape Hatteras (North Carolina) is becoming apparent.

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6. Literature Cited

Andrews, R.D., R.L. Pitman, and L.T. Ballance. 2008. Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. *Polar Biology* 31:1461–1468.

Baird, R.W., D.L. Webster, D.J. McSweeney, A.D. Ligon, G.S. Schorr, and J. Barlow. 2006. Diving behaviour of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawai'i. *Canadian Journal of Zoology* 84:1120–1128.

Baird, R.W., D.L. Webster, G.S. Schorr, D.J. McSweeney and J. Barlow. 2008. Diel variation in beaked whale diving behavior. *Marine Mammal Science* 24:630–642.

Baird, R.W., G.S. Schorr, D.L. Webster, D.J. McSweeney, M.B. Hanson, and R.D. Andrews. 2010. Movements and habitat use of satellite-tagged false killer whales around the main Hawaiian Islands. *Endangered Species Research* 10:107–121.

Baird, R.W., D.L. Webster, Z. Swaim, H.J. Foley, D.B. Anderson, and A.J. Read. 2015. *Spatial Use by Cuvier's Beaked Whales, Short-finned Pilot Whales, Common Bottlenose Dolphins, and Short-beaked Common Dolphins, Satellite Tagged off Cape Hatteras, North Carolina, in 2014.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N6247010-D-3011, Task Orders 14 and 21, issued to HDR Inc., Virginia Beach, Virginia 17 July 2015. Available from http://www.cascadiaresearch.org/reports/Bairdetal2015HatterasOdontocetes.pdf

Baird, R.W., D.L. Webster, Z. Swaim, H.J. Foley, D.B. Anderson, and A.J. Read. 2016. Spatial Use by Odontocetes Satellite Tagged off Cape Hatteras, North Carolina in 2015. Final report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Order 57 and N62470-15- 8006, Task Order 07, issued to HDR Inc., Virginia Beach, Virginia. 29 July 2016. Available from http://www.cascadiaresearch.org/reports/Bairdetal2016Hatteras.pdf

Foley, H., D. Waples, Z. Swaim, R.W. Baird, D.L. Webster, J. Bell, and A. Read. 2015a. Should I stay or should I go: movement and residency patterns of satellite tagged pilot whales offshore of Cape Hatteras, NC. In Abstracts of the 21st Biennial Conference on the Biology of Marine Mammals, 13–18 December 2015, San Francisco, California.

Foley, H., Z. Swaim, D. Waples, and A. Read. 2015b. *Deep Divers and Satellite Tagging Projects in the Virginia Capes OPAREA – Hatteras, NC: January 2014 – December 2014*. Draft Report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011 Task Order CTO 38 issued to HDR, Inc., Norfolk, Virginia. February 2015.

Foley, H., N. Quick, D. Waples, Z. Swaim, and A. Read. 2016. Deep Divers and Satellite Tagging Projects in the Virginia Capes OPAREA – Cape Hatteras, NC: January 2015 – December 2015. Draft Report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Orders 48 and 07 issued to HDR, Inc., Virginia Beach, Virginia. 12 February 2016.

Foley, H.J., D.M. Waples, Z.T. Swaim, and A.J. Read. 2017a. *Deep Divers and Satellite Tagging Project in the Virginia Capes OPAREA–Cape Hatteras, North Carolina: January 2016–December 2016*. *Draft Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 07 issued to HDR, Inc., Virginia Beach, Virginia. 01 February 2017.

Foley, H.J, D.M. Waples, R.W. Baird, Z.T Swaim, D.L. Webster, and A.J. Read. 2017b. *Protected Species Monitoring in Navy OPAREAs off the U.S. Atlantic Coast, January 2016-December 2016. Draft Report.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract Nos. N62470-10-3011, Task Orders 04 and 34, and N62470-10-D-8006, Task Order 07 issued to HDR, Inc., Virginia Beach, Virginia. 01 February 2017.

McSweeney, D.J., R.W. Baird, and S.D. Mahaffy. 2007. Site fidelity, associations and movements of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales off the island of Hawai'i. Marine Mammal Science 23:666-687.

Schorr, G.S., R.W. Baird, M.B. Hanson, D.L. Webster, D.J. McSweeney, and R.D. Andrews. 2009. Movements of satellite-tagged Blainville's beaked whales off the island of Hawai'i. *Endangered Species Research* 10:203–213.

Schorr, G.S., E.A. Falcone, D.J. Moretti, and R.D. Andrews. 2014. First long-term behavioral records from Cuvier's beaked whales (*Ziphius cavirostris*) reveal record-breaking dives. *PLoS ONE* 9(3):e92633. doi:10.1371/journal.pone.0092633

Swaim, Z., H. Foley, D. Waples, K. Urian, and A. Read. 2014. *Protected Species Monitoring in Navy OPAREAS off the US Atlantic Coast January 2013–December 2013*. In: *Annual Report for 2013*. Submitted to the Department of the Navy, Norfolk, Virginia by Duke University, Marine Laboratory, Beaufort, North Carolina.

Thorne, L., H. Foley, D.L. Webster, R.W. Baird, Z. Swaim, J. Bell, and A. Read. 2015. Life on the edge: short-finned pilot whales (*Globicephala macrorhynchus*) target shelf break waters in the U.S. mid-Atlantic bight. In Abstracts of the 21st Biennial Conference on the Biology of Marine Mammals, 13–18 December 2015, San Francisco, California.

Tyack, P.L., M. Johnson, N.A. Soto, A. Sturlese, and P.T. Madsen. 2006. Extreme diving of beaked whales. *Journal of Experimental Biology* 209:4238–4253.

Wells, R.S., E.M. Fougeres, A.G. Cooper, R.O. Stevens, M. Brodsky, R. Lingenfelser, C. Dold, and D.C. Douglas. 2013. Movements and dive patterns of short-finned pilot whales (*Globicephala macrorhynchus*) released from a mass stranding in the Florida Keys. *Aquatic Mammals* 39:61–72.

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Figures

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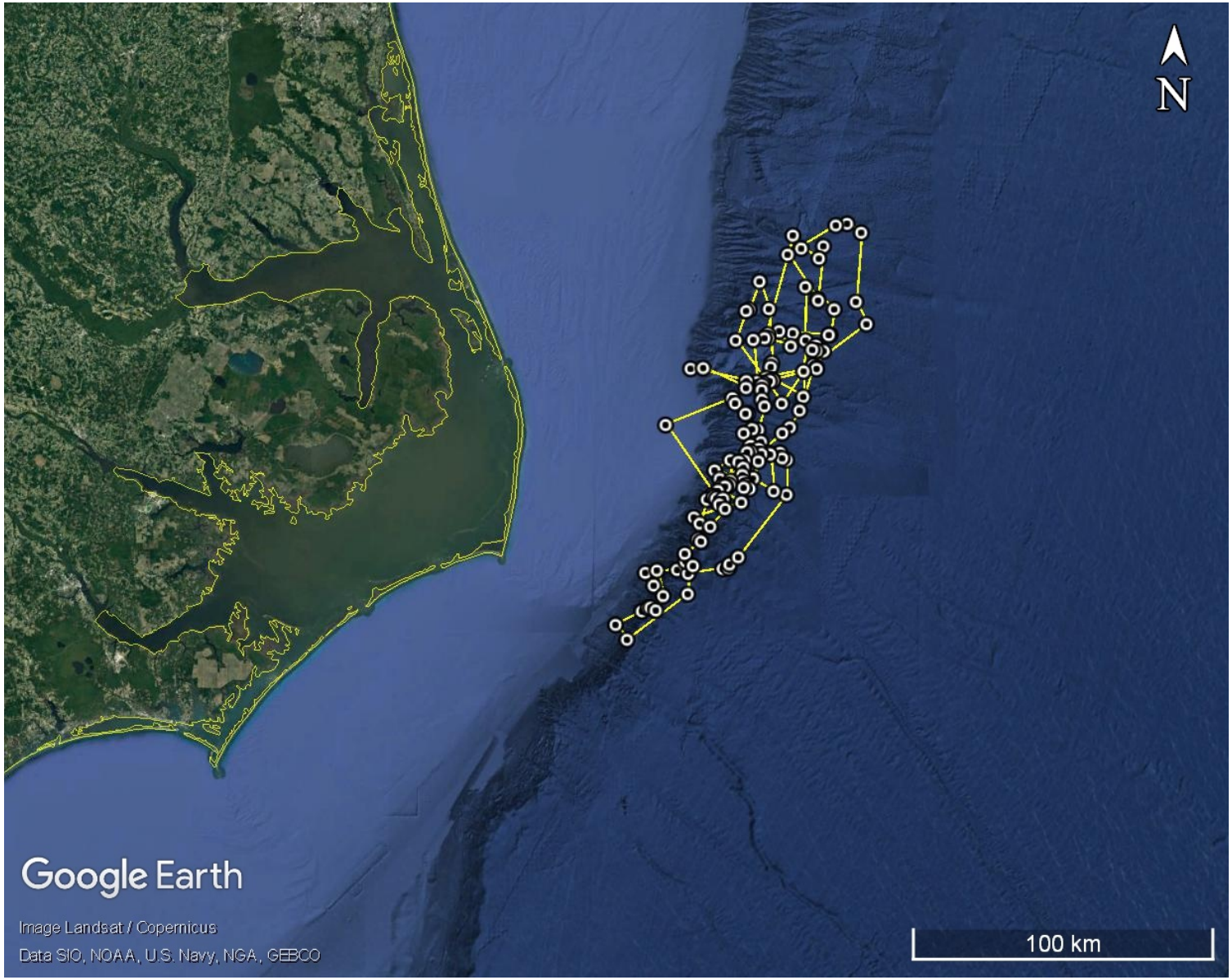

Figure 1. All filtered locations of bottlenose dolphin TtTag029 over the 13.1-day tag-attachment duration, with consecutive locations joined by a line.

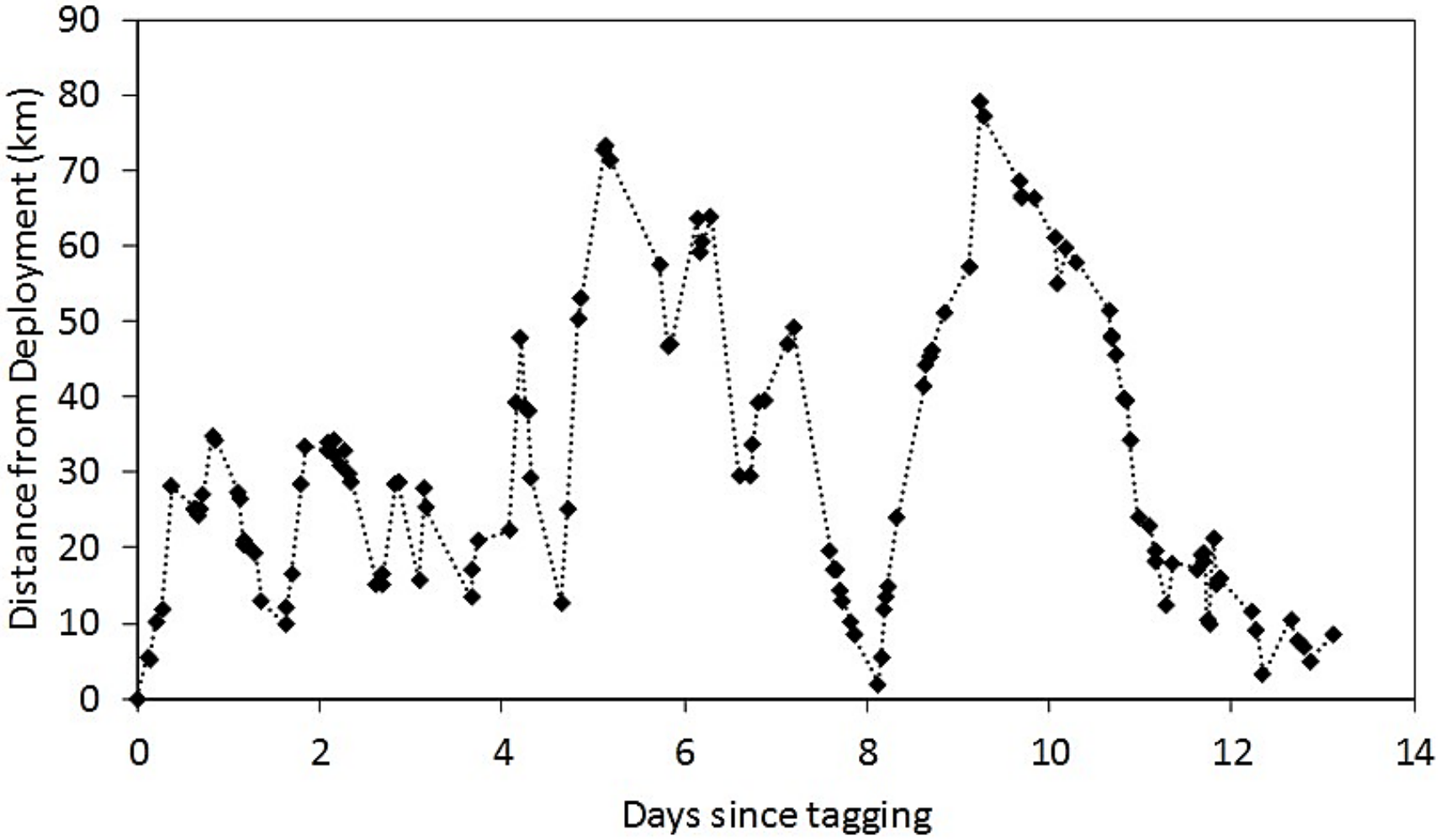

Figure 2. Distance from tag deployment location for bottlenose dolphin TtTag029 over the 13.1-day tag-attachment duration.

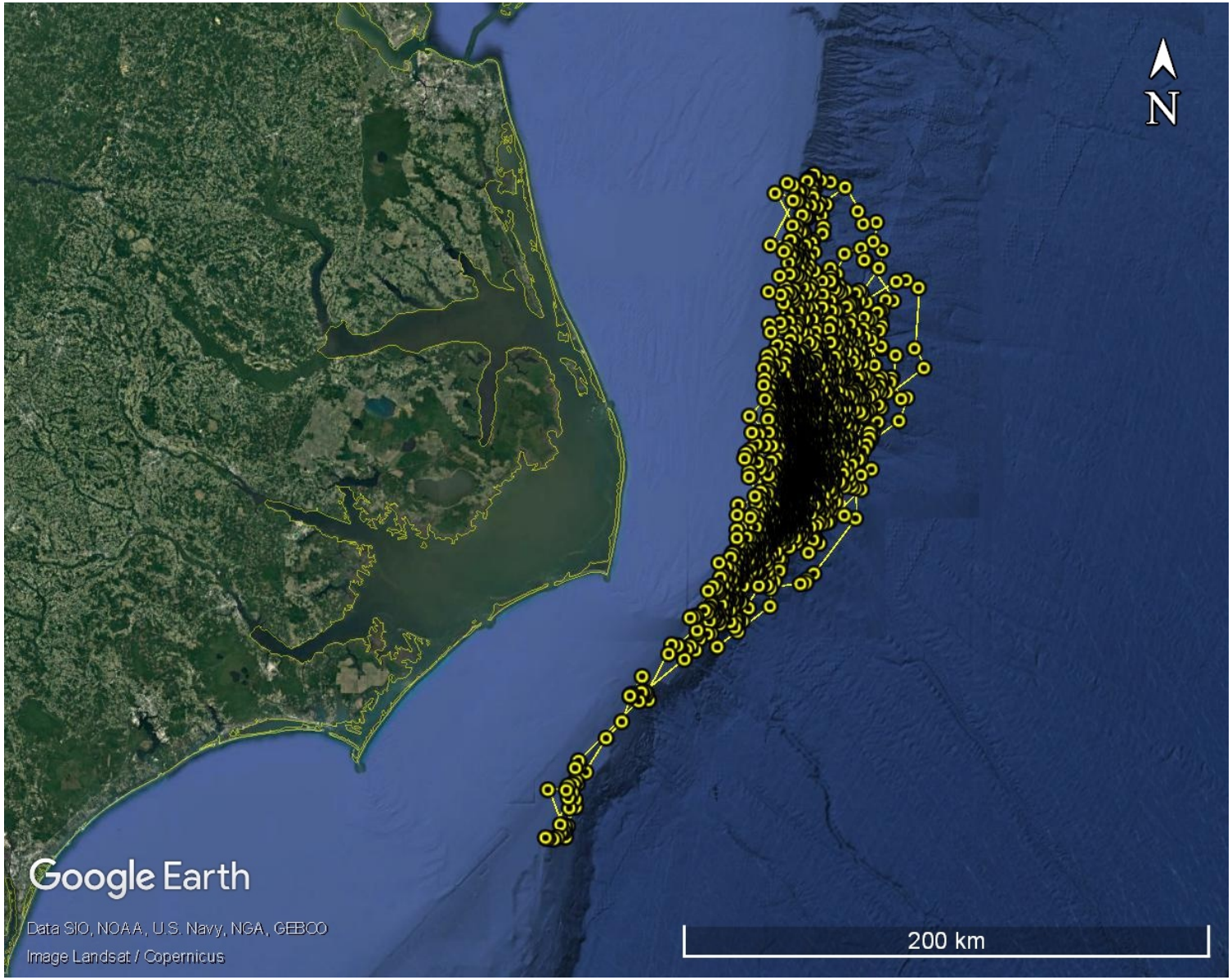

Figure 3. All filtered locations of all 10 satellite-tagged bottlenose dolphins off North Carolina in 2014 (*n*=5), 2015 (*n*=4), and 2016 (*n*=1), with consecutive locations for each individual joined by a yellow line.

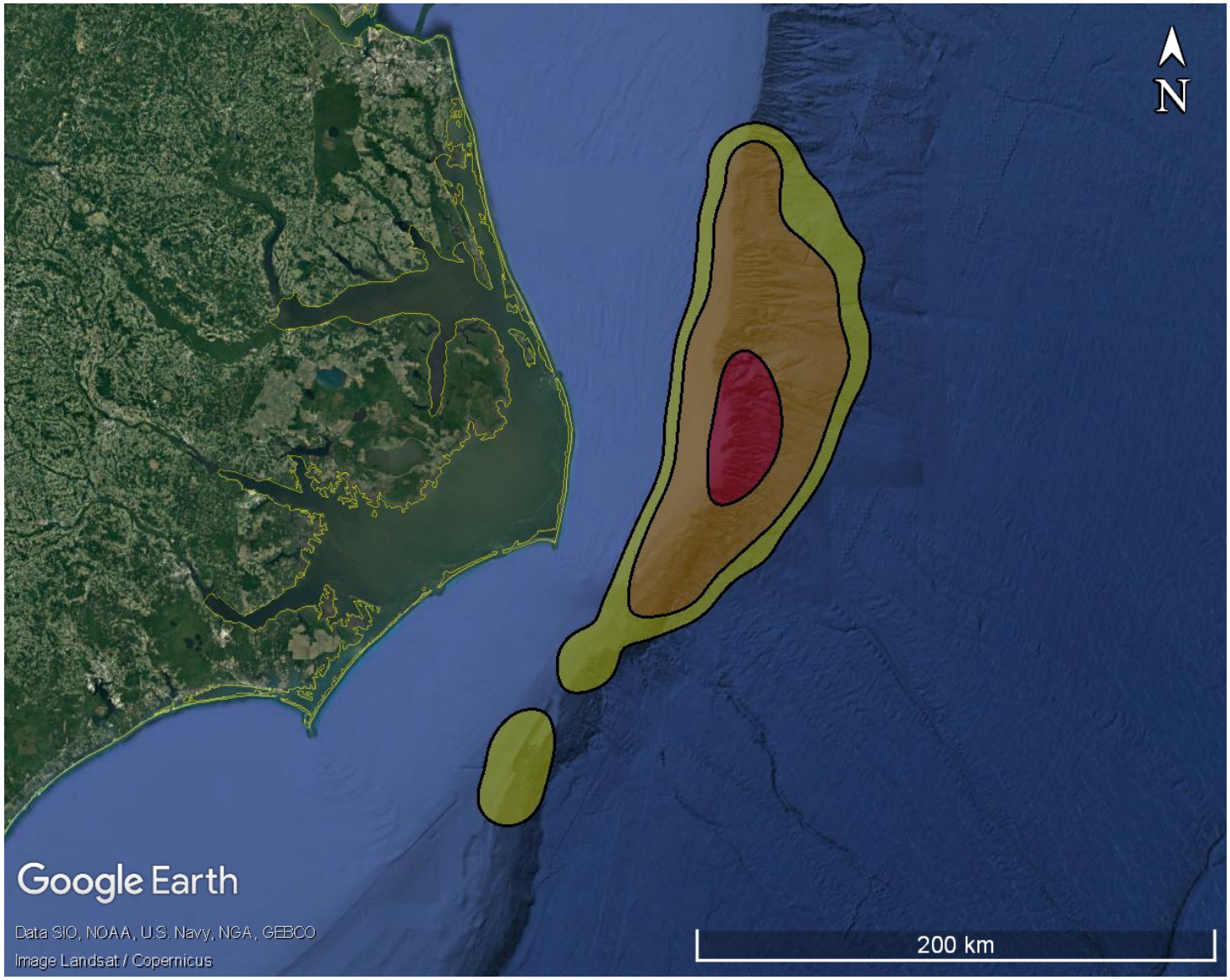

Figure 4. A probability density representation of bottlenose dolphin location data from 10 individuals satellite-tagged off North Carolina from 2014 through 2016. The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95 percent polygon, and the yellow represents the 99 percent polygon.

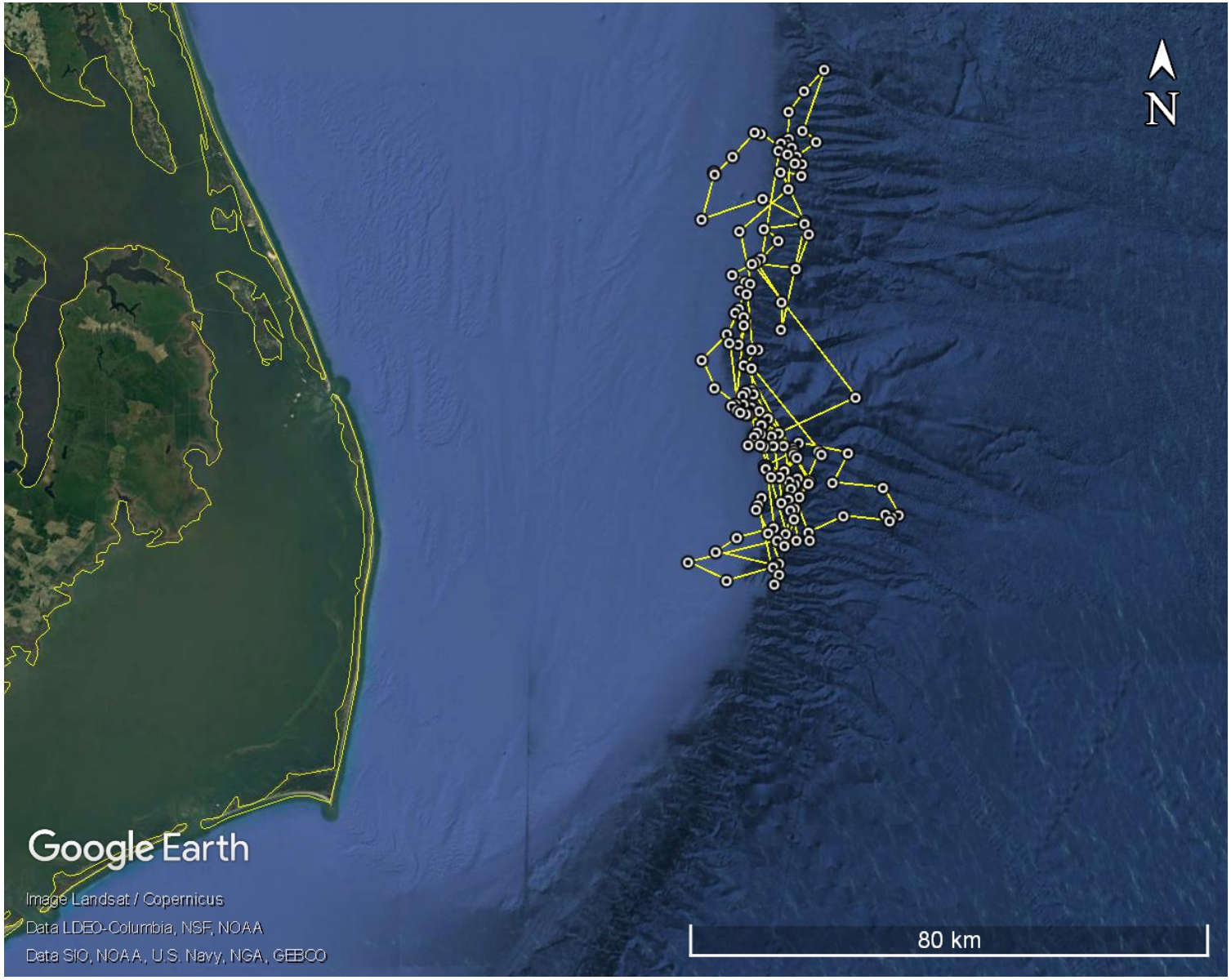

Figure 5. All filtered locations of a short-beaked common dolphin tagged off North Carolina in 2016 over an 11-day period, with consecutive locations joined by a line.

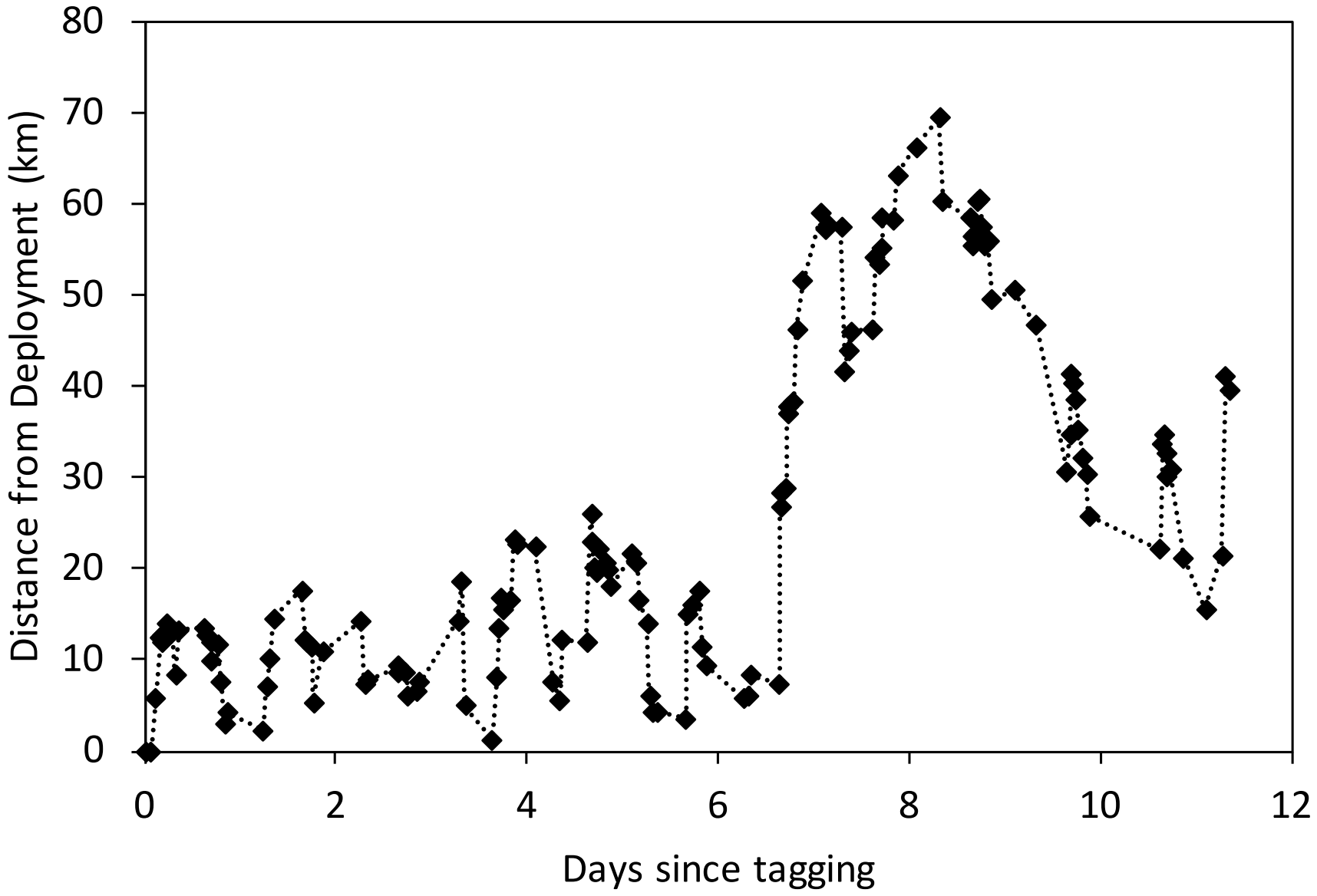

Figure 6. Distance from deployment location for the short-beaked common dolphin satellite tagged off North Carolina in 2016.

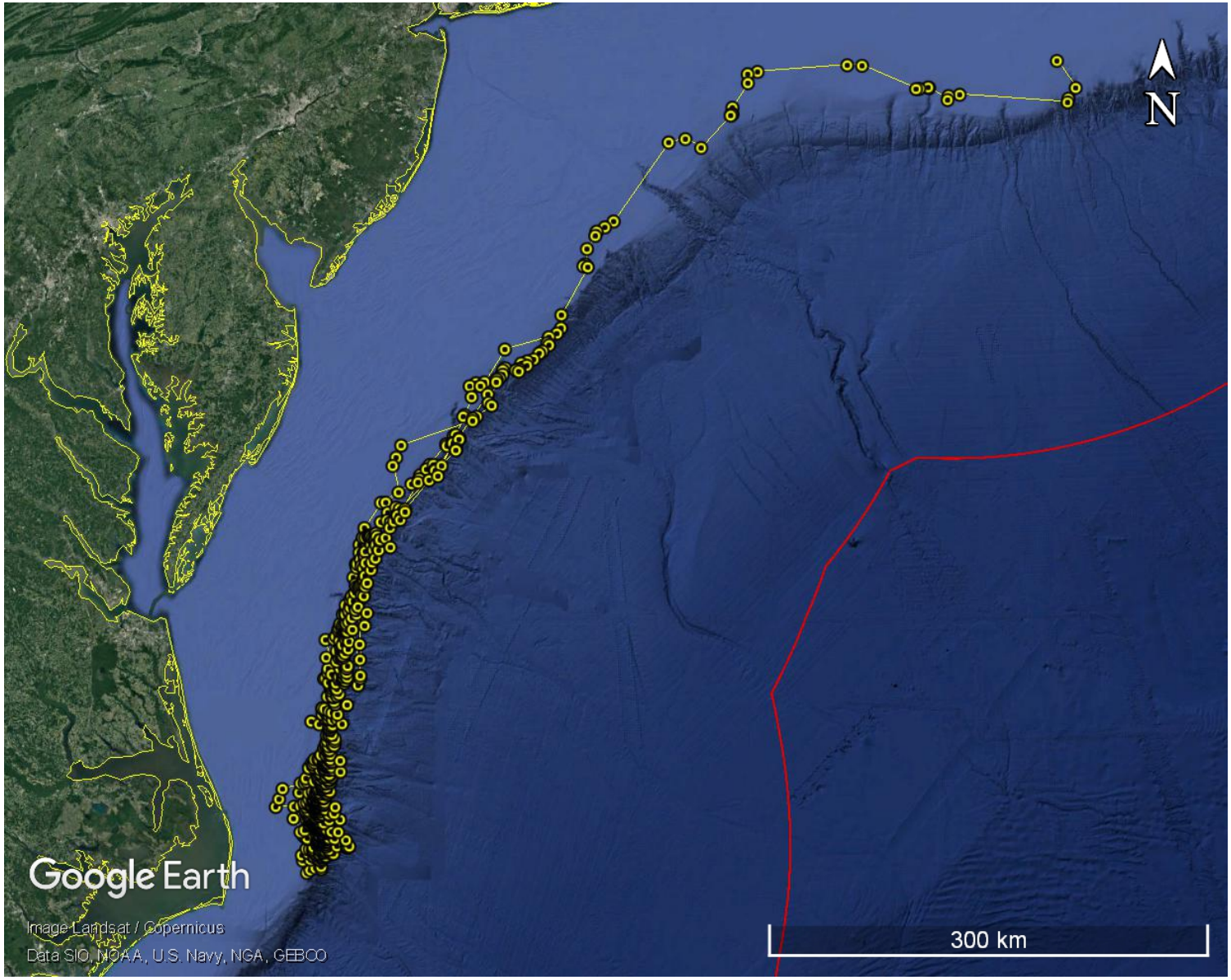

Figure 7. All filtered locations of two short-beaked common dolphins tagged off North Carolina in 2015 and 2016, with consecutive locations joined by a line. The outer boundary of the U.S. EEZ is shown with a red line.

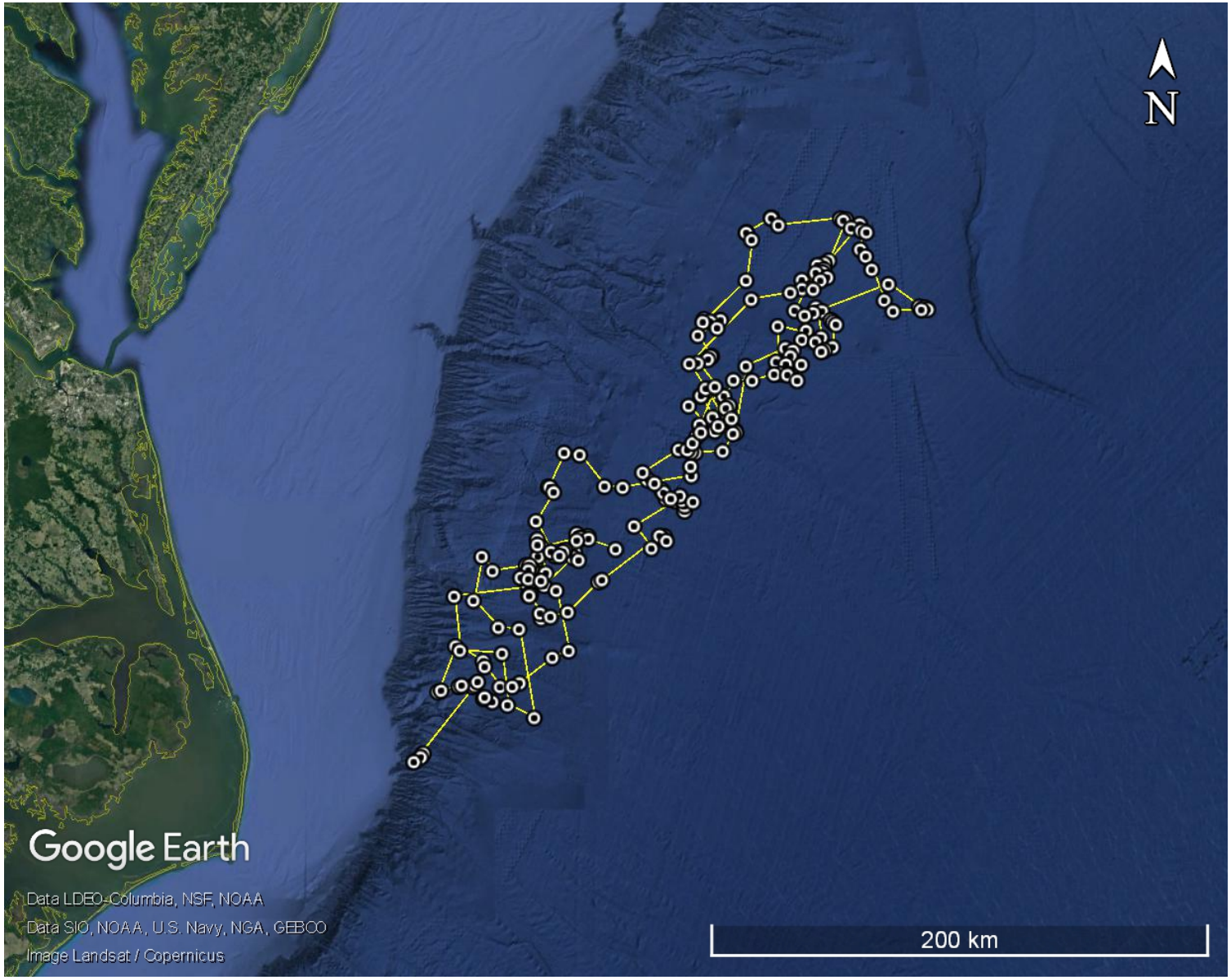

Figure 8. All filtered locations of a Clymene dolphin tagged off North Carolina in 2016 over a 20-day period, with consecutive locations joined by a line.

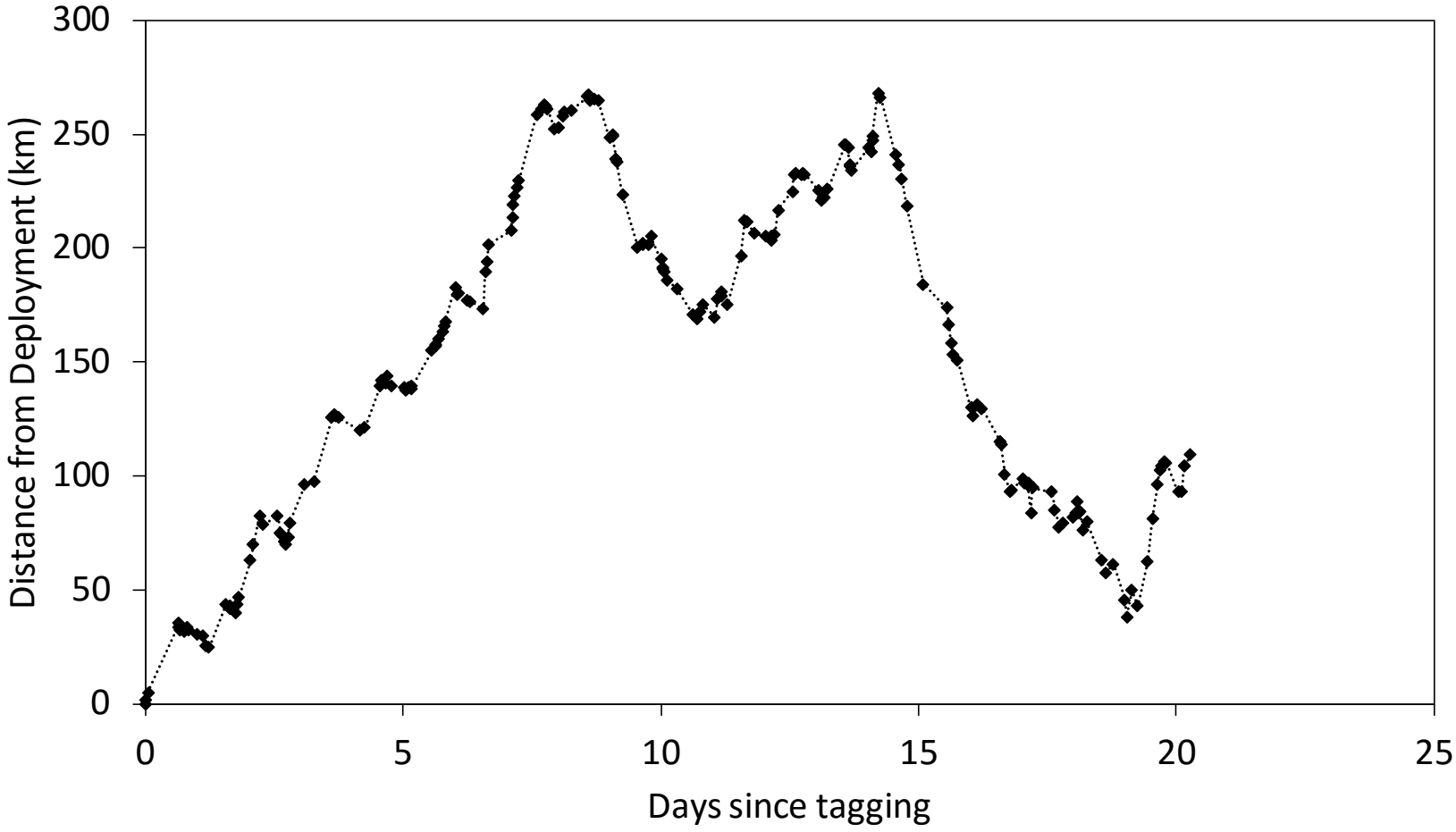

Figure 9. Distance from deployment location for the Clymene dolphin tagged off North Carolina in May 2016, over a 20-day period.

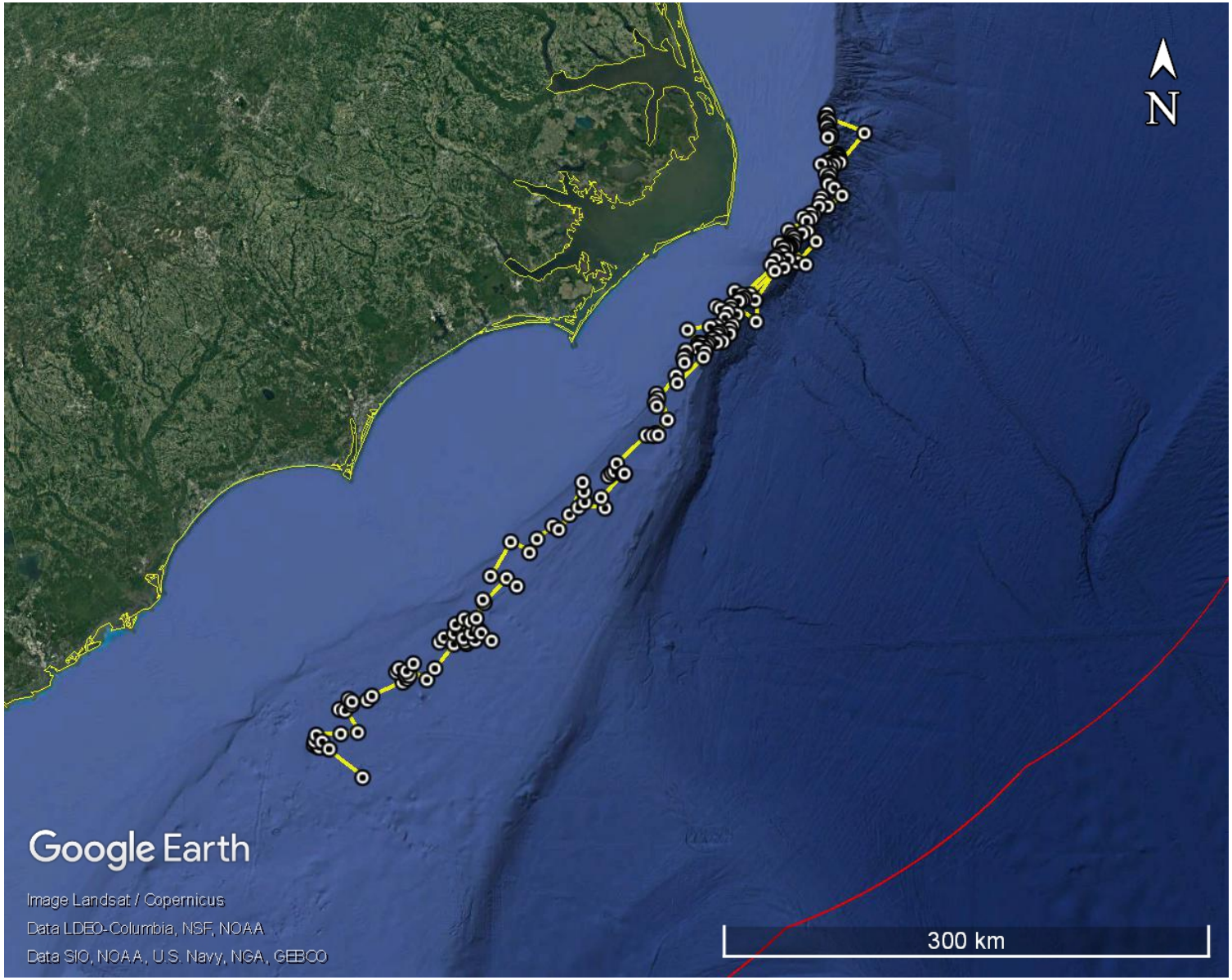

Figure 10. All filtered locations of a Risso's dolphin tagged off North Carolina in August 2016 over a 17.5-day period, with consecutive locations joined by a line. The outer boundary of the US EEZ is shown with a red line.

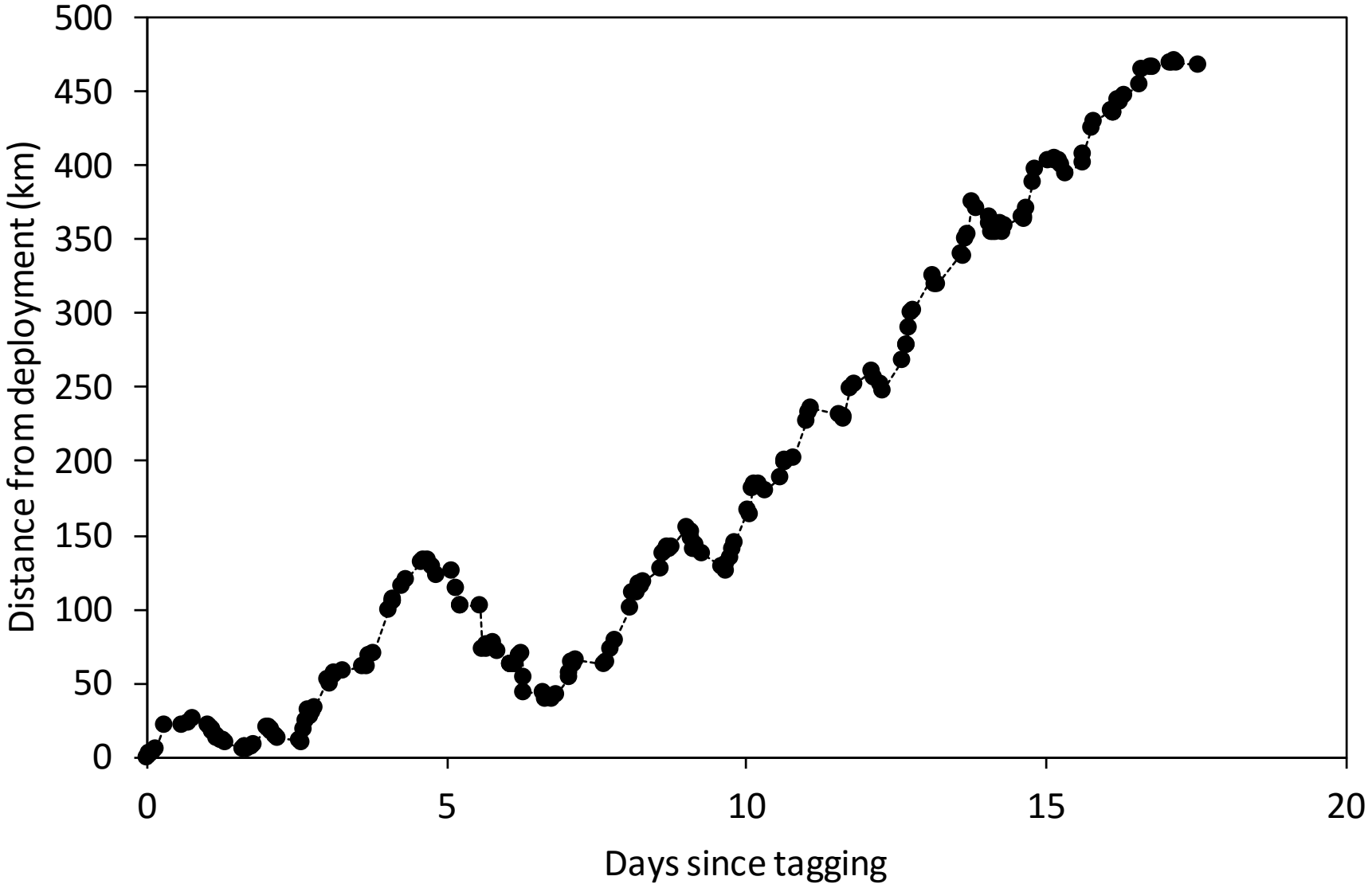

Figure 11. Distance from deployment location for the Risso's dolphin tagged off North Carolina in August 2016.

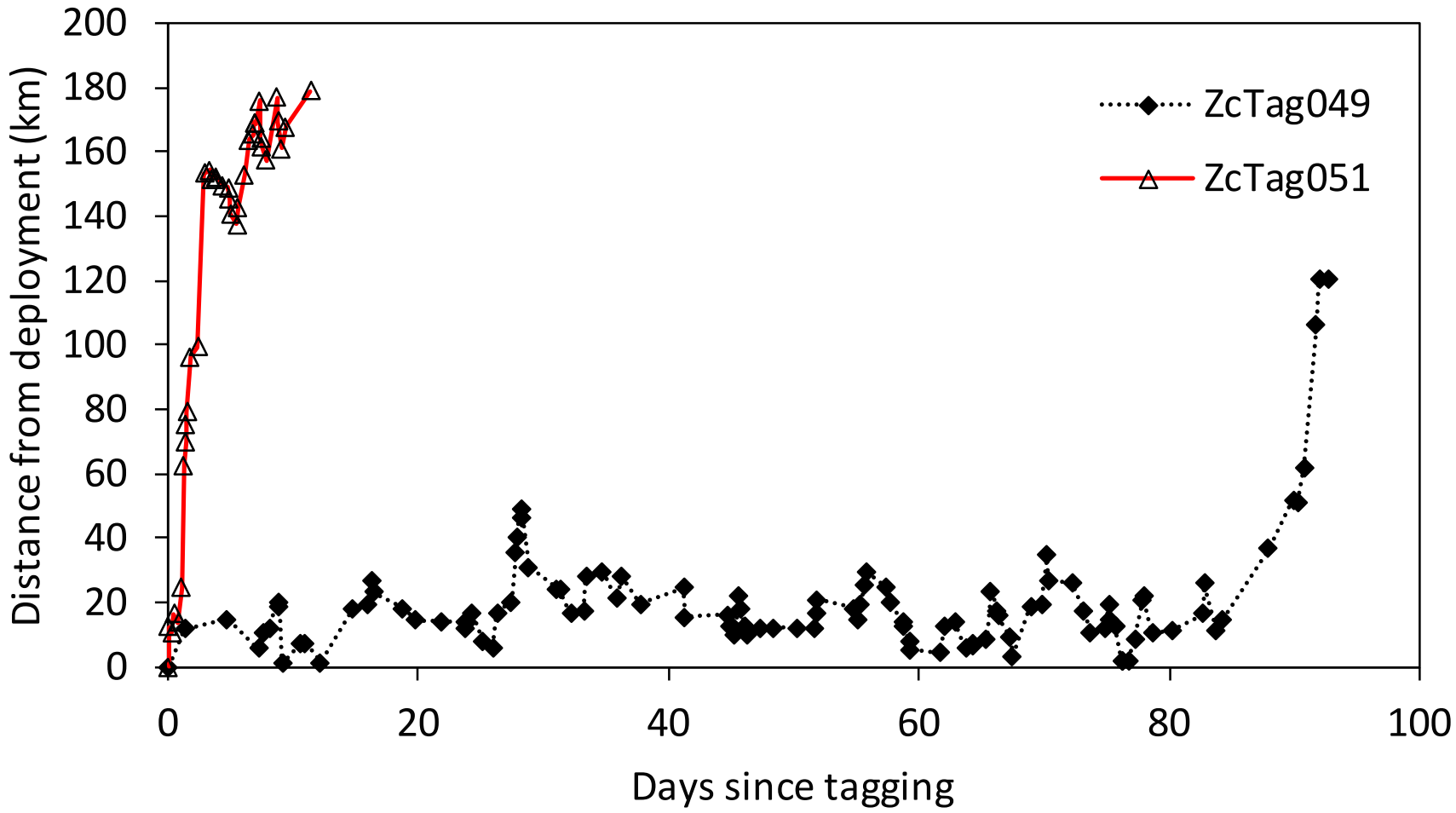

Figure 12. Distance from deployment location for two Cuvier's beaked whales tagged off North Carolina in 2016. ZcTag049 remained relatively close to the tagging location for over 80 days, before moving to a maximum of 120 km away when the tag stopped transmitting after 92 days, while ZcTag051 moved over 140 km from the tagging location within 3 days of tagging. Other individuals (not shown) showed no long-term directional movements away from the general area where they were tagged (see Table 2).

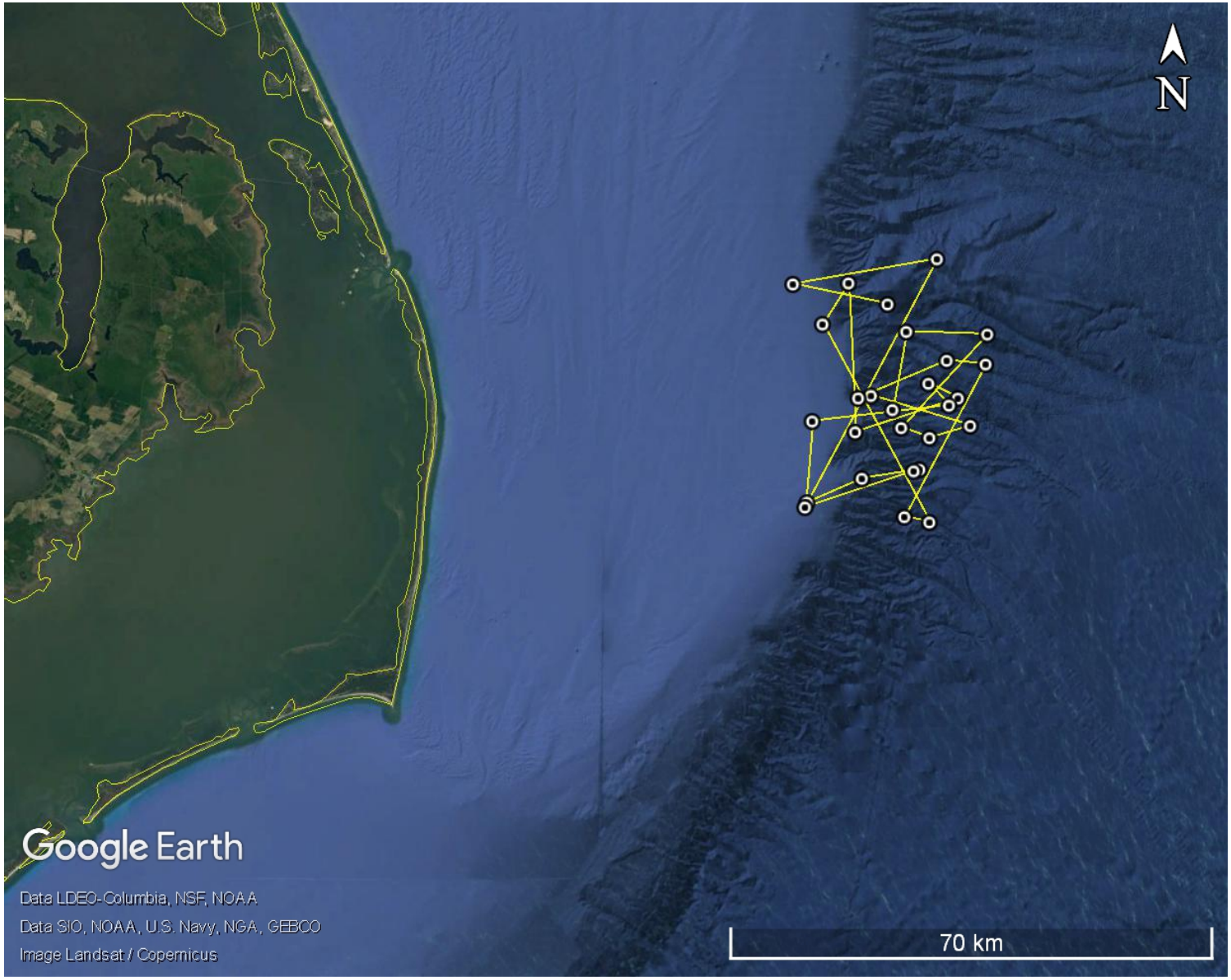

Figure 13. All filtered locations of Cuvier's beaked whale ZcTag046 tagged off North Carolina over a 16.1-day period, with consecutive locations joined by a line.

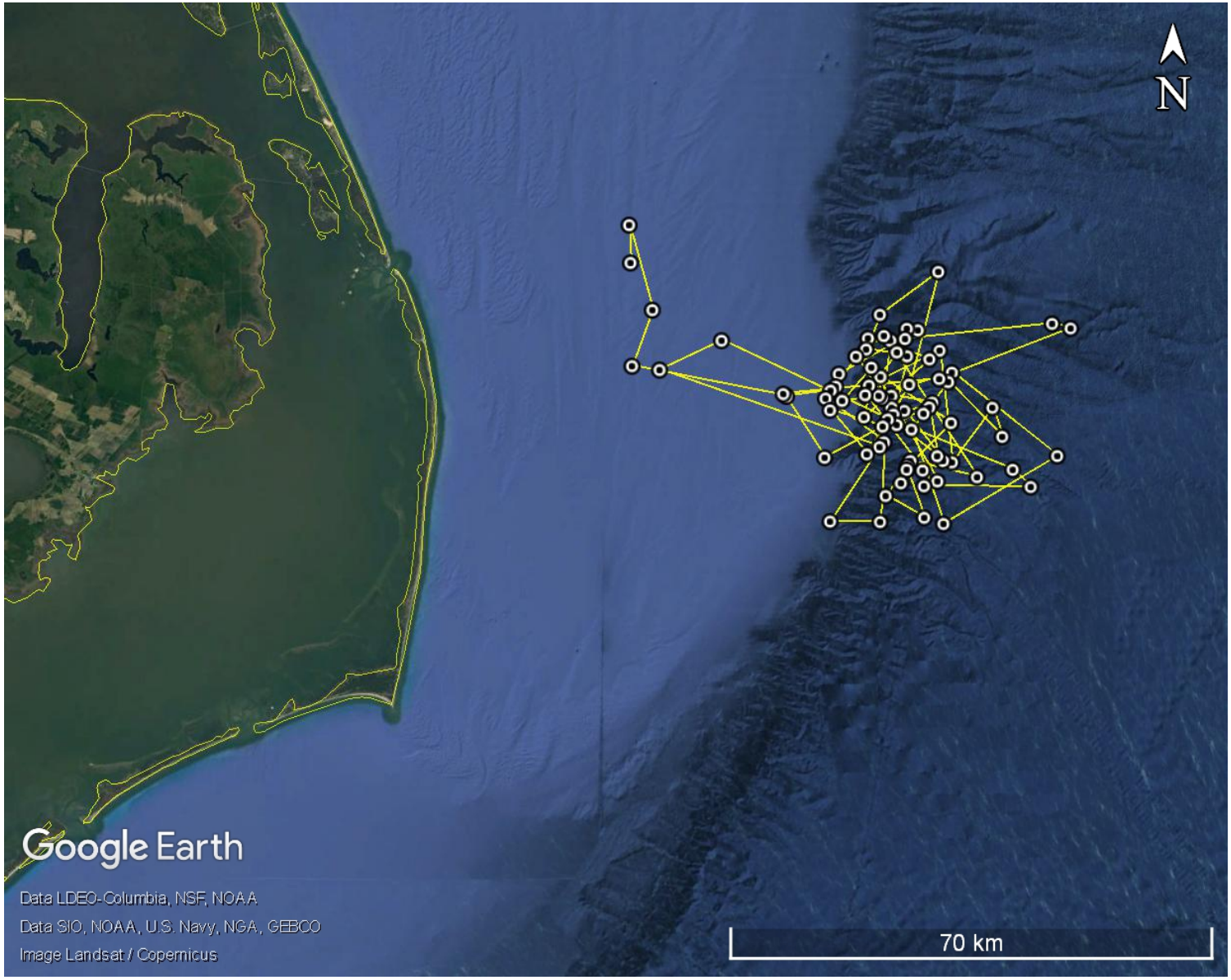

Figure 14. All filtered locations of Cuvier's beaked whale ZcTag047 tagged off North Carolina over a 66.9-day period, with consecutive locations joined by a line. Note that the locations on the shelf may be artifacts related to low quality Argos-derived locations

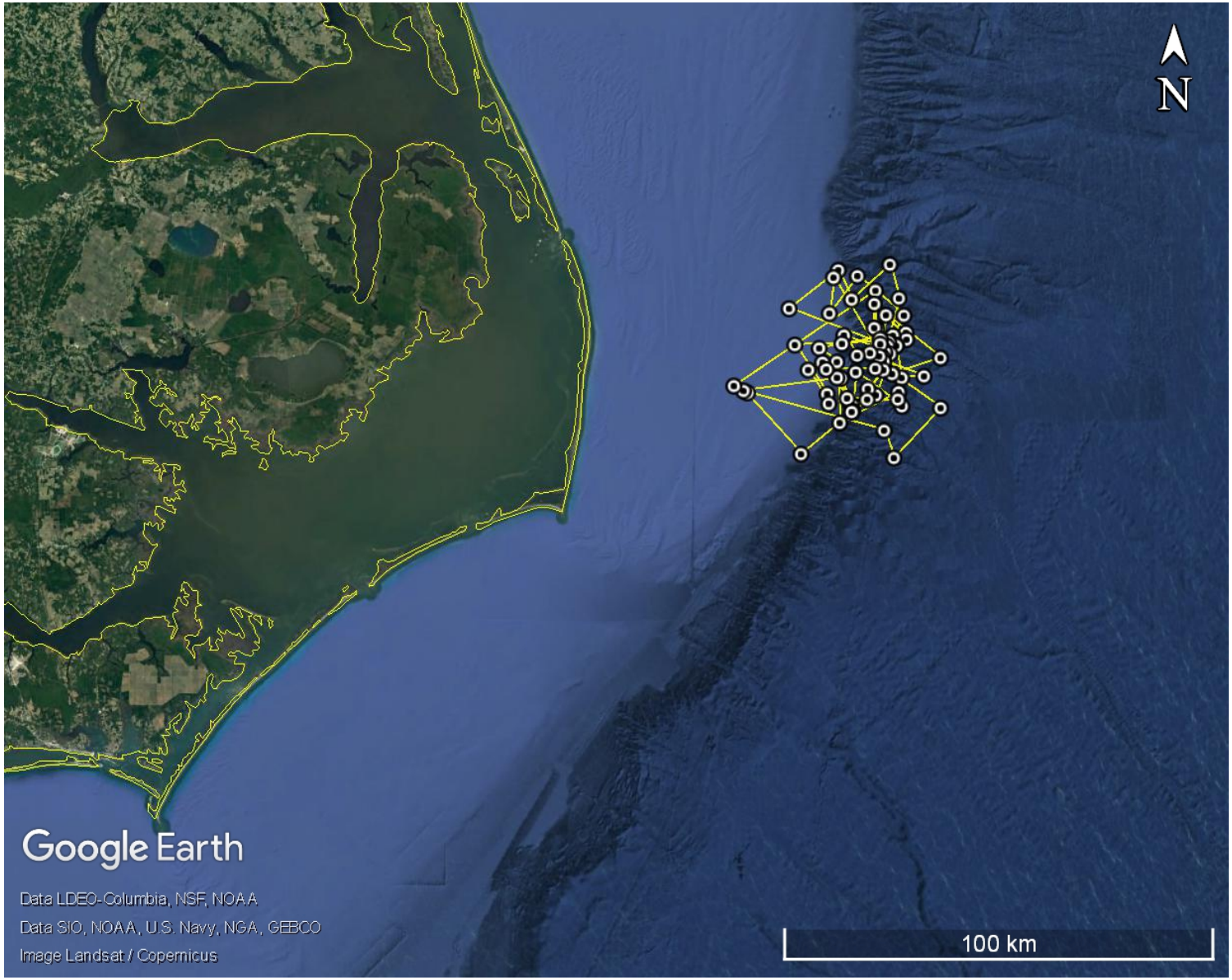

Figure 15. All filtered locations of Cuvier's beaked whale ZcTag048 tagged off North Carolina over a 36.4-day period, with consecutive locations joined by a line.

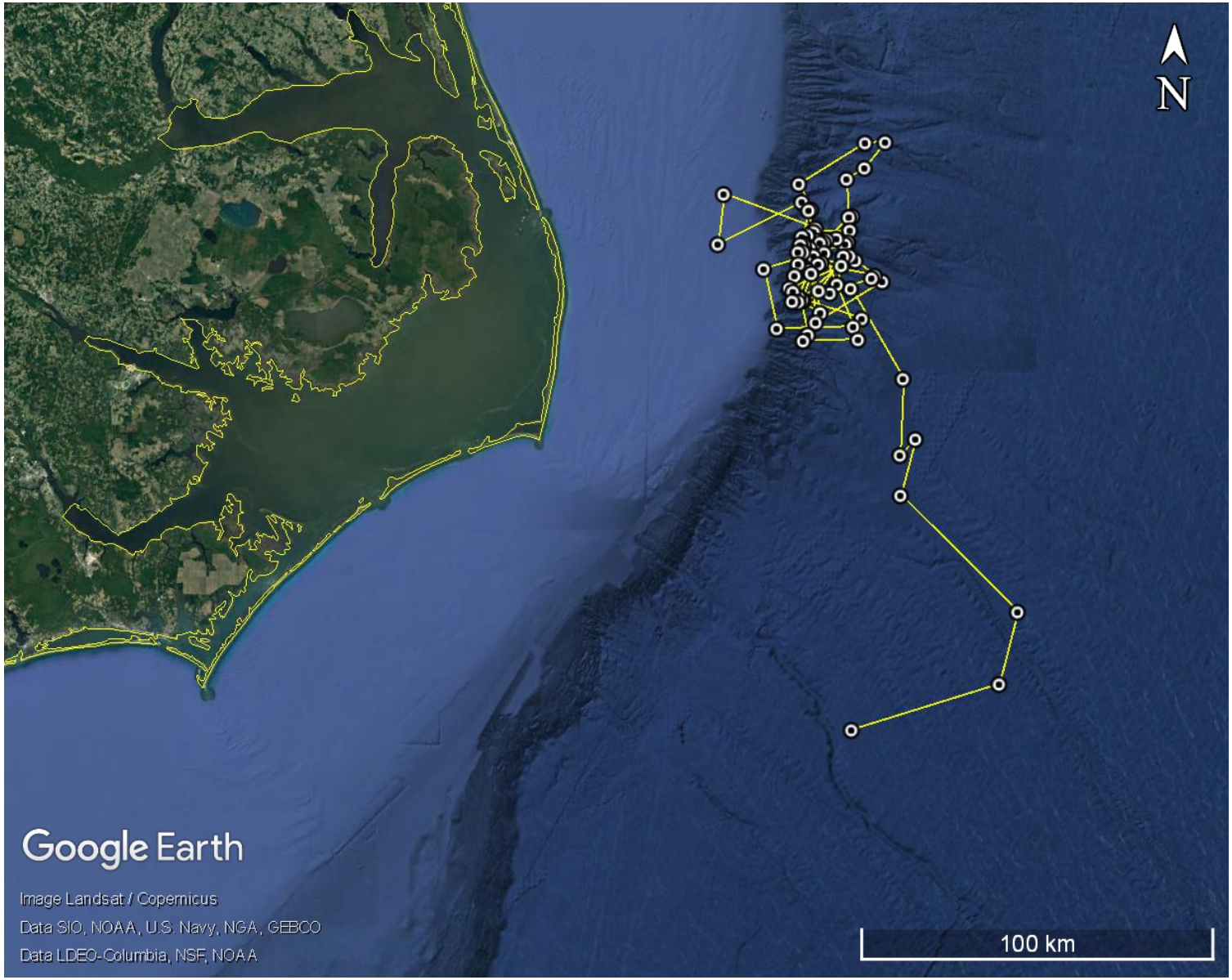

Figure 16. All filtered locations of Cuvier's beaked whale ZcTag049 tagged off North Carolina over a 92.8-day period, with consecutive locations joined by a line.

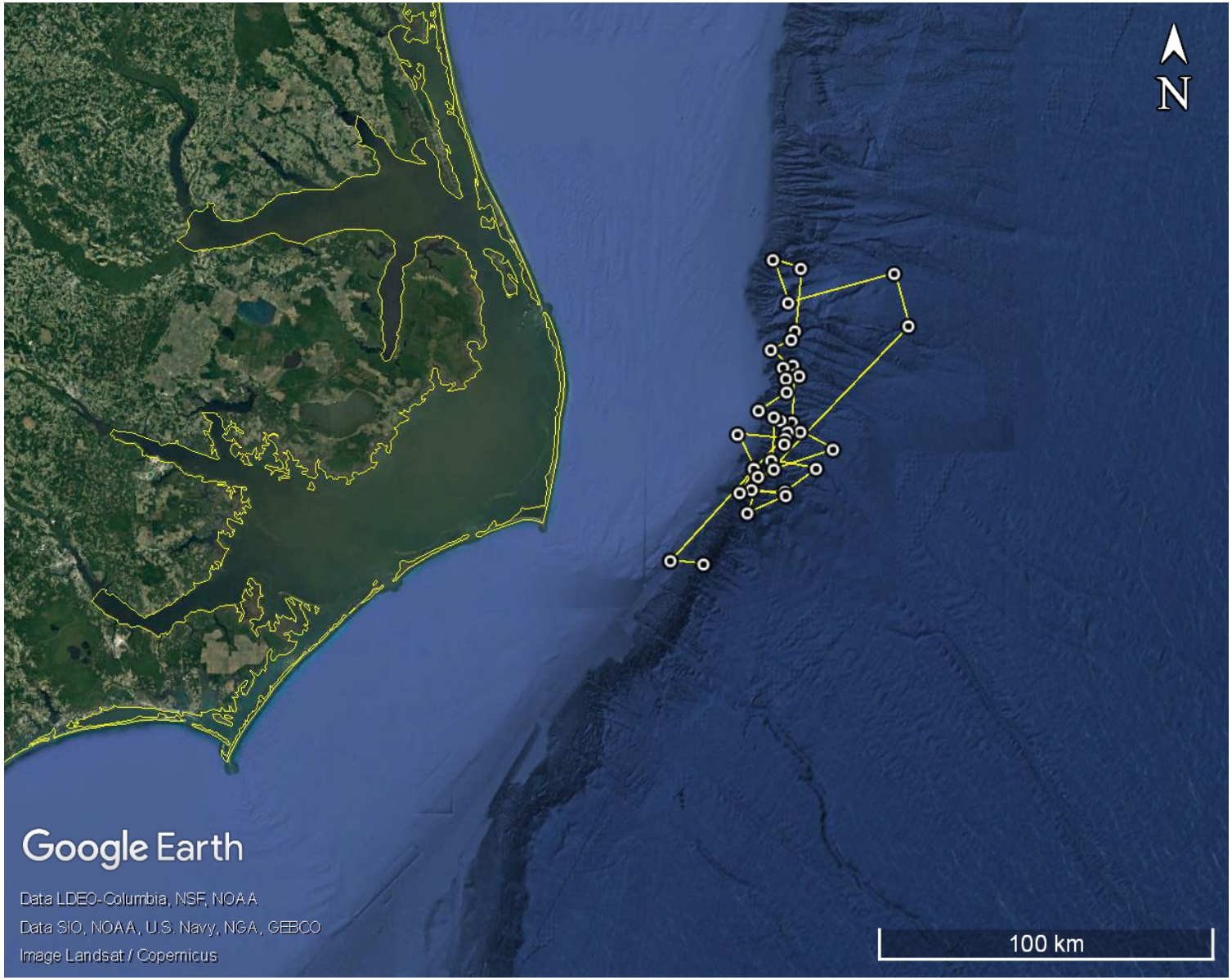

Figure 17. All filtered locations of Cuvier's beaked whale ZcTag050 tagged off North Carolina over a 30.3-day period, with consecutive locations joined by a line.

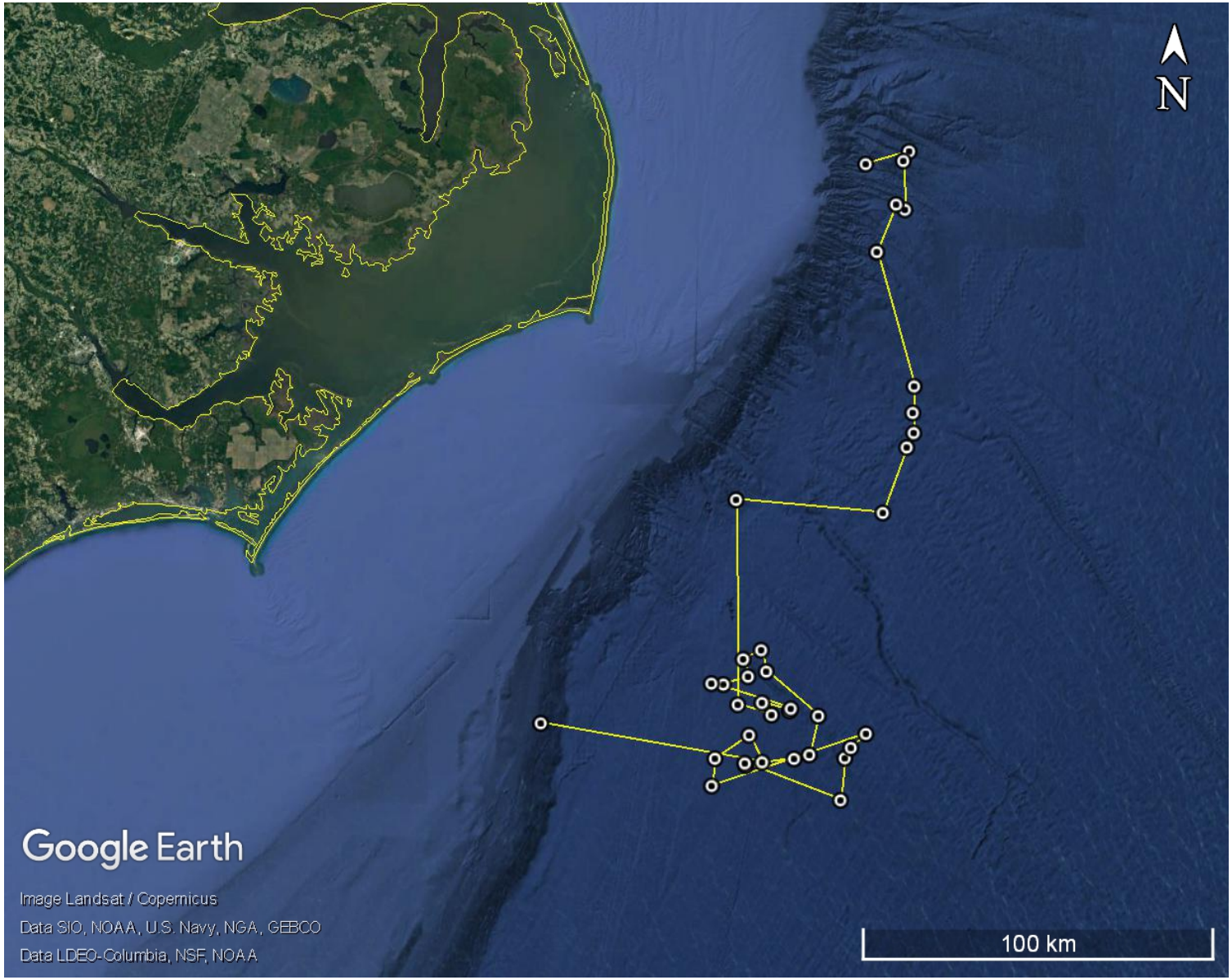

Figure 18. All filtered locations of Cuvier's beaked whale ZcTag051 tagged off North Carolina over a 11.4-day period, with consecutive locations joined by a line.

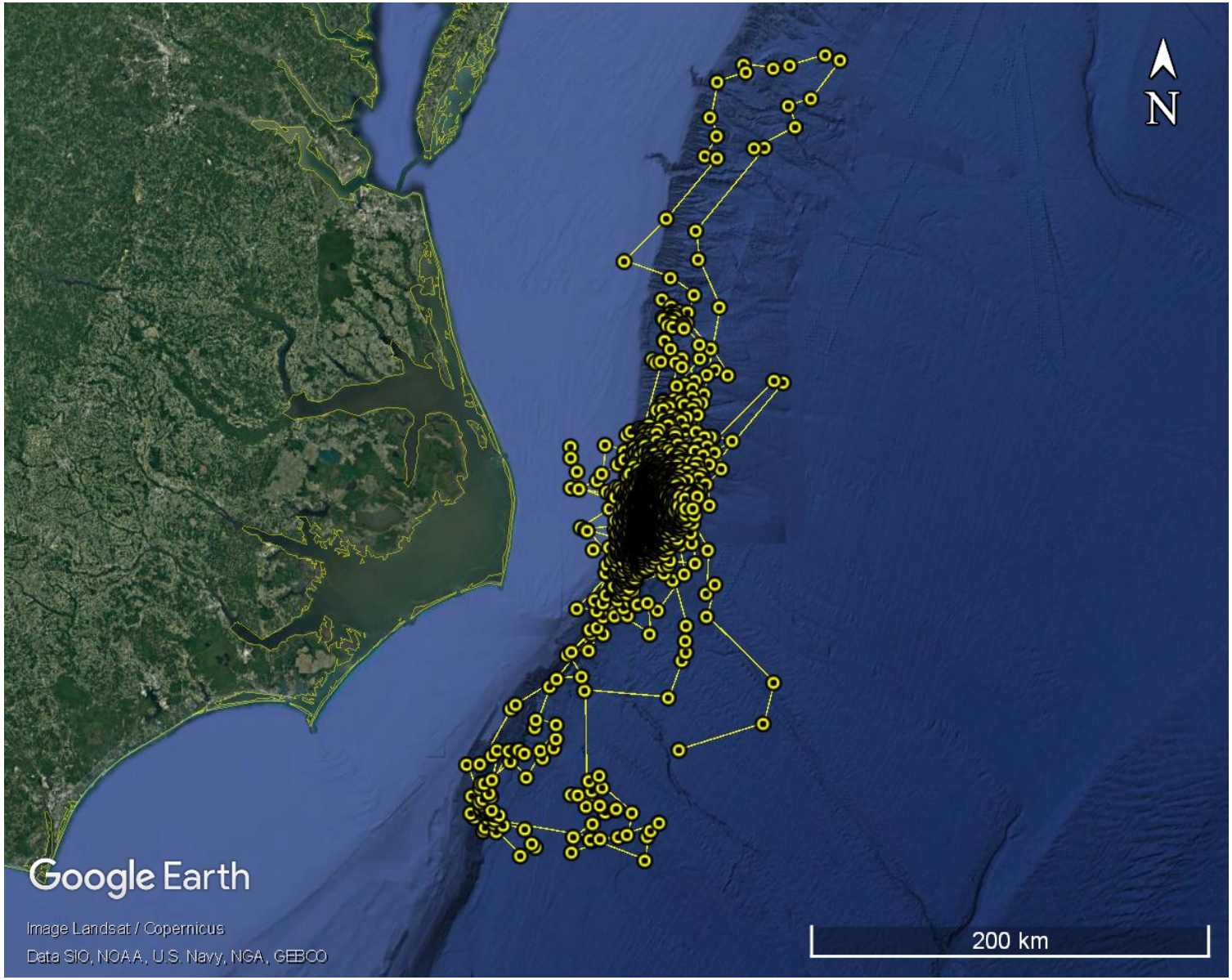

Figure 19. All filtered locations of Cuvier's beaked whales tagged off North Carolina in 2014, 2015 and 2016, with consecutive locations joined by a line.

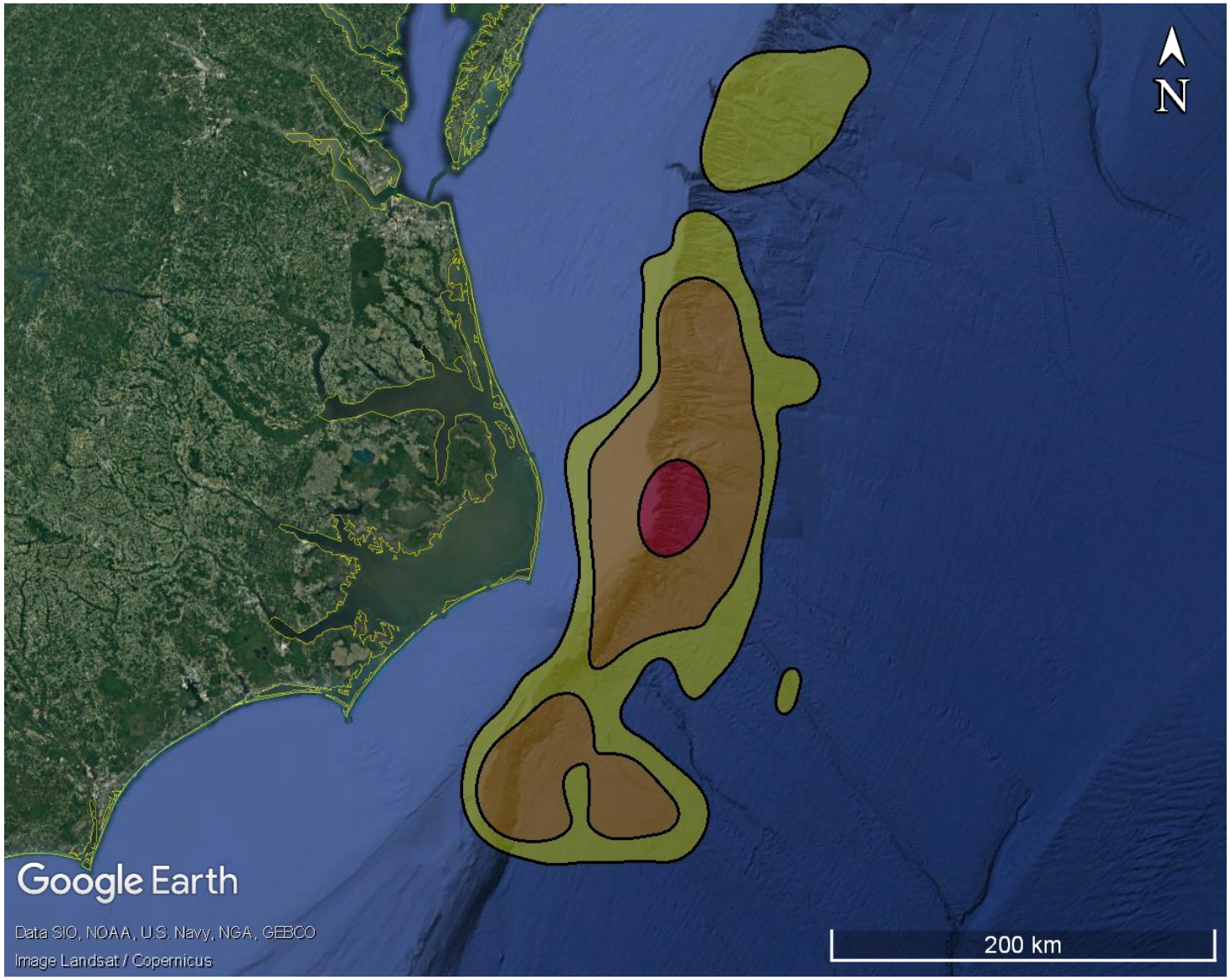

Figure 20. A probability density representation of Cuvier's beaked whale location data from 15 individuals tagged off North Carolina in 2014 (*n*=3), 2015 (*n*=6), and 2016 (*n*=6). The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95 percent polygon, and the yellow represents the 99 percent polygon.

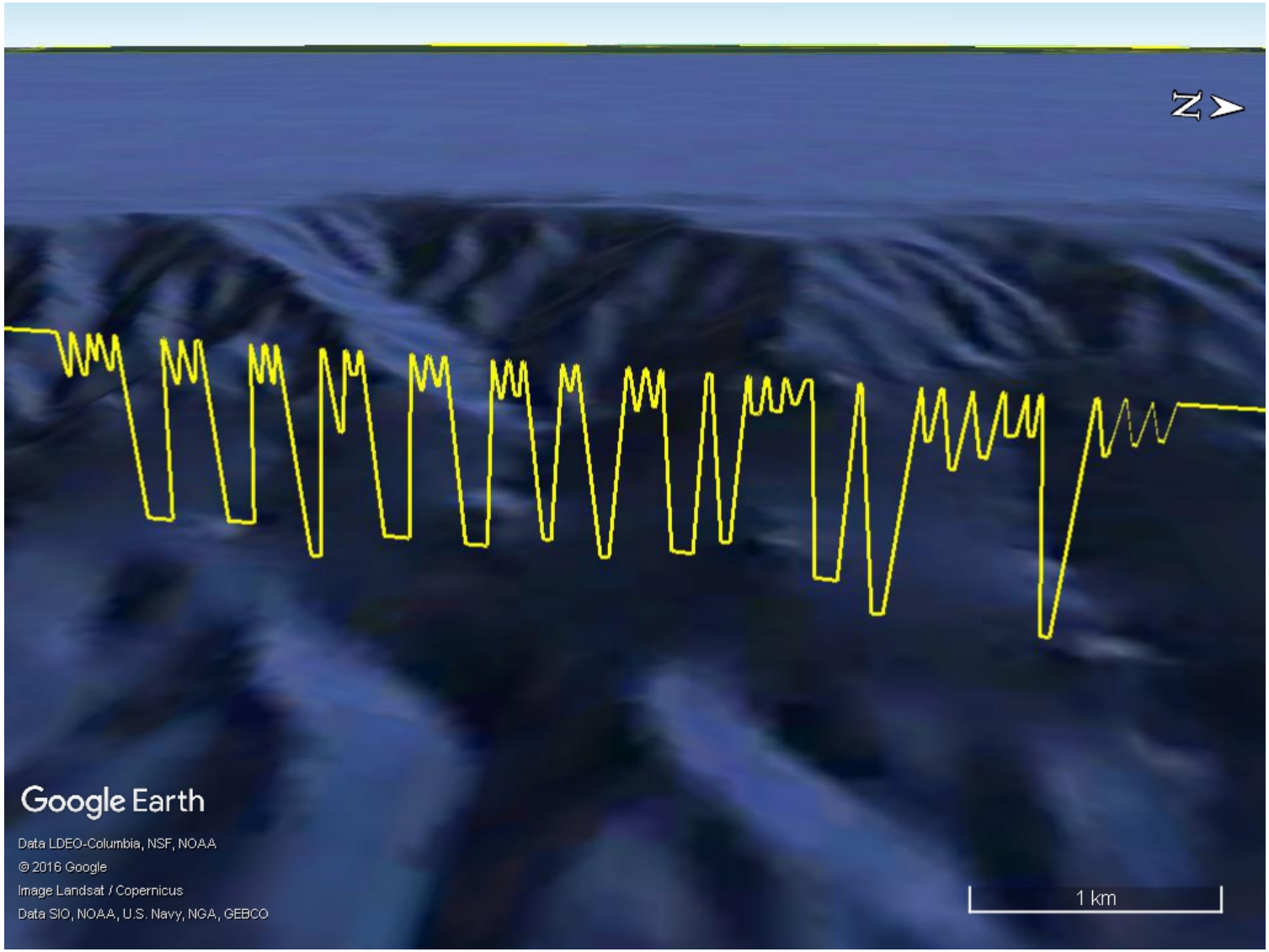

Figure 21. An example pseudotrack of location and depth data from Cuvier's beaked whale ZcTag046 over a 17.5-hr period starting with the first dive on 25 May 2016 at 1900 (GMT), traveling from left to right. The individual was located on the continental slope, with this perspective from offshore of the track and the land of Cape Hatteras visible in the back. The vertical (depth) axis is exaggerated. The deep dives shown here range from 887 to 1207 m in depth.

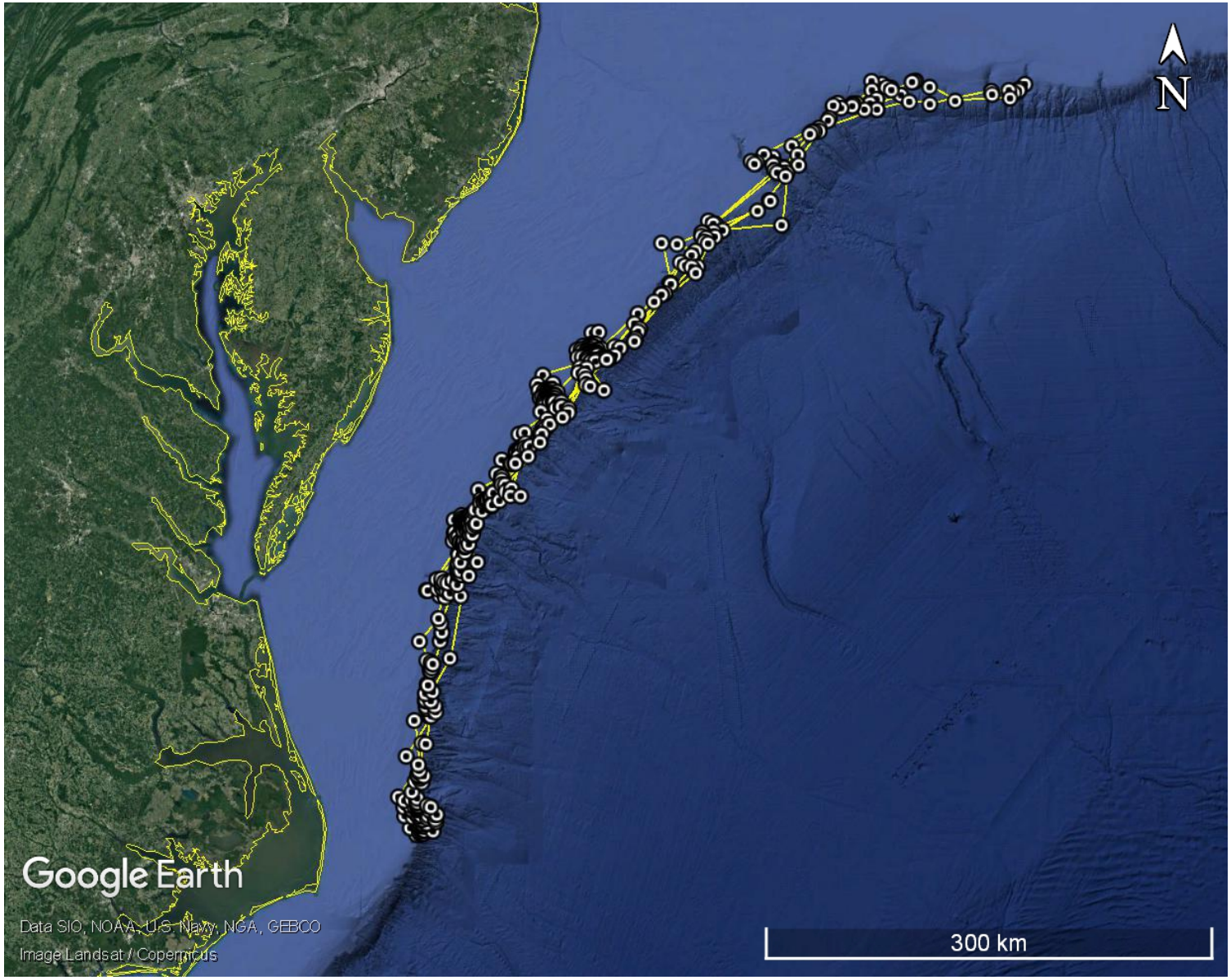

Figure 21. All filtered locations of short-finned pilot whale GmTag157 tagged off North Carolina over a 131.8-day period, with consecutive locations joined by a yellow line.

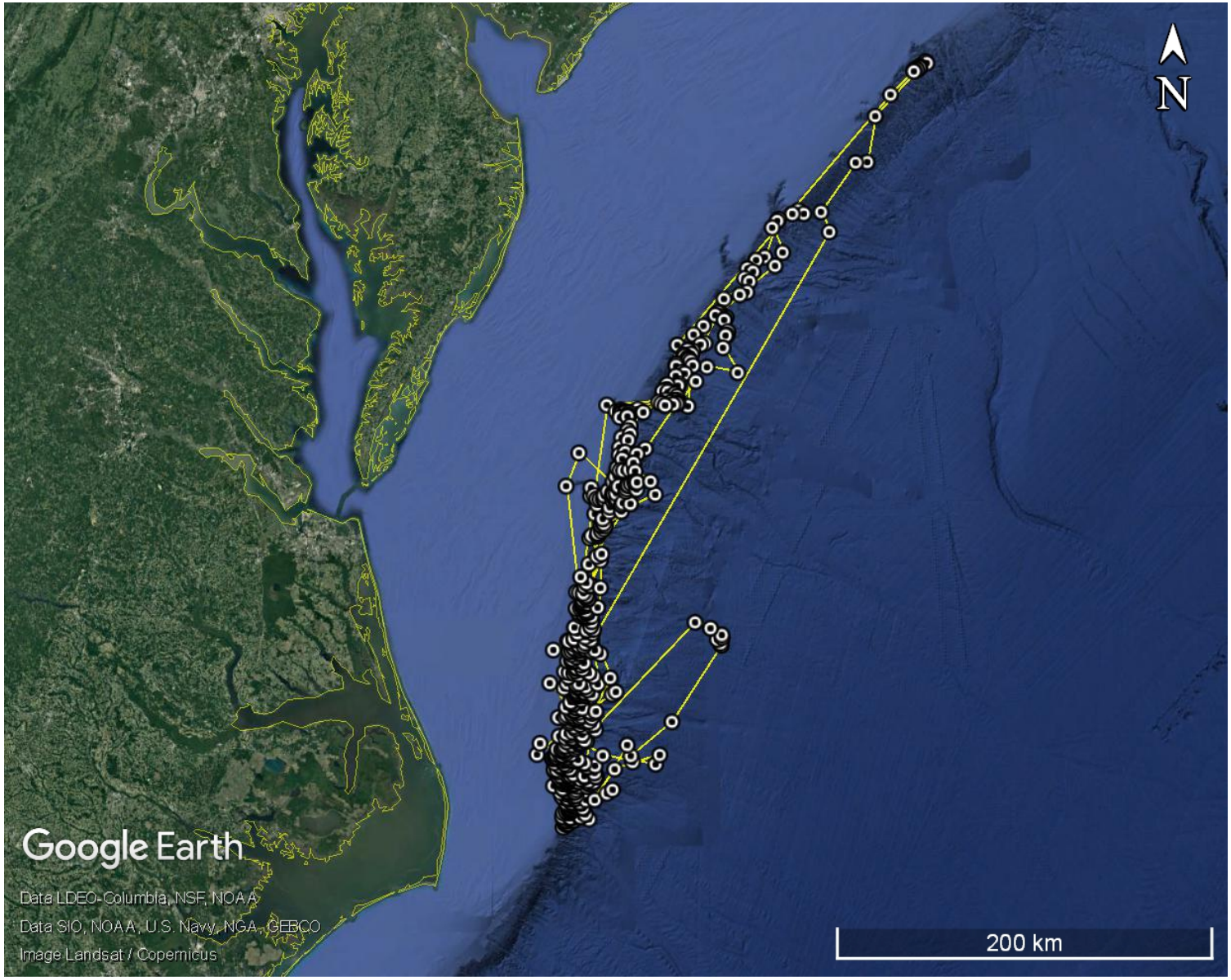

Figure 22. All filtered locations of short-finned pilot whale GmTag158 tagged off North Carolina over a 151.4-day period, with consecutive locations joined by a yellow line.

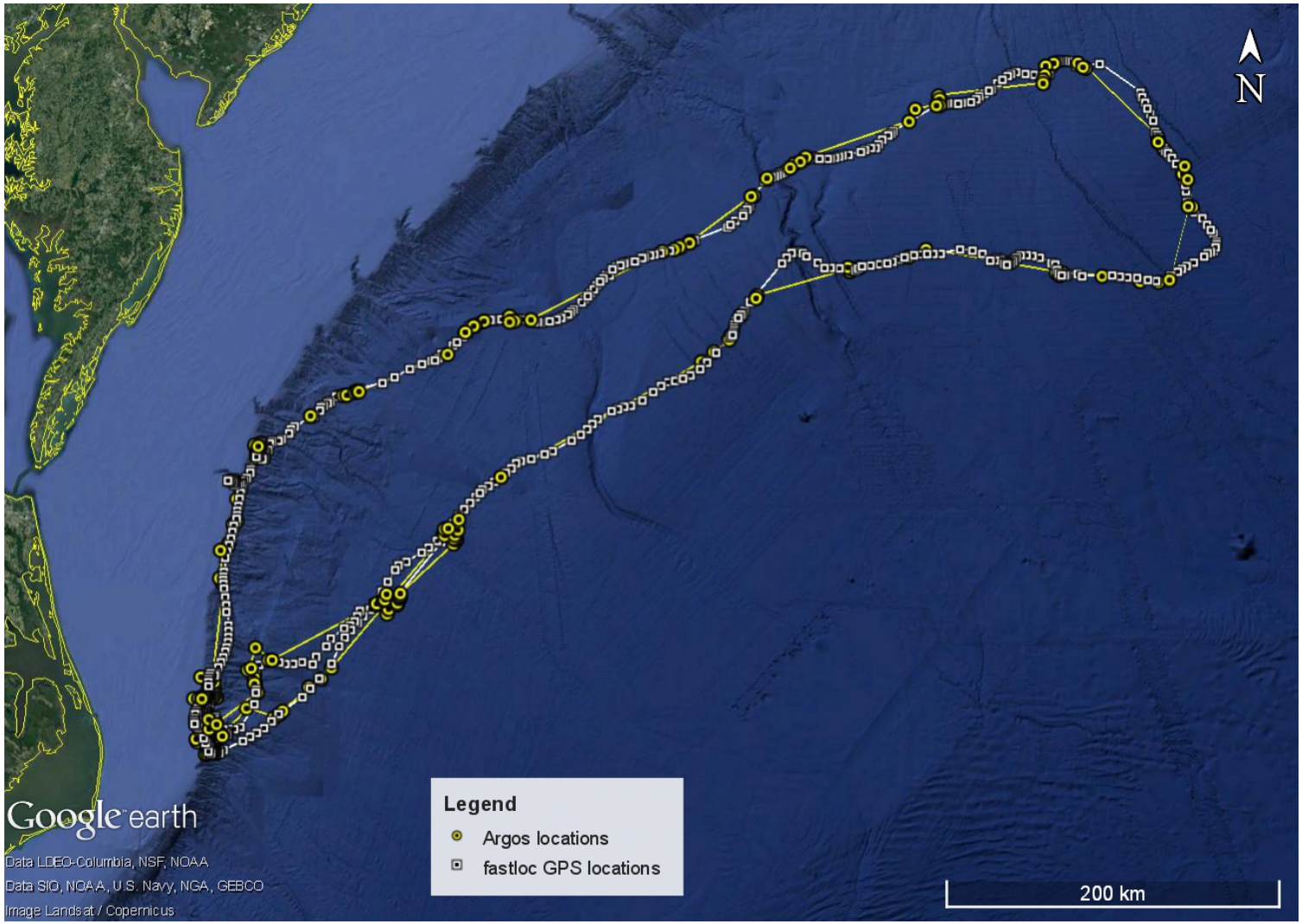

Figure 23. All filtered Argos locations (yellow circles) and Fastloc-GPS locations (white squares) of short-finned pilot whale GmTag159 tagged off North Carolina over a 24.5-day period, with consecutive locations joined by a line (yellow for Argos locations, white for Fastloc-GPS locations).

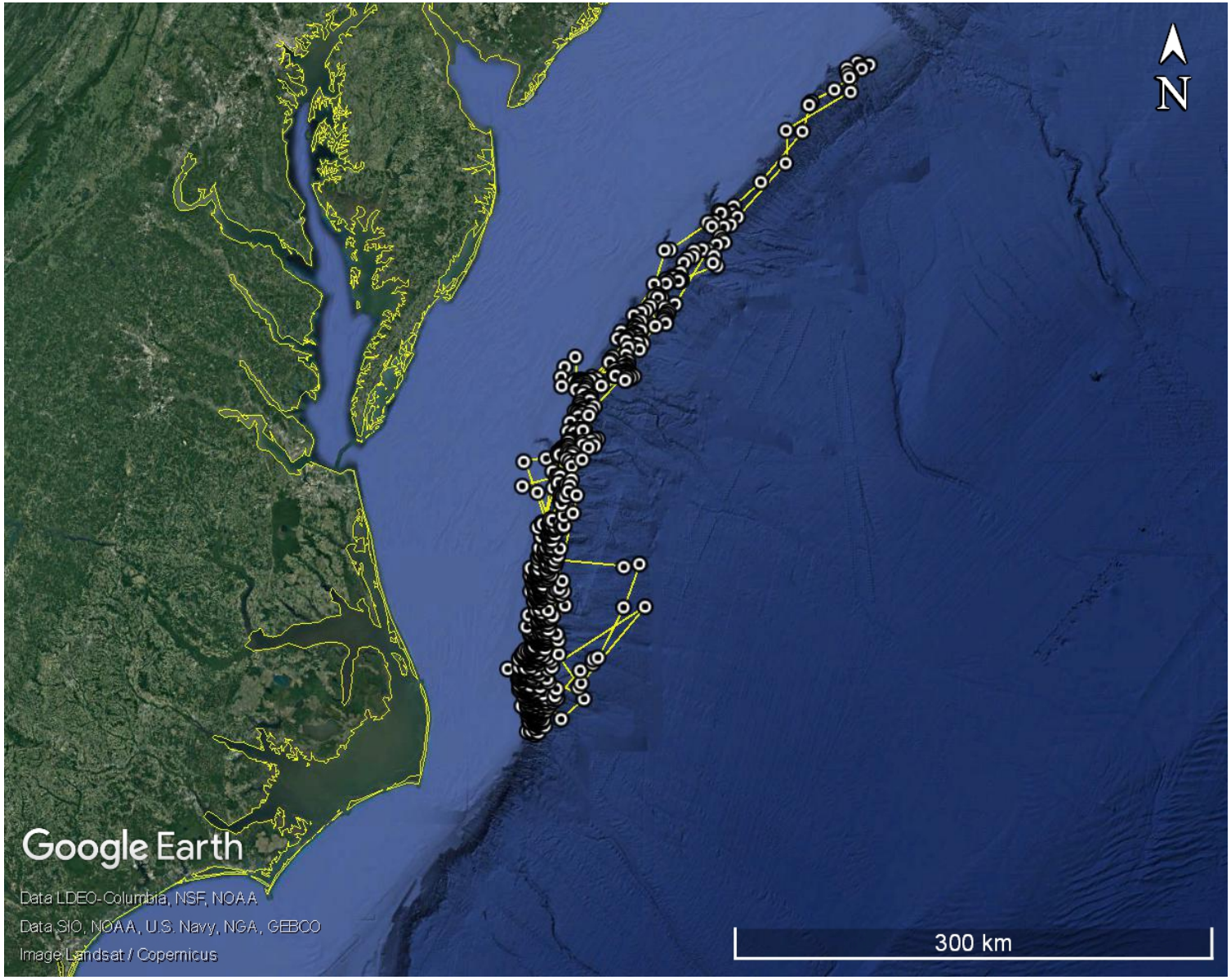

Figure 24. All filtered locations of short-finned pilot whale GmTag160 tagged off North Carolina over a 156.7-day period, with consecutive locations joined by a yellow line.

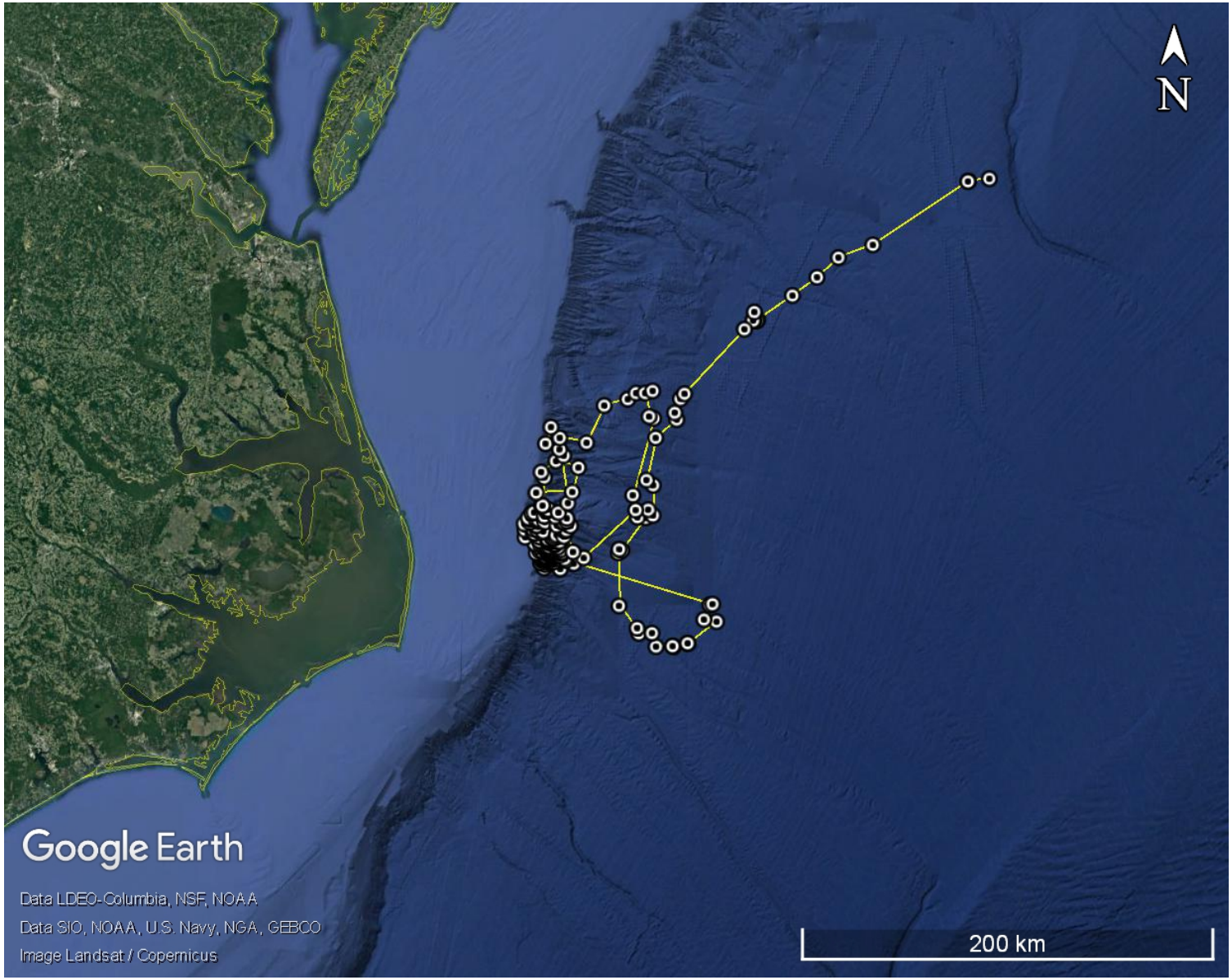

Figure 25. All filtered locations of short-finned pilot whale GmTag161 tagged off North Carolina over a 24.4-day period, with consecutive locations joined by a yellow line.

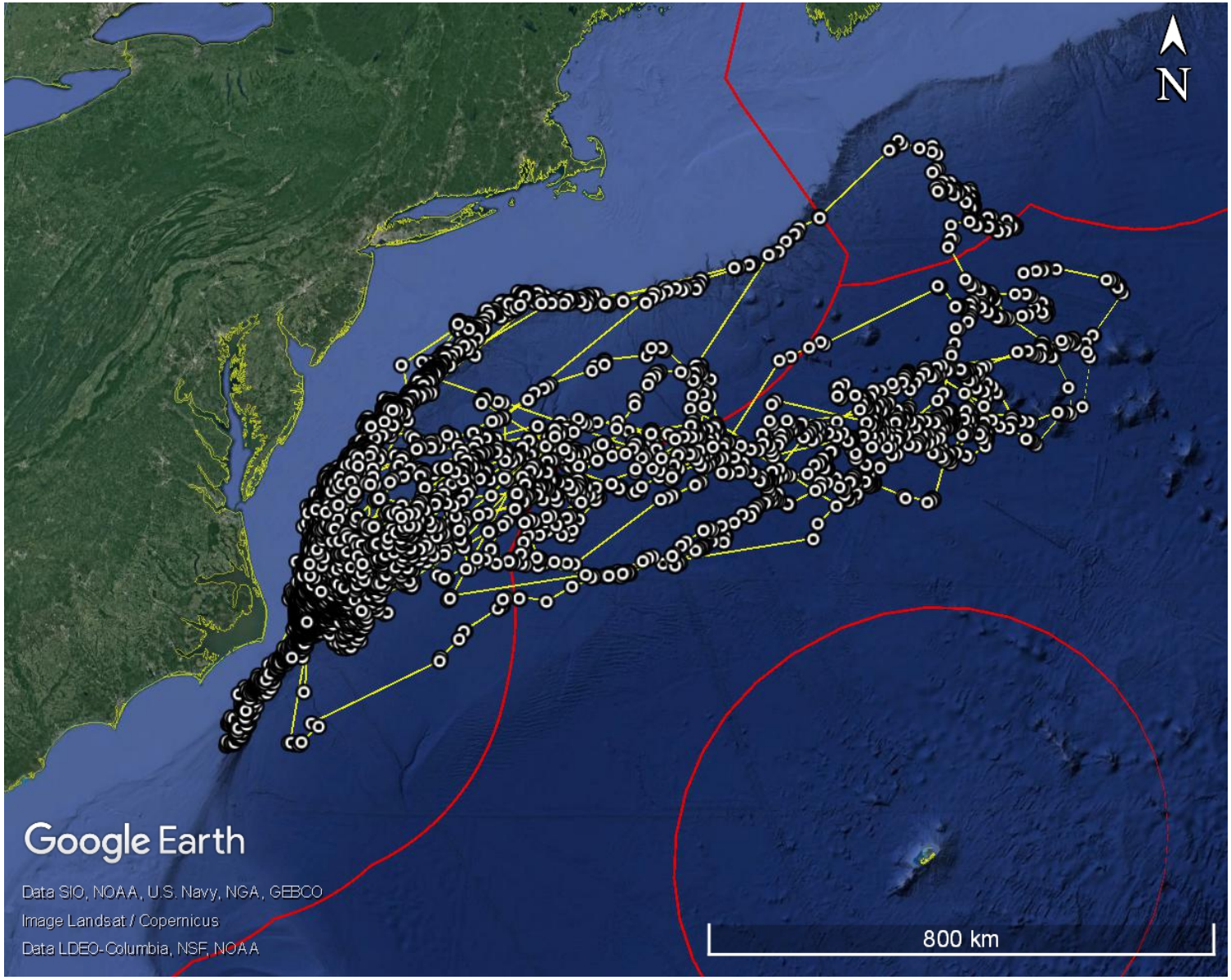

Figure 26. All filtered locations of all short-finned pilot whales tagged off North Carolina in 2014 (*n*=17), 2015 (*n*=19), and 2016 (*n*=5) (see Baird et al. 2015, 2016, Table 1). EEZ boundaries are shown with red lines.

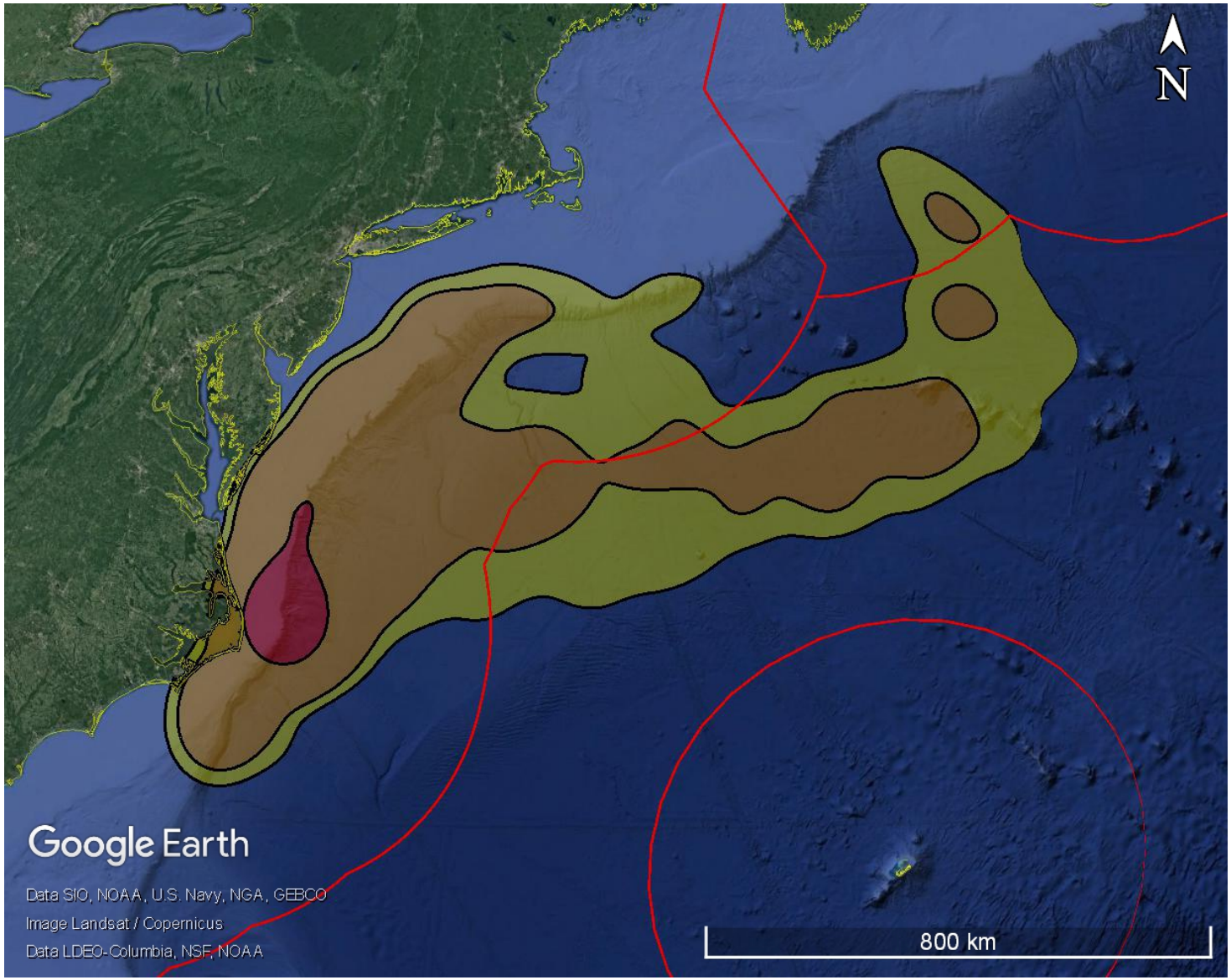

Figure 27. A probability-density representation of short-finned pilot whale location data from all individuals tagged off Hatteras in 2014 (*n*=17), 2015 (*n*=19), and 2016 (*n*=5). The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95 percent polygon, and the yellow represents the 99 percent polygon. EEZ boundaries are shown with red lines.

B

Tables

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Table 1. Summary details on satellite tag deployments off Cape Hatteras, North Carolina, during 2016

Species[1]/ Tag ID	Sex/age class	Tag Type	Deployment Date	Sighting #	Deployment Latitude (°N)	Deployment Longitude (°W)	Depth at tagging location (m)	Tag duration (days)
DdTag002	Unknown adult	Spot5	5/27/2016	6	35.59	74.74	1,298	11.34
GgTag017	Unknown adult	Spot6	8/20/2016	7	35.61	74.79	309	17.55
GmTag157	Adult female	Spot6	5/25/2016	4	35.59	74.75	1,216	131.80
GmTag158	Sub-adult male	Spot5	5/25/2016	2	35.60	74.75	1,168	151.42
GmTag159	Adult Male	SPLASH10-F	5/26/2016	4	35.62	74.71	1,635	24.55
GmTag160	Sub-adult male	Spot6	5/26/2016	5	35.70	74.74	1,177	156.70
GmTag161	Adult male	Spot6	5/27/2016	4	35.60	74.74	1,299	24.44
ScTag001	Unknown adult	Spot6	5/25/2016	9	35.61	74.69	1,666	20.27
TtTag029	Unknown adult	Spot6	5/25/2016	8	35.60	74.64	1,970	13.12
ZcTag046	Adult male	SPLASH10	5/25/2016	2	35.59	74.75	1,185	16.08
ZcTag047	Unknown sub-adult	SPLASH10	5/25/2016	2	35.60	74.75	1,164	66.86
ZcTag048	Adult male	SPLASH10	5/27/2016	5	35.59	74.74	1,284	36.39
ZcTag049	Adult male	Spot6	5/27/2016	5	35.58	74.74	1,257	92.79
ZcTag050	Adult female	SPLASH10	8/20/2016	5	35.63	74.76	1,141	30.35
ZcTag051	Adult male	SPLASH10	8/21/2016	5	35.61	74.69	1,774	11.38

Dd = *Delphinus delphis*; Gg = *Grampus griseus*; Gm = *Globicephala macrorhynchus*; Sc = *Stenella clymene*; Tt = *Tursiops truncatus*, Zc = *Ziphius cavirostris*, Key: Spot = Smart Position and Temperature

Table 2. Characteristics of movements in relation to tagging distance for satellite-tagged odontocetes tagged off North Carolina in 2016

Tag ID	# locations after filtering	Mean (SD) distance from tagging location (km)	Maximum distance from tagging location (km)	Total distance traveled (km)
DdTag002	136	25.8 (18.8)	69.5	678.0
GgTag017	202	170.6 (146.6)	470.8	1,453.8
GmTag157	483	259.2 (154.3)	628.2	4,646.3
GmTag158	541	105.8 (97.3)	428.9	4,941.4
GmTag159	206	212.2 (220.0)	667.8	2,186.0
GmTag160	707	100.6 (99.1)	436.0	6,133.0
GmTag161	201	33.3 (49.3)	274.2	1,373.0
ScTag001	205	152.4 (73.1)	268.0	1,684.5
TtTag029	132	30.2 (19.0)	79.1	1,016.4
ZcTag046	27	11.7 (5.8)	22.6	337.3
ZcTag047	104	12.7 (10.1)	52.9	1,168.0
ZcTag048	67	13.2 (7.9)	34.9	691.8
ZcTag049	110	20.4 (19.4)	120.7	1,137.1
ZcTag050	35	24.8 (15.3)	65.0	447.5
ZcTag051	37	122.2 (56.8)	178.8	524.2

Key: Dd = *Delphinus delphis*; Gg = *Grampus griseus*; Gm = *Globicephala macrorhynchus*; Sc = *Stenella clymene*; Tt = *Tursiops truncatus*, Zc = *Ziphius cavirostris*); km = kilometer(s);

Table 3. Depth and distance from shore and the 200-m isobath from GIS analysis of filtered satellite-tag locations.

Tag ID	Depth (m)		Distance from shore (km)			Distance from 200-m isobath (km)	
	Median	Max	Min	Median	Max	Median	Max
DdTag002	573.2	2,025.6	47.4	64.9	86.7	4.6	15.4
GgTag017	328.0	2,393.3	33.8	73.2	162.4	7.3	54.1
GmTag157	516.8	1,762.7	51.3	108.1	183.6	3.7	25.8
GmTag158	1,028.1	2,764.9	51.2	91.3	163.0	8.5	76.8
GmTag159	2,044.3	4,315.7	57.9	160.4	375.9	63.4	220.9
GmTag160	971.4	2,671.9	53.0	90.9	159.9	7.6	71.8
GmTag161	1,505.7	3,326.8	54.2	85.9	264.4	20.3	155.5
ScTag001	2,688.9	3,154.8	65.7	175.7	259.7	85.7	153.5
TtTag029	1,836.9	2,538.4	43.0	77.6	122.7	16.8	51.4
ZcTag046	1,103.2	2,003.9	52.7	65.6	78.6	6.8	14.6
ZcTag047	1,260.0	2,411.0	28.2	64.9	101.1	6.2	37.1
ZcTag048	1,009.6	2,257.4	33.8	62.4	81.0	6.7	26.3
ZcTag049	1,639.8	3,614.6	44.2	72.6	144.5	8.6	99.5
ZcTag050	1,340.4	2,300.1	38.8	65.7	101.8	6.8	37.5
ZcTag051	3,017.8	3,724.3	65.3	110.6	151.1	56.6	98.7

Key Dd = *Delphinus delphis* (short-beaked common dolphin); Gg = *Grampus griseus* (Risso's dolphin); Sc = *Stenella clymene* (Clymene dolphin); Tt = *Tursiops truncatus* (bottlenose dolphin); Gm = *Globicephala macrorhynchus* (short-finned pilot whale); km = kilometer(s); m = meter(s); Zc = *Ziphius cavirostris* (Cuvier's beaked whale)

Table 4. Distances between pairs of Cuvier's beaked whales or short-finned pilot whales with temporally overlapping tag data. Distances are calculated when locations are received during the same satellite overpass.

Pair	Age/Sex of pair	Mean distance apart (km)	Max distance apart (km)	Timing of tagging
ZcTag046-047	Adult male/sub-adult unknown	8.6	16.3	Same group
ZcTag048-049	Adult male/adult male	31.7	59.1	Same group
ZcTag046-048	Adult male/adult male	16.9	21.2	Different day
ZcTag046-049	Adult male/adult male	12.8	12.8	Different day
ZcTag047-048	Sub-adult unknown/adult male	16.2	27.7	Different day
ZcTag047-049	Sub-adult unknown/adult male	17.4	47.7	Different day
ZcTag049-051	Adult male/adult male	77.3	77.3	Different day
ZcTag050-051	Adult female/adult male	28.9	28.9	Different day
GmTag157-158	Adult female/sub-adult male	137.6	558.9	Same day
GmTag159-160	Adult male/sub-adult male	190.5	675.2	Same day
GmTag157-159	Adult female/adult male	175.0	591.1	Different day
GmTag157-160	Adult female/sub-adult male	155.3	571.3	Different day
GmTag157-161	Adult female/adult male	125.0	255.3	Different day
GmTag158-159	Sub-adult male/adult male	202.2	676.0	Different day
GmTag158-160	Sub-adult male/sub-adult male	8.5	82.1	Different day
GmTag158-161	Sub-adult male/adult male	54.0	254.9	Different day
GmTag159-161	Adult male/adult male	213.9	620.2	Different day
GmTag160-161	Sub-adult male/adult male	66.6	254.4	Different day

Key. Zc = *Ziphius cavirostris* (Cuvier's beaked whale); Gm = *Globicephala macrorhynchus* (short-finned pilot whale); km = kilometer(s)

Table 5. Summary of diving behavior data from location-depth tags.

Tag ID	# days behavior data	percent of total record	# dives > 50 m	Max dive depth (m)	Max dive duration (min)
ZcTag046	4.05	40.6	196	1,847.7	68.7
ZcTag048	11.9	39.3	582	1,999.5	74.6
ZcTag050	1.6	6.6	59	2,159.5	152.5
ZcTag051*	5.9	63.2	147	3,567.5*	78.5

Key: percent = percent; m = meter(s); min = minute(s); Zc = *Ziphius cavirostris* (Cuvier's beaked whale); *Pressure sensor on location-depth tags are rated to 2,000 m and have been tested to 3,000 m only a few times, thus this maximum dive depth should be treated with caution, as it is deeper than the known maximum dive depth for this species.

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