Supporting Offshore Wind Siting in the Gulf of Maine

– Marine Birds –

Prepared for:

Maine Department of Inland Fisheries and Wildlife

Prepared by:

Julia Stepanuk, Ph.D.

Evan Adams, Ph.D.

Sarah Dodgin

Andrew Gilbert

Wing Goodale, Ph.D.

Edward Jenkins

Biodiversity Research Institute

276 Canco Road, Portland, ME 04103

(wing_goodale@briloon.org; julia.stepanuk@briloon.org)

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1 Summary

The Bureau of Ocean Energy Management (BOEM) has reconvened the Gulf of Maine Intergovernmental Renewable Energy Task Force commercial planning process to aid in identifying potential renewable energy lease areas on the Outer Continental Shelf in the Gulf of Maine (GOM). To support the State of Maine Department of Inland Fisheries and Wildlife during the offshore wind commercial planning process, Biodiversity Research Institute (BRI) conducted a desktop study and literature review to determine regions of importance for breeding and migrating marine birds in the Gulf of Maine to inform regions of higher and lower risk to marine birds. The study relied on three primary analyses: a buffer around colonial nesting marine bird islands during the breeding season based on the maximum foraging distance; a combined exposure and vulnerability assessment using regional marine bird models; and movement models of three diving bird species.

The results indicate that there is substantial variability in marine bird use across the region. More marine bird colonies are found in the Midcoast region of Maine than any other region within the Gulf of Maine and there is substantial overlap in foraging habitat among species in that region, suggesting that this region in the Gulf of Maine may be of particular importance for many nesting marine bird species. In addition, marine birds that inhabit the Gulf of Maine during all or part of the year exhibit variable exposure and vulnerability (i.e. risk) to offshore wind development in the Gulf of Maine: the nearshore environment and George's Bank are regions of relatively high risk while the central Gulf of Maine, characterized by deep water basins, is an area of lower risk for birds. The results presented here are preliminary based on the data available at the time of analysis. Maps will be updated as new data become available.

The specific conclusions from the analysis are:

- Major foraging habitat for nesting marine birds, based on known colonies and foraging distances travelled, focused on Midcoast Maine, far Downeast Maine, and Cape Cod and primarily were within 64 km (40 miles) of the coast (Figure 1).

- Lower vulnerability to offshore wind development for marine birds and lower habitat use for nesting marine birds was predicted in the Central Gulf of Maine, an area associated with deeper water and muddy seafloor in the northeast (Jordan Basin) and west (Wilkinson Basin) Gulf of Maine coastlines (Figure 2).

- Higher vulnerability to offshore wind development for marine birds and higher habitat use for nesting marine birds was predicted in nearshore shallower regions and around banks and ledges (Figure 2).

- Movement modeling of birds captured in the mid-Atlantic indicate broad migratory movements through the Gulf, but that core use areas are concentrated closer to shore and near shoals.

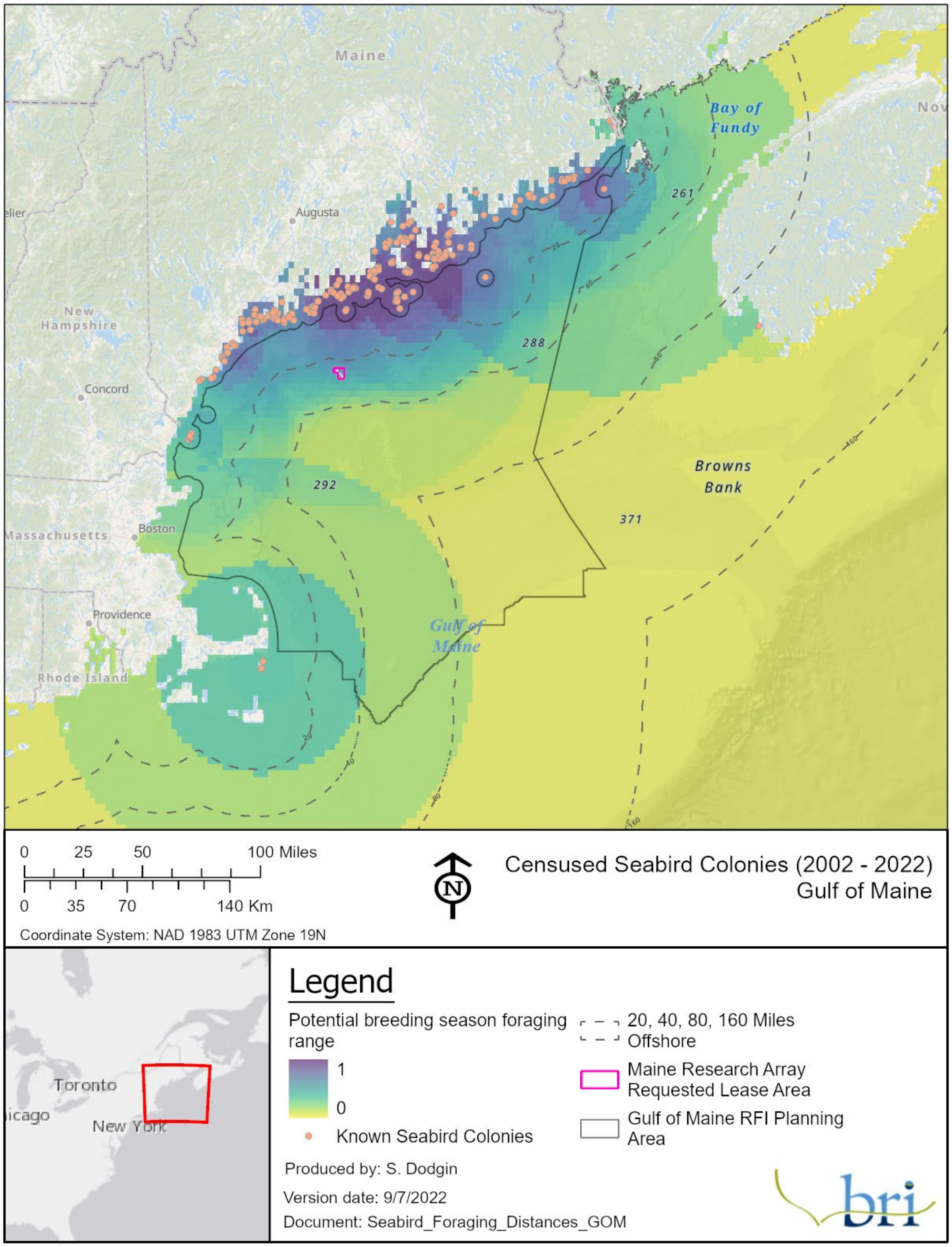

Figure 1. Foraging areas of importance for 14 species of nesting marine birds built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

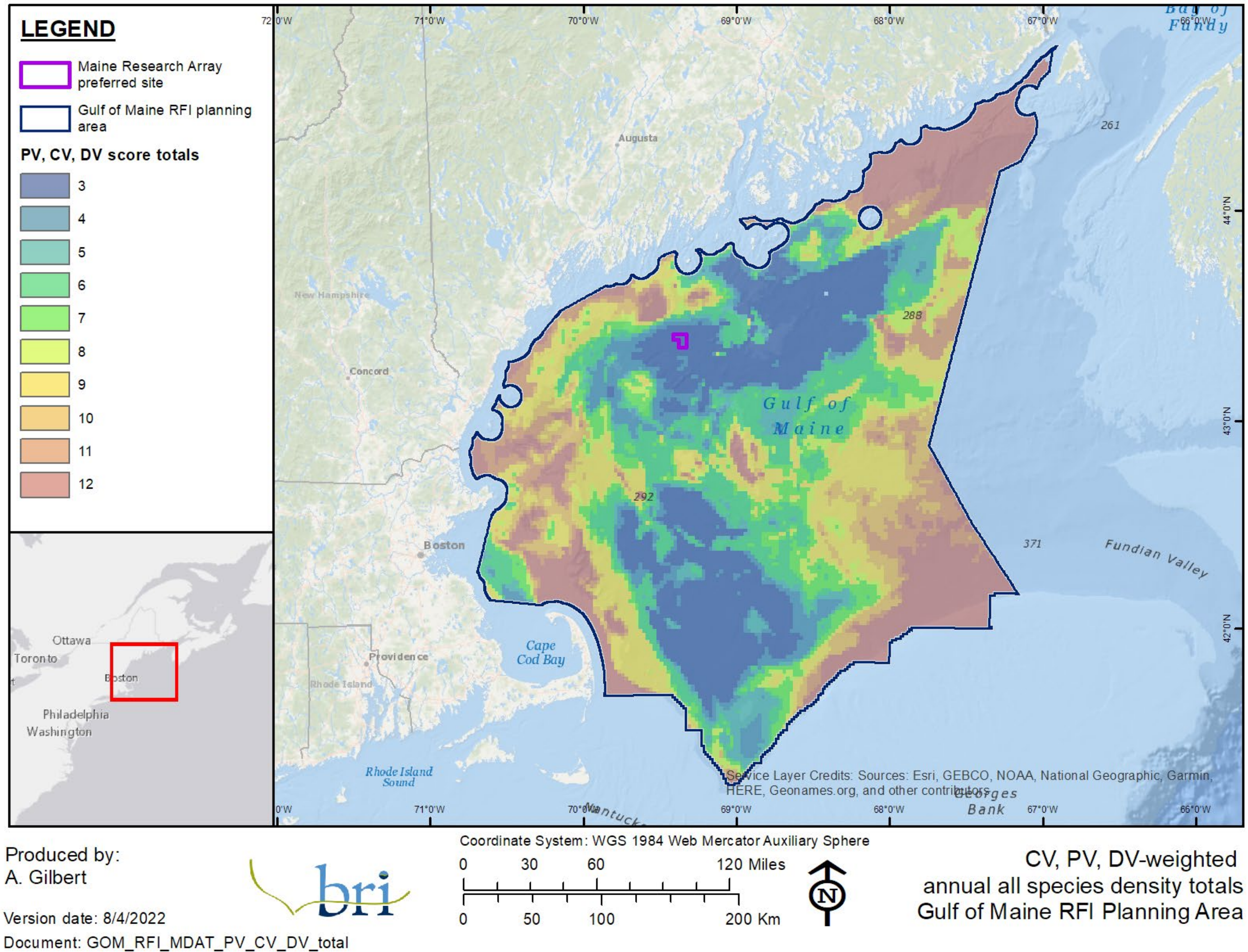

Figure 2. Weighted density analysis of population vulnerability (PV), displacement vulnerability (DV), and collision vulnerability (CV) for all marine bird species built using MDAT models. Species included any species that inhabits the Gulf of Maine region, including both species that nest and species that do not nest in this region. Areas in blue indicate lower species density of vulnerable species, and areas in red indicate higher species density of vulnerable species.

2 Introduction

Marine birds rely on the Gulf of Maine for wintering, migration, and breeding (Powers et al. 2017, Scopel et al. 2019). The Gulf of Maine is a primary wintering habitat for a number of arctic and sub-arctic breeding species such as Dovekie, Thick-billed Murre, scoters, loons, Black-legged Kittiwake and other gulls, as well as non-breeding habitat for austral breeders such as Great Shearwater, Wilson's Storm-Petrel, and South Polar Skua. Species that breed in the GOM include gulls (Herring, Great Black-backed, and Laughing Gulls,); terns (Roseate, Common, Arctic, and Least Terns), auks (Black Guillemot, Atlantic Puffin, Common Murre, and Razorbill); cormorants (Double-crested and Great Cormorant), Common Eiders, and Leach's Storm-Petrel. When breeding, marine birds are central-place foragers, where they are required to return to a central place after each foraging bout (Boyd et al. 2014). Thus, marine birds are reliant on marine habitats proximate to their nesting sites during breeding periods, and disturbances to the marine habitats could influence foraging habitat use (Velando and Munilla 2011) or reproductive success (Watson et al. 2014, Kress et al. 2017). Some marine birds migrate in a directed way through the GOM on their way south to primary wintering habitat in the Mid-Atlantic (e.g., diving bird species such as Northern Gannet, Red-throated Loon, scoters) or move north through the GOM to continue their journey north and east and eventually on to breeding sites in the southern Atlantic (e.g., Great Shearwater, Wilson's Storm-Petrel) and thus their presence is lasting, but spatially transitory. These species may not spend significant periods of time in any specific area in the GOM, but they may still be vulnerable to anthropogenic impacts such as offshore wind development.

Both nesting and transitory marine bird species are variably at risk from offshore wind development during all periods of the year. Risk to marine birds can come in the form of collision risk as well as displacement risk from marine birds avoiding offshore wind farms. Collision risk has an obvious negative effect on marine bird populations, but displacement due to avoidance of wind farms is more difficult to characterize relative to population level effects (Welcker and Nehls 2016). Gulls are considered to have high collision vulnerability because they can fly within the rotor sweep zone (RSZ; Johnston et al. 2014), they have a documented attraction to Wind turbine generators (WTG; Vanermen et al. 2015), and individual birds have been documented to collide with WTGs (Skov et al. 2018). Cormorants have been documented to be attracted to WTGs due to increased food resources around the WTG and newly available loafing habitat (i.e., perching areas; Krijgsveld et al. 2011, Lindeboom et al. 2011) which has the potential to increase vulnerability to collision in the Gulf of Maine.

Diving birds such as loons, gannets, and scoters are particularly vulnerable to displacement as a result of offshore wind development and exhibit unique foraging behaviors that should be considered in the offshore wind development process (Stenhouse et al. 2020). Loons are identified as the birds most vulnerable to displacement (Garthe and Hüppop 2004, Furness et al. 2013); and after loons, sea ducks, particularly scoters, are considered to have greater displacement vulnerability than all other marine birds (Furness et al. 2013). Many studies indicate that Northern Gannets avoid wind developments (Krijgsveld et al. 2011, Cook et al. 2012, Hartman et al. 2012, Vanermen et al. 2015b, Dierschke et al. 2016, Garthe et al. 2017). Displacement of these species should be considered relative to their potential exposure (i.e., spatial and temporal use patterns) in understanding overall risk to these species.

On August 19, 2022, BOEM announced a request for interest (RFI)[1] and a request for competitive interest (RFCI)[2] as the first steps in the commercial leasing process in the Gulf of Maine (GOM). As part of the planning process for siting commercial offshore wind in the Gulf of Maine, BOEM has established a task force comprised of federal officials and Tribal, state, and local officials from Maine, New Hampshire, and Massachusetts to facilitate coordination and information sharing. On behalf of the Maine Department of Inland Fisheries and Wildlife (MDIFW), BRI has compiled information relating to offshore wind development in the GOM and marine birds, with the goal of this work being to better understand the foraging and movement ecology of these species in reference to the placement of future offshore wind development in the Gulf of Maine to inform the BOEM commercial leasing area selection process.

3 Methods

This document presents a series of maps and their respective data layers that we hope provides some documentation of the important use areas for the Gulf of Maine with respect to the potential offshore wind development. This is by no means exhaustive, but includes the following with methods:

1) Marine bird foraging habitat use by colony relative by population size
2) Species Vulnerability Mapping
3) Diving Bird Dynamic Brownian Bridge Movement Modeling

3.1 Marine bird foraging habitat use

3.1.1 Foraging distance determination

Fourteen breeding marine birds in the Gulf of Maine were considered for this report: Atlantic Puffin, Razorbill, Black Guillemot, Common Eider, Common Tern, Roseate Tern, Least Tern, Arctic Tern, Leach's Storm-Petrel, Herring Gull, Great Black-backed Gull, Laughing Gull, Great Cormorant, and Double-crested Cormorant.

To determine regions of importance for foraging marine birds in the GOM, the minimum, mean, and maximum foraging distances from nesting colonies for each of the thirteen breeding marine birds were obtained from both unpublished and published data. A literature review was conducted to identify foraging distances, which was compiled into a database (Table 1). The literature search was conducted both in the BRI in-house literature repository as well as using the website Google Scholar.

Additional data on foraging distances in the GOM were calculated from marine bird tracking data collected as recently as 2022, which were used to bolster the dataset. During the summer of 2022,

[1] https://www.federalregister.gov/documents/2022/08/19/2022-17921/request-for-interest-rfi-in-commercial-leasing-for-wind-energy-development-on-the-gulf-of-maine

[2] https://www.federalregister.gov/documents/2022/08/19/2022-17922/research-lease-on-the-outer-continental-shelf-ocs-in-the-gulf-of-maine-request-for-competitive

Oregon State University graduate students Keenan Yakola and Will Kennerley tracked multiple marine bird species from nesting colonies spanning southern to mid-coast Maine. GPS tags were deployed on Common and Arctic Terns, Leach's Storm-Petrels, and Atlantic Puffins, which are species of state, regional, and national significance that are also of specific concern and/or unstudied with respect to offshore wind. GPS tags were purchased from Pathtrack Ltd. (Otley, UK; www.pathtrack.co.uk). Remote data downloading (via VHF link) tags deployed on Terns and Puffins attempted a GPS location every 10 minutes from dawn to dusk, while locations of Leach's Storm-Petrels were collected once per hour 24hrs/day on archival (data logging) tags. At Matinicus Rock, nine Atlantic Puffins were tracked between July 5th and July 30th. Common Terns were tracked at Stratton Island (n=8), Eastern Egg Rock (n=8), and Seal Island National Wildlife Refuge (NWR) (n=10). Arctic Terns were tracked at Eastern Egg Rock (n=5) and Seal Island NWR (n=11). GPS tags were deployed on Terns between June 7th and 15th and collected data throughout the breeding season and after the breeding season. Leach's Storm-Petrels nesting at Eastern Egg Rock (n=10) and Matinicus Rock (n=26) were tracked between July 14th and August 24th, with an average deployment of six days for each individual. Work to date has been sponsored by the National Audubon Society Seabird Institute and conducted in collaboration with the U.S. Fish and Wildlife Service's Maine Coastal Islands NWR and other partners.

Foraging distance data were not available in the GOM for all species of interest. Therefore, data from regions outside of the GOM, data derived from non-traditional tracking methods, or anecdotal data were used as proxies for foraging distance when necessary. Data sources were classified into six categories to rank relevance to GOM marine birds from most relevant (1) to less relevant (6):

1) GPS or radio tracking data from colonies in GOM
2) GPS or radio tracking data from colonies outside of GOM, but in the Atlantic
3) GPS or radio tracking data from colonies anywhere
4) Other foraging studies using non-traditional tracking methods
5) Anecdotal information on colonies in GOM
6) Anecdotal information on colonies outside of GOM

The best available data for each species was identified and was used for subsequent analyses and are reported in Table 1.

3.1.2 Colony importance weighting

Importance of foraging regions for nesting marine birds in the Gulf of Maine was quantified by combining foraging ranges and colony population size for each marine bird species. Marine bird colony population data and georeferenced colony locations were obtained from the Gulf of Maine Seabird Working Group (GOMSWG) census and the U.S. Fish and Wildlife Service. Counts of nesting pairs at colonies in the GOM were obtained from the Maine nesting seabird atlas and database maintained by the U.S. Fish and Wildlife Service. To investigate risk to recently inhabited nesting colonies located in Maine waters, colonies that were active within the last 20 years in the State of Maine dataset were identified and annual estimates of colony breeding pairs were averaged over all years that census data were available. Additional colony count data were available for some species (Common, Arctic, Roseate, and Least Terns, Laughing Gulls, Atlantic Puffins, Razorbills, and Common Murres) for colonies located in the GOM that were outside of the state of Maine (Nova Scotia, New Brunswick, New Hampshire, and Massachusetts) from the GOMSWG census for 2019. All available data were combined to provide one average colony count per species averaged from 2002-2022 (for colonies in Maine, derived from the Maine nesting seabird atlas and database) and one average colony count per species for 2019 (for colonies outside of Maine, derived from the 2019 GOMSWG census).

The distribution and foraging ranges for each marine bird species varied, so important foraging regions were calculated per-species. For each species, each colony was buffered by the maximum species foraging range (Table 1) which was then cropped to exclude the contiguous coastline. To determine the relative abundance of marine birds in the GOM to weigh the importance of the foraging area around each colony, colony counts were divided by the overall per-species abundance in the GOM to obtain a metric of per-species relative abundance. The foraging buffers were weighted by the proportion of breeding colony count of total species colony counts in the GOM across all active colonies and were scaled between 0 and 1 to indicate regions of relatively high and low foraging regions for each species weighted by population level importance. Finally, the foraging regions were summed across species to obtain a single composite output of important foraging areas in the Gulf of Maine for all relevant colonial nesting marine birds.

3.2 Species Vulnerability Mapping

A series of maps were created that indicate spatial avian risk across three categories: population vulnerability (PV), collision vulnerability (CV), and displacement vulnerability (DV) for species believed to use the proposed Maine Research Array "Area of Interest", using version 2 of the Marine-life Data and Analysis Team (MDAT) marine bird relative density and distribution models (hereafter MDAT models; Curtice et al. 2016). Seasonal predictions of density were developed by NOAA for BOEM to support Atlantic marine renewable energy planning. Version 2 of these models are available directly from Duke University's Marine Geospatial Ecology Lab MDAT model web page[3]. The MDAT analysis integrated survey data (1978–2016) from the Atlantic Offshore Seabird Dataset Catalog with a range of environmental variables to produce long-term average annual and seasonal models.

Vulnerability rankings PV, CV, and DV risks were each independently evaluated for all possible species where data was available to support estimates. Researchers in Europe and the U.S. have assessed the vulnerability of birds to offshore wind facilities and general disturbance by combining ordinal scores across a range of key variables (Furness et al. 2013, Willmott et al. 2013, Wade et al. 2016, Fliessbach et al. 2019). The purpose of these indices is to prioritize species in environmental assessments (Desholm 2009) and provide a relative rank of vulnerability (Willmott et al. 2013).

The population vulnerability (PV) score was determined using Partners in Flight (PiF) "continental combined score" (CCSmax), a local "state status" (SSmax) using the maximum of state threatened and endangered status and "species of greatest conservation need" (SGCN) score, adult survival score (AS), and the regional population score (POP) – an annual measure of the population using the study area and the Marine-life MDAT models. This approach is based on methods used by Kelsey et al. (2018) and

[3] http://seamap.env.duke.edu/models/mdat/

Fliessbach et al. (2019). Each factor included in this assessment (CCSmax, SSmax, AS, and POP) is added together (Equation 1) and rescaled 0–1.

$$PV = CCS_{max} + SS_{max} + AS + POP \quad \text{(Equation 1)}$$

CCSmax is included in scoring because it integrates various factors PiF uses to indicate global population health. *SSmax* is included to account for local conservation status, which is not included in the CCSmax. *AS* is included because species with higher adult survival rates are more sensitive to increases in adult mortality. The POP component was included as a metric for population use of the study area relative to the rest of the "population" based on MDAT model relative density estimates.

The collision vulnerability (CV) assessment includes scores for nocturnal flight activity, diurnal flight activity, avoidance, proportion of time within the rotor swept zone (RSZ), maneuverability in flight, and percentage of time flying (Willmott et al. 2013, Furness et al. 2013, Kelsey et al. 2018). The assessment process conducted here follows Kelsey et al. (2018) and includes proportion of time within the RSZ (RSZt), a measure of avoidance (MAc), and flight activity (NFA and DFA). All factors were added together (Equation 2) and rescaled to 0–1.

$$CV = RSZt + MAc + \frac{NFA+DFA}{2} \qquad \text{(Equation 2)}$$

RSZt is included in the score to account for the probability that a bird may fly through the RSZ. The proportion of animals within the RSZ was estimated using methods similar to Johnston et al. (2014) by modeling flight heights using a smooth spline and integrating across the height range to estimate the proportion of the animals using the RSZ. Flight height data was taken from the Northwest Atlantic Seabird Catalog (NWASC). The RSZ was assigned the values 25–300 m based on recent example turbine configurations. MAc is included to account for macro-avoidance rates that would decrease collision risk. The scores used in the assessment were based on Willmott et al. (2013), but updated to reflect the most recent empirical studies (Krijgsveld et al. 2011, Cook et al. 2012, 2018, Vanermen et al. 2015b, Skov et al. 2018), and indices (Garthe and Hüppop 2004, Furness et al. 2013, Bradbury et al. 2014, Adams et al. 2016, Wade et al. 2016, Kelsey et al. 2018).

NFA and DFA include scores of estimated percentages of time spent flying at night (NFA) and during the day (DFA) based on the assumption that more time spent flying would increase collision risk. The NFA scores were taken directly from Willmott et al. (2013). The DFA scores were calculated from behavioral observations from the NWASC within 200 km of the research array study area. Per Kelsey et al. (2018), the NFA and DFA scores were equally weighted and averaged.

The displacement vulnerability (DV) assessment accounts for two factors: (1) disturbance from ship/helicopter traffic and the wind facility structures (MAd); and (2) habitat flexibility (HF; Furness et al. 2013, Kelsey et al. 2018). Empirical studies indicate that for some species, particularly sea ducks, avoidance behavior may change through time, and several years after projects have been built some individuals may forage within the wind facility. The taxonomic-specific text indicates if there is evidence that displacement may be partially temporary. The displacement vulnerability scores (DV=MAd+HF) are rescaled to 0–1.

MAd is included to account for behavioral responses from birds that lead to macro-avoidance of wind facilities and have the potential to cause effective habitat loss if birds are permanently displaced (Fox et al. 2006). The MAd scores used in the assessment were based on Willmott et al. (2013), but updated to reflect the most recent empirical studies (Krijgsveld et al. 2011, Cook et al. 2012, 2018, Vanermen et al. 2015b, Skov et al. 2018), and indices (Garthe and Hüppop 2004, Furness et al. 2013, Bradbury et al. 2014, Adams et al. 2016, Wade et al. 2016, Kelsey et al. 2018). The scores are the same as the MAc scores described above, but, following methods from Kelsey et al. (2018), are inverted. HF accounts for the degree to which a species is considered a habitat generalist (i.e., can forage in a variety of habitats) or a specialist (i.e., requires specific habitat and prey type). The assumption is that generalists are less likely to be affected by displacement, whereas specialists are more likely to be affected (Kelsey et al. 2018). The values for HF used in this assessment were taken from Willmott et al. (2013).

Vulnerability categories (PV, CV, DV) were used to weight annual MDAT modeled species density estimates to provide an annual estimate of total avian risk across the proposed Maine Research Array area. MDAT models were created for 47 avian species, but only 36 were used in this assessment, based on species detected within 200 km of the research area. To create a single annual risk map for each vulnerability metric, we first standardized each annual MDAT density models so total density for any species is one (1); weighted each species model by the vulnerability metric (0 to 1); and summed these weighted species models across all species to yield a final total risk model by vulnerability category for birds. Final maps were created using ArcMAP 10.8.1 (ESRI, Inc.). The quartiles of the PV, CV, DV-weighted densities were added together to give a total score ranging from 3-12. Higher values have greater species density of vulnerable species.

3.3 Diving Bird Dynamic Brownian Bridge Movement Modeling

A satellite telemetry tracking study in the Mid-Atlantic was developed and supported by BOEM and the USFWS with objectives aimed at determining fine-scale use and movement patterns of three species of marine diving birds during migration and winter (Spiegel et al. 2017, Stenhouse et al. 2020). These species – the Red-throated Loon, Surf Scoter, and Northern Gannet– are all considered species of conservation concern and exhibit various traits that make them vulnerable to offshore wind development. Nearly 400 individuals were tracked using satellite transmitters, Argos platform terminal transmitters (PTTs), over the course of five years (2012–2016), as part of the Atlantic and Great Lakes Sea Duck Migration Study by the Sea Duck Joint Venture (SDJV). Of note, the Gulf of Maine was not the target for the Diving Bird study and no effort was made to capture birds in the GOM; therefore, distribution of these species may be not capture the full winter and migration use of these species due to the implicit capture bias. For example, Red-throated Loons were found to not move much in winter, yet wintering Red-throated Loons are found in the GOM and thus the winter utilization distribution will most likely under-represent the true use in the GOM. This would also apply to Surf Scoters. Northern Gannet are probably the least capture biased since their winter movements appear to be most extensive of the diving birds.

Utilization distributions (UDs) were determined for each species by calculating individual level dynamic Brownian-bridge movement model (dBBMM) surfaces (Kranstauber et al. 2012) using package Move for R (Kranstauber and Smolla 2016). Separate dBBMM surfaces were calculated for each of two winters with at least five days of data and combined into a weighted mean surface for each animal (as a percentage of the total number of days represented in the surface) with a minimum 30 total combined days of data. This method of combining multiple seasons was used for the migration periods as well, but with relaxed requirements for days of data, requiring only five days per year and seven total days per period since migration duration often occurred over a much shorter time period. Utilization contour levels of 50%, 75%, and 95% were calculated for the mean UD surface. The final UD was cropped to the 95% contour for mapping and further analyses (Spiegel et al. 2017).

3.4 Non-marine migratory birds in the GOM

Non-marine migratory bird satellite transmitter data have been obtained throughout the Northeast U.S. for Peregrine Falcons, Merlins, Ospreys, and Great Blue Herons.

3.4.1 Peregrine Falcons and Merlins

To facilitate research efforts on migrant raptors (i.e., migration routes, stopover sites, space use relative to Atlantic OCS wintering/summer range, origins, contaminant exposure), BRI deployed satellite transmitters on fall migrating raptors at three different raptor migration research stations along the north Atlantic coast (DeSorbo et al. 2012, 2018b, 2018a). Research stations include the Block Island Raptor Research Station at Block Island, Rhode Island (Peregrines Falcons [*Falco peregrinus*]: 3 adult [ad.] females, 18 hatch year [HY] females, 17 HY males; Merlins [*Falco columbarius*]: 3 ad. females and 13 HY females; DeSorboet al. 2018); Monhegan Island, Maine (Peregrine Falcons: 2 HY females); and Cutler, Maine (Peregrine Falcons: 1 ad. female).

Satellite-tagged Peregrine Falcons and Merlins provided information on fall migration routes along the Atlantic flyway. Positional data was filtered to remove poor quality locations using the Douglas Argos Filtering tool (Douglas et al. 2012) available online on the Movebank data repository[4] where these data are stored and processed. A request for data use was made to Chris DeSorbo, Raptor Program Director at BRI, who provided permission to utilize the results of the migrant raptor studies.

3.4.2 Great Blue Herons

Since 2016, the Maine Department of Inland Fisheries and Wildlife (MDIFW) has been capturing Great Blue Herons each year in Maine and tracking their migrations with solar GPS satellite transmitters. The full dataset is available in the Movebank repository.

3.4.3 Osprey

Between 2000 and 2019, 106 tracking devices were fitted to Ospreys (*Pandion haliaetus*) captured at various locations between Chesapeake Bay and northern New Hampshire (www.ospreytrax.com). This data set includes both adults and juveniles, but emphasized tagging juveniles prior to their first migration. It represents the first dedicated study of dispersal, mortality, and migration in juvenile Osprey. Satellite transmitters were used in early years, but beginning in 2012, higher resolution cellular

[4] www.movebank.org

Global Positioning System transmitters were deployed on adult males to better document their foraging behavior around nests and to provide additional details about migration (e.g., thermal soaring over land and dynamic soaring over water; Horton et al. 2014).

Separately, satellite Argos PTT tags were deployed on Ospreys in the U.S. and Canada between 1995 and 2001 (Martell et al. 2001, Martell and Douglas 2019). These data have been used to delineate both fall and spring migratory routes used by Ospreys breeding in the U.S.. Tagging locations included areas in Oregon, Washington, Minnesota, New York, and New Jersey. Birds tagged in eastern states generally migrated along the U.S. Atlantic coast.

To characterize potential utilization of the offshore environment by Ospreys, UDs were generated for individual animals using a dBBMM (Kranstauber et al. 2012). Both Argos satellite data and GPS-derived positional data were used from the two different telemetry datasets from Movebank (as above). Both datasets were compiled together and a max speed filter by animal was applied, which excluded locations with instantaneous speeds greater than 100 kph (62 mph) and also filtered points outside of an extent including the eastern U.S. and Atlantic Canada (including all offshore points for this region). Individual dBBMMs were generated for the last 365 consecutive days of available data per tag (or less if the tags provide less than 365 consecutive days), thus representing an annual cycle within the U.S. Models were composited into a weighted UD for the sampled population, weighting each animal's UD by the number of days data were available of the total number of days of all animals providing models.

4 Results and Discussion

4.1 Important foraging areas for nesting marine birds

Marine bird tagging data from 2022 provided preliminary results on foraging distances and habitat use for multiple nesting marine bird species in the Gulf of Maine. For nine individual Atlantic puffins tagged at Matinicus Rock, some tracks indicated travel up to 140km from the colony (Figure 3). Arctic terns were tagged at Seal Island NWR and Eastern Egg Rock, and tracks were observed in the Maine DMR offshore wind Area of Interest, with a maximum distance from the colony of 67km (Figure 4). Common terns were tagged at Seal Island NWR, Eastern Egg Rock, and Stratton Island. Tracking points were observed in the Maine DMR offshore wind Area of Interest for individuals tagged at Stratton Island, and the maximum distance from the colony was 72km (Figure 5). Leach's storm-petrels were tagged on Eastern Egg Rock and Matinicus Rock and were observed up to 692km from the respective colony. Leach's storm-petrels were observed throughout the Gulf of Maine, exhibiting the farthest foraging distances of any species tagged in 2022 (Figure 6). Foraging of this species seemed to be focused on the Great South Channel, eastern flank of Nantucket Shoals, and outer continental shelf, though foraging habitat is not solely limited to these regions based on previous tagging studies (Hedd et al. 2018). Data were obtained for one common tern that captured post-breeding dispersal from the Seal Island NWR colony to Cape Cod, MA (Figure 7). For all species tagged in 2022, the maximum distance from the colony was incorporated into the literature review (Table 1). Further analyses of these tagging data and future incorporation of tagging data from other sources will provide more detailed information about marine bird movements in the GOM.

Important regions for nesting marine bird foraging, based on foraging distances, colony populations, and species varied throughout the Gulf of Maine (Figure 1). The highest overlap of important foraging regions for all species combined was along the coast, particularly in the Midcoast region from east of Casco Bay to Mount Desert Island, extending offshore (Figure 1). Colonies in this region were inhabited by relatively large populations of Atlantic Puffins (Figure 8), Double-crested (Figure 9) and Great Cormorants (Figure 10), Herring Gulls (Figure 11), Great Black-Backed Gulls (Figure 12), Arctic Terns (Figure 13), and Common Eiders (Figure 14), which all exhibited overlapping foraging regions.

There were additional regions of importance for multiple species including Cape Cod, the far Downeast Maine region east to Grand Manan, and along the coast of Southern Maine (Figure 1). Species reliant on the Cape Cod region included Common (Figure 14) and Roseate terns (Figure 16) as well as Laughing Gulls (Figure 17). All species except Great Cormorants (Figure 10) and Roseate Terns (Figure 16) relied on the Downeast Maine region extending towards Grand Manan, and the Southern Maine coast included foraging areas for all gulls (Figure 11, Figure 12, Figure 17), terns (Figure 13, Figure 14, Figure 16), Atlantic Puffins (Figure 8), and Double-crested Cormorants (Figure 9). Important regions for Razorbill foraging primarily focused on the Midcoast and Downeast Maine regions, particularly southwest of Grand Manan (Figure 18). Black Guillemot colonies were distributed along the entire Maine coast and exhibited relatively short maximum foraging distances when compared to other species analyzed (Figure 19). Leach's Storm-petrels are predicted to use the entire GOM (Figure 18) based on the tracking data obtained in 2022 (Figure 6), but future modeling and analyses will better define the areas of greatest use. Common Murres were only observed at a few nesting sites and exhibited the shortest maximum foraging distance of all species analyzed (Figure 21). The research array requested lease area is proposed within the maximum foraging range for some species, including Great Black-backed Gulls, Herring Gulls, Laughing Gulls, Arctic and Common Terns, Atlantic Puffins, and Leach's Storm-petrels. Importantly, many colonies with relatively large populations and overlapping foraging regions are proximate to the lease area.

In this analysis, Roseate Terns were the only endangered species assessed. Important colonies and foraging regions for Roseate Terns were distributed throughout southern Maine more than northern Maine, with some additional colonies and thus foraging regions off the southern coast of Nova Scotia and Cape Cod, a region that is a major staging area for Roseate Tern breeding in the U.S. (Figure 16; Mostello et al. 2014). In addition, the maximum foraging distance recorded for Roseate Terns was very low relative to other species analyzed (Table 1), so Roseate tern foraging regions may be restricted closer to shore.

4.2 Species vulnerability in the GOM

Species vulnerability to offshore wind development was highest in inshore regions and around banks and ledges such as Jeffreys Ledge, Cashes Ledge, and George's Bank (Figure 2). Areas of low vulnerability were associated with deeper water and muddy seafloor in the northeast (Jordan Basin) and west (Wilkinson Basin) Gulf of Maine (Figure 2). Areas of higher vulnerability were associated with bottom topography such as slope, shoals, and banks (Figure 2). The Maine Research Array preferred site occurs west of Jordan Basin and north of Platts Bank in another smaller but deep basin called Mistaken Ground. This is also an area of lower species vulnerability. There was seasonal variability in species vulnerability, with high vulnerability in inshore regions and around banks during spring and summer, and lower vulnerability in the Downeast region relative to southern and offshore regions in the winter (Figure 22).

4.3 Diving bird use of the GOM

There was seasonal variability in habitat use for all diving bird species in the Gulf of Maine (Figure 23, Figure 24, Figure 25). All species used the region as a migratory area in the spring, and Northern Gannets also inhabited the Gulf of Maine broadly in the fall (Figure 25). For Surf Scoters (Figure 23), the core habitat use area in the spring was close to shore, and in the winter, the core habitat use was in the southern Gulf of Maine, however capture bias may have led to a bias in winter utilization. For Northern Gannets, there was higher habitat use in nearshore waters along the coastline of the Gulf of Maine in the winter, with some core habitat use in the spring in the southern Gulf of Maine (Figure 25). The southern Gulf of Maine and southern New England regions were important for Red-throated Loons in all seasons, with additional broad habitat use throughout the Gulf of Maine in the spring (Figure 24), but again capture bias may have led to a bias in modeled use particularly for fall and winter utilization since captures were in the Mid-Atlantic and movements are more restricted than for Northern Gannet. Though these results are informative for presence of diving marine bird species in this region, the core habitat use and home ranges for each species were derived from tag data from individuals captured in the Mid-Atlantic, rather than the Gulf of Maine. It is possible that Gulf of Maine individuals would exhibit additional, or different, habitat use than the Mid-Atlantic individuals. Therefore, these maps should be interpreted with caution and are not necessarily informative for interpreting the absence of species in the Gulf of Maine, rather the maps could be informative for seasonal variability in habitat use and risk.

4.4 Non-marine migratory birds in the GOM

In addition to marine birds, many land and coastal birds, including waterfowl, wading birds, shorebirds, raptors, and songbirds, migrate across the GOM (Figure 26, Figure 27, Figure 28, Smetzer et al. 2017). Some species will likely stay closer to shore, while others, such as some wading birds, shorebirds, and songbirds will cross further offshore in the GOM, particularly in fall when they are traveling south. Due to the orientation of the GOM and the position of Nova Scotia relative to Cape Cod, some species will likely fly directly across GOM as this will be the shortest distance between land masses. The flight paths of these non-marine birds will vary depending on the species, time of year, and weather patterns, and therefore migratory flyways (regular paths) may not occur for these species (Figure 26, Figure 27, Figure 28). Therefore, non-marine birds may be more broadly exposed to potential offshore wind development than marine birds with more restricted patterns of use in the GOM, but exact patterns of use by non-marine birds in the GOM are still to be explored and the level of risk these species may experience needs further study.

5 Conclusions

The primary conclusions that can be drawn from this analysis are as follows:

- Major foraging habitat for nesting marine birds, based on known colonies and foraging distances travelled, focused on Midcoast Maine, far Downeast Maine, and Cape Cod and primarily were within 64 km (40 miles) of the coast.
- Lower vulnerability to offshore wind development for marine birds and lower habitat use for nesting marine birds was predicted in the Central Gulf of Maine, an area associated with deeper water and muddy seafloor in the northeast (Jordan Basin) and west (Wilkinson Basin) Gulf of Maine coastlines.
- Higher vulnerability to offshore wind development for marine birds and higher habitat use for nesting marine birds was predicted in nearshore shallower regions and around banks and ledges.
- Movement modeling of birds captured in the mid-Atlantic indicate broad migratory movements through the Gulf, but that core use areas are concentrated closer to shore and near shoals.

Table 1. Table of foraging distance data for relevant nesting marine bird species in the Gulf of Maine. The minimum, mean, maximum, and mean maximum foraging distances are reported in km. The maximum foraging distance was used for subsequent spatial analyses of foraging habitat. Cells for which data are not available are indicated by "NA".

Common Name	Season	Study Location	Min. Dist	Mean Dist.	Max. Dist.	Mean Max. Dist.	Reference	Tier
Roseate Tern	Breeding	Nova Scotia	2.1	10.5	23.9	15.45	Rock et al. 2007, Pratte et al. 2021	1
Atlantic Puffin	Breeding	Matinicus Rock	*NA*	*NA*	140.0	*NA*	Figure 1	1
Razorbill	Breeding	UK Marine Protected Areas	*NA*	23.7	35.0	95.0	Thaxter et al. 2012	2
Black Guillemot	Breeding	UK	*NA*	*NA*	26.5	6.5	Johnston 2019, Johnston et al. 2022	2
Common Tern	Breeding	GOM	*NA*	28.0	72.0	60.0	Carloni 2018; Figure 3	1
Arctic Tern	Breeding	GOM	*NA*	*NA*	68.0	*NA*	Figure 2	1
Leach's Storm-Petrel	Breeding	GOM	*NA*	567	692.0	*NA*	Hedd et al. 2018; Figure 4	1
Herring Gull	Breeding	GOM	*NA*	29.5	80.0	*NA*	Steenweg et al. 2011, Shlepr et al. 2021	1
Least Tern	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Great Black-backed Gull	Breeding	GOM	0.1	41.3	66.6	14.9	Maynard and Ronconi 2018	1
Great Cormorant	Breeding	UK Marine Protected Areas		5.2	35.0	25.0	Thaxter et al. 2012	2
Double-crested Cormorant	Breeding	Lake Erie; Columbia River	0.5	11.85	47.2	*NA*	Anderson 2002, Stapanian et al. 2002	3
Laughing Gull	Breeding	New Jersey	7.0	*NA*	144.0	*NA*	Dosch 2003	2
Common Murre	Breeding	Newfoundland	*NA*	*NA*	16.9	*NA*	Gulka et al. 2019	2
Common Eider	Breeding	Nova Scotia	*NA*	*NA*	14.0	9.4	Ronconi et al. 2022	1

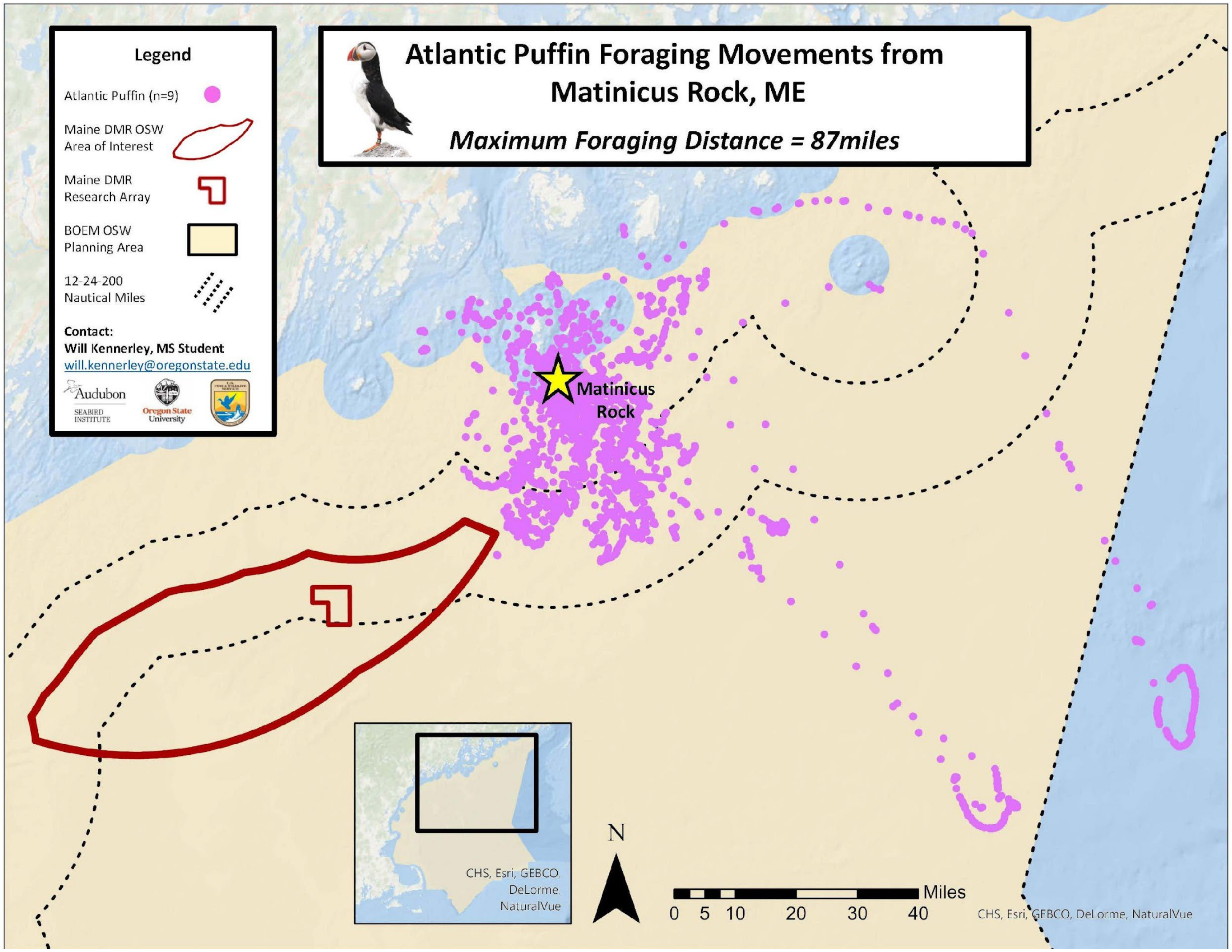

Figure 3. Atlantic Puffin foraging movements from 9 individuals tagged at Matinicus Rock, ME in summer 2022. The maximum foraging distance was 140km (87 statute miles). The Maine area of interest and research array are indicated in red. Distance from shore is indicated with black hash marks.

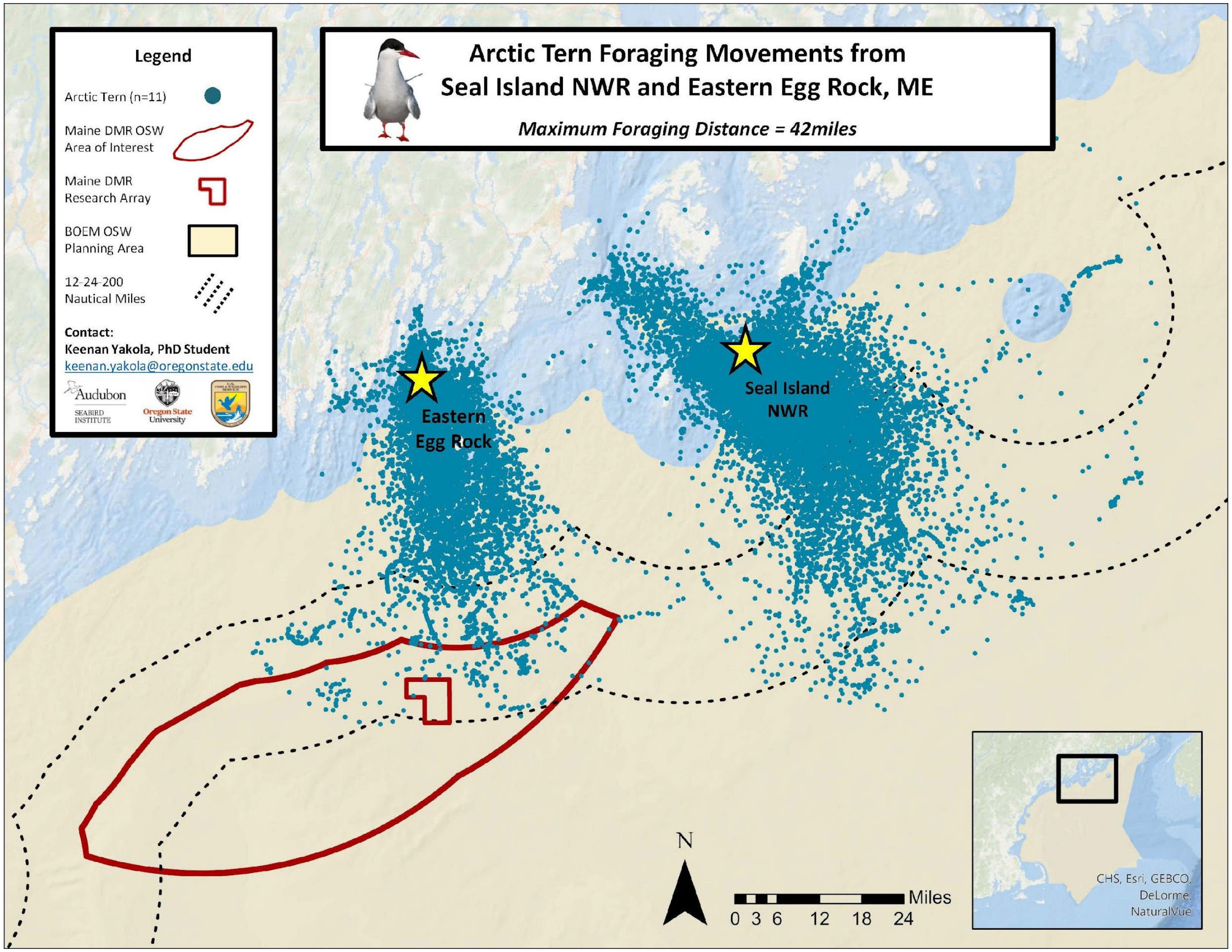

Figure 4. Arctic Tern foraging movements from 11 individuals tagged at Seal Island National Wildlife Refuge and Eastern Egg Rock, ME in summer 2022. The maximum foraging distance was 67.5km (42 statute miles). The Maine area of interest and research array are indicated in red. Distance from shore is indicated with black hash marks.

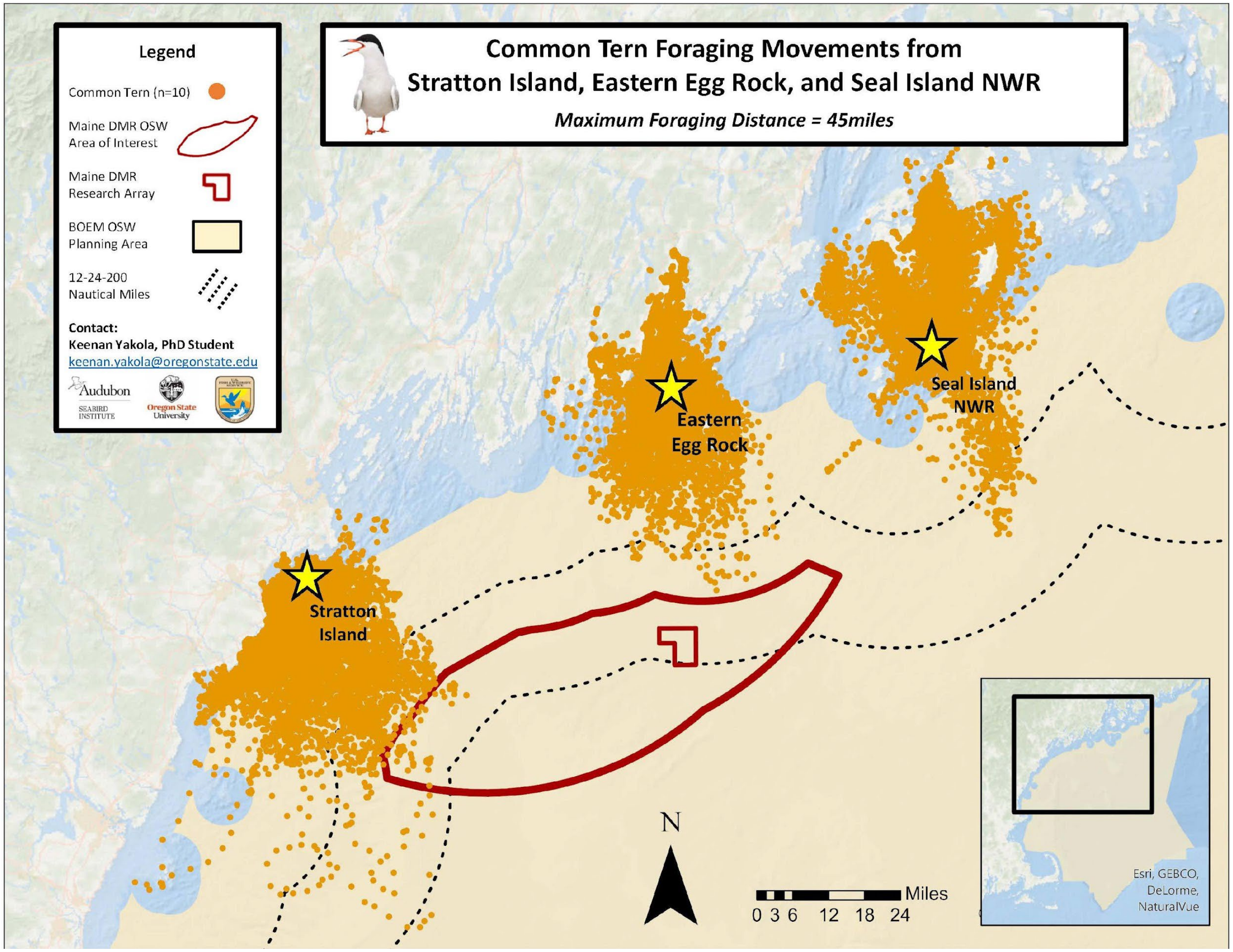

Figure 5. Common Tern foraging movements from 10 individuals tagged at Seal Island National Wildlife Refuge, Stratton Island, and Eastern Egg Rock, ME in summer 2022. The maximum foraging distance was 72km (45 statute miles). The Maine area of interest and research array are indicated in red. Distance from shore is indicated with black hash marks.

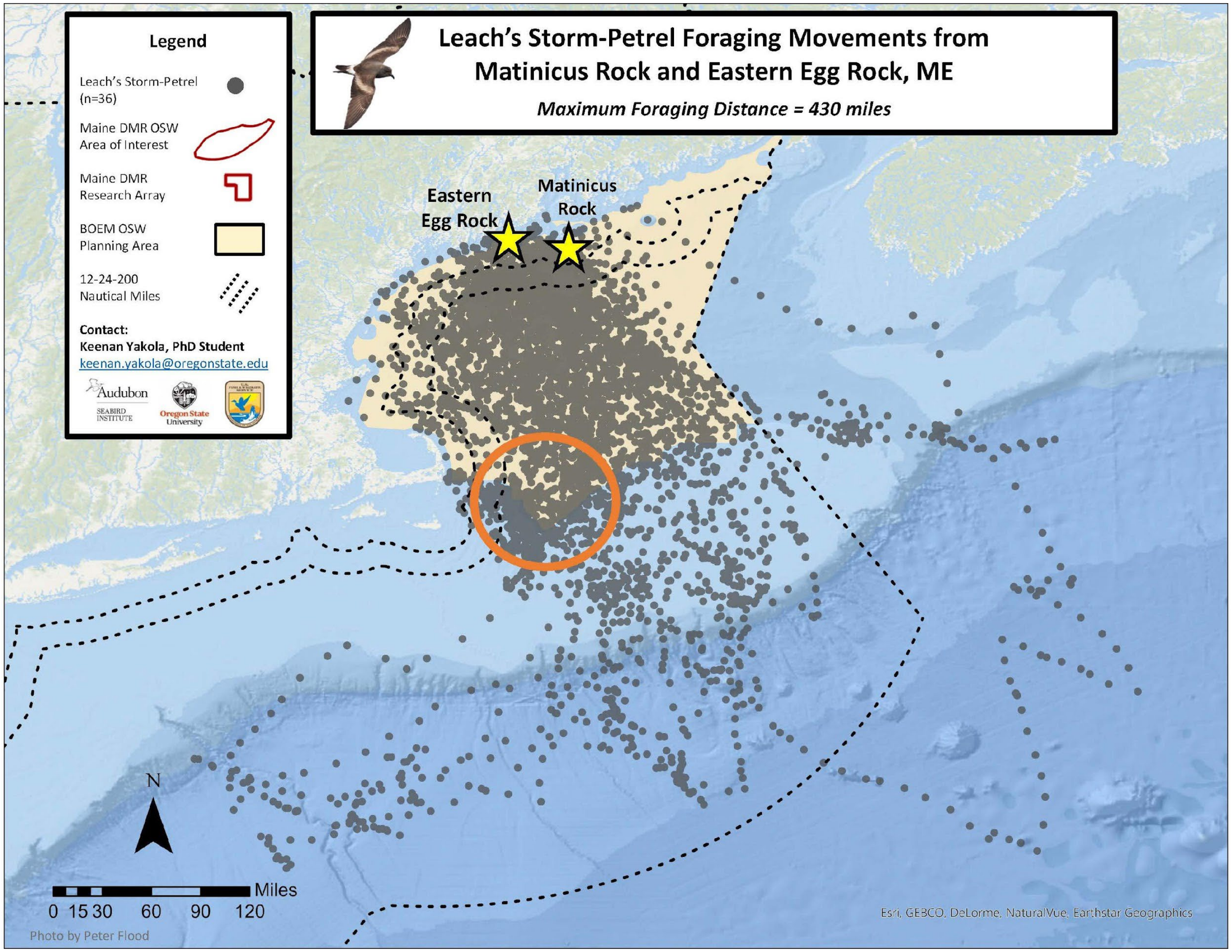

Figure 6. Leach's Storm-petrel foraging movements from 36 individuals tagged at Matinicus Rock, and Eastern Egg Rock, ME in summer 2022. The maximum foraging distance was 692km (430 statute miles). The Maine area of interest and research array are indicated in red. Distance from shore is indicated with black hash marks.

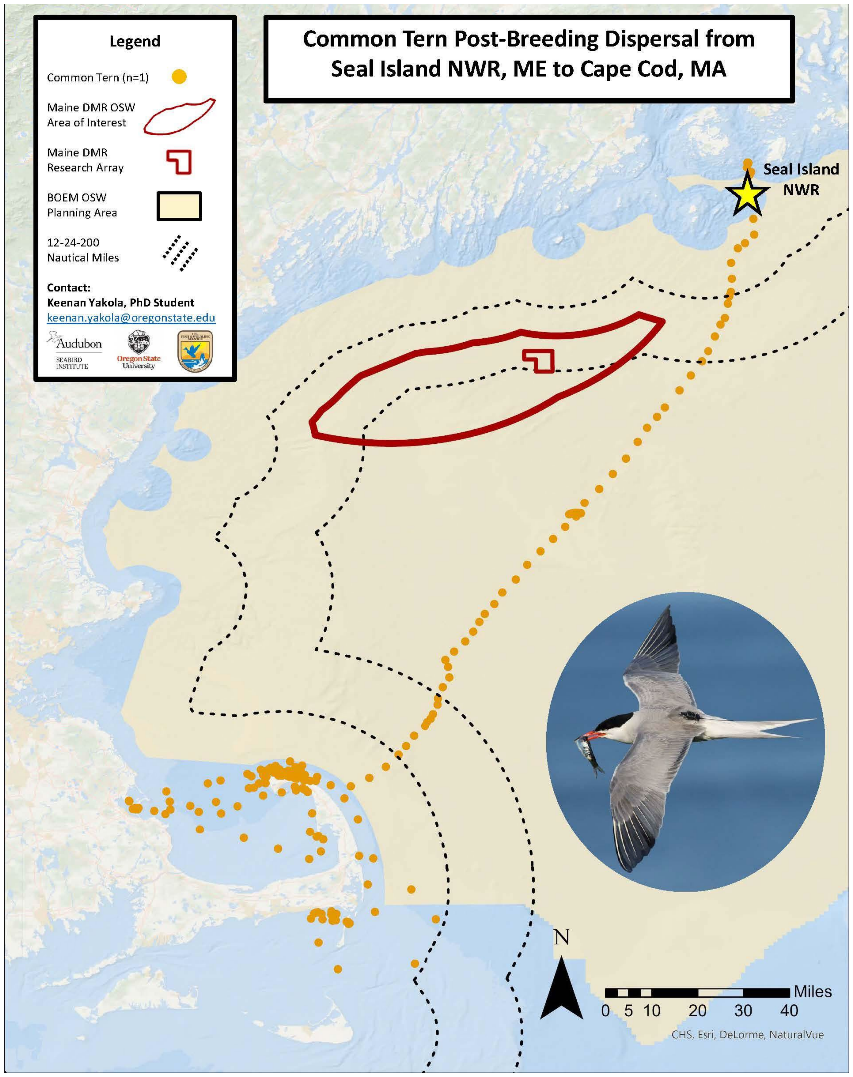

Figure 7. Common Tern post-breeding dispersal from 1 individual tagged at Seal Island National Wildlife Refuge, ME in summer 2022 and subsequent migration to Cape Cod, MA. The Maine area of interest and research array are indicated in red. Distance from shore is indicated with black hash marks.

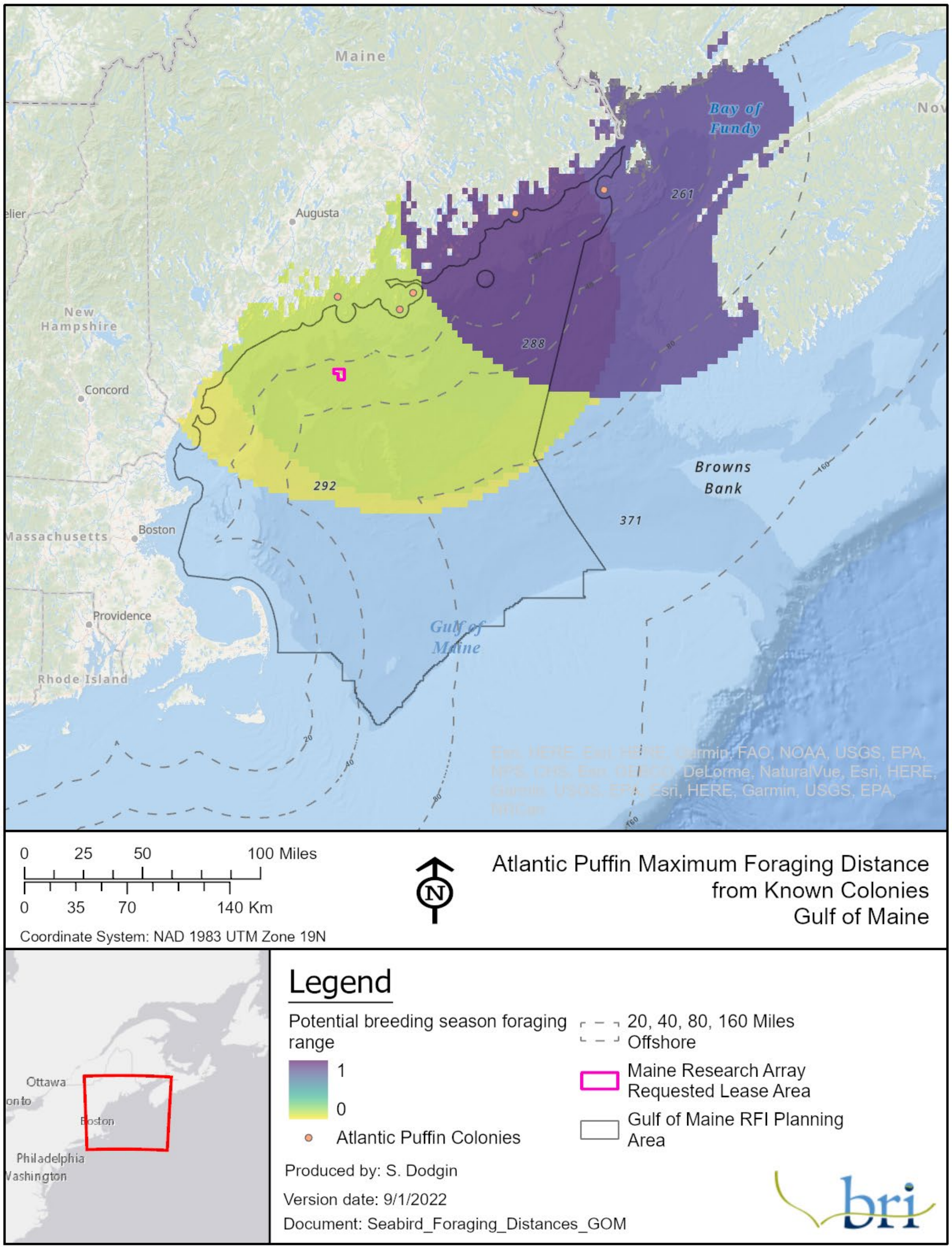

Figure 8. Foraging areas of importance for nesting Atlantic Puffins built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. The Maine Atlantic Puffin colonies are the only Atlantic Puffin colonies in the U.S., and are also listed as “threatened” by the State of Maine.

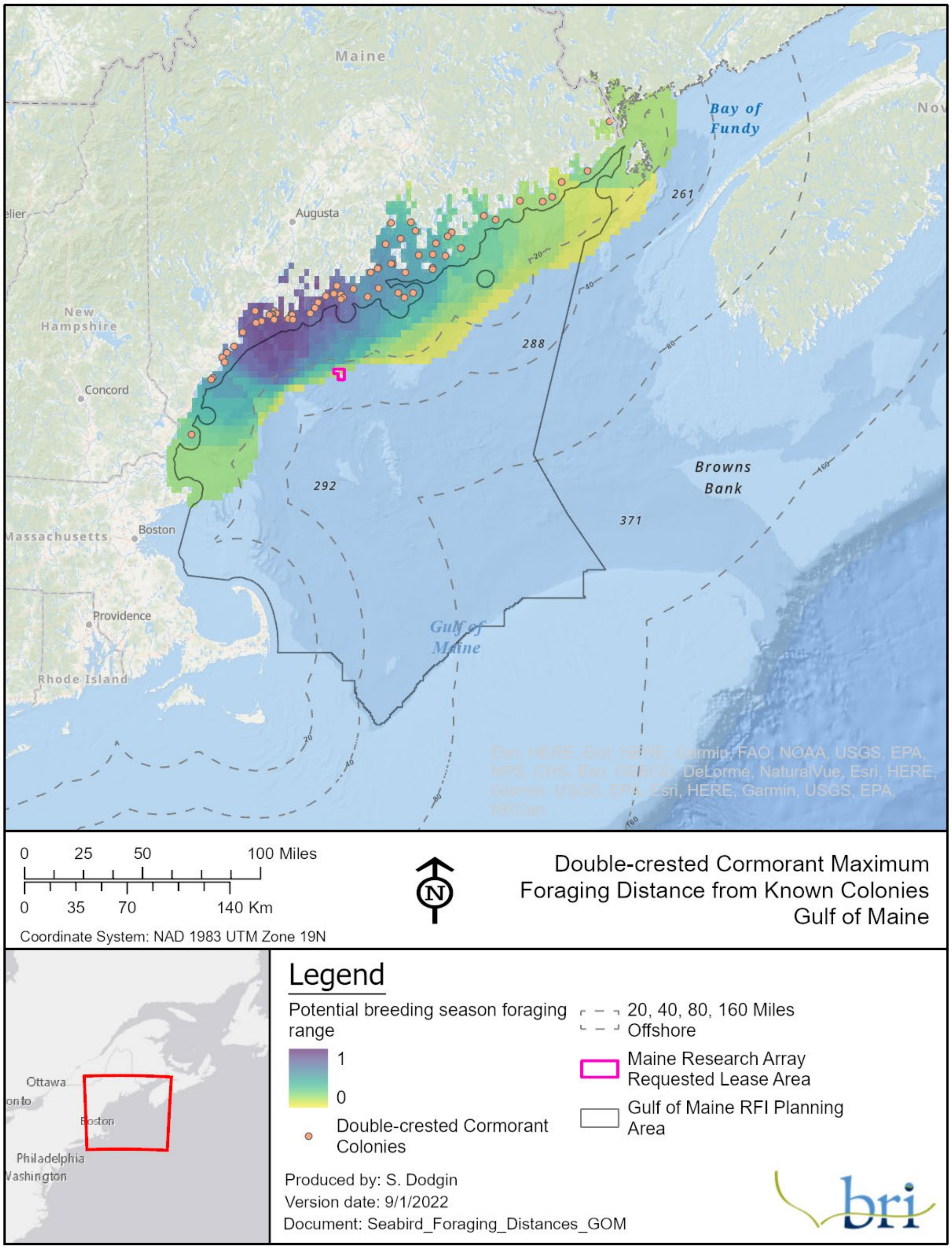

Figure 9. Foraging areas of importance for nesting Double-crested Cormorants built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

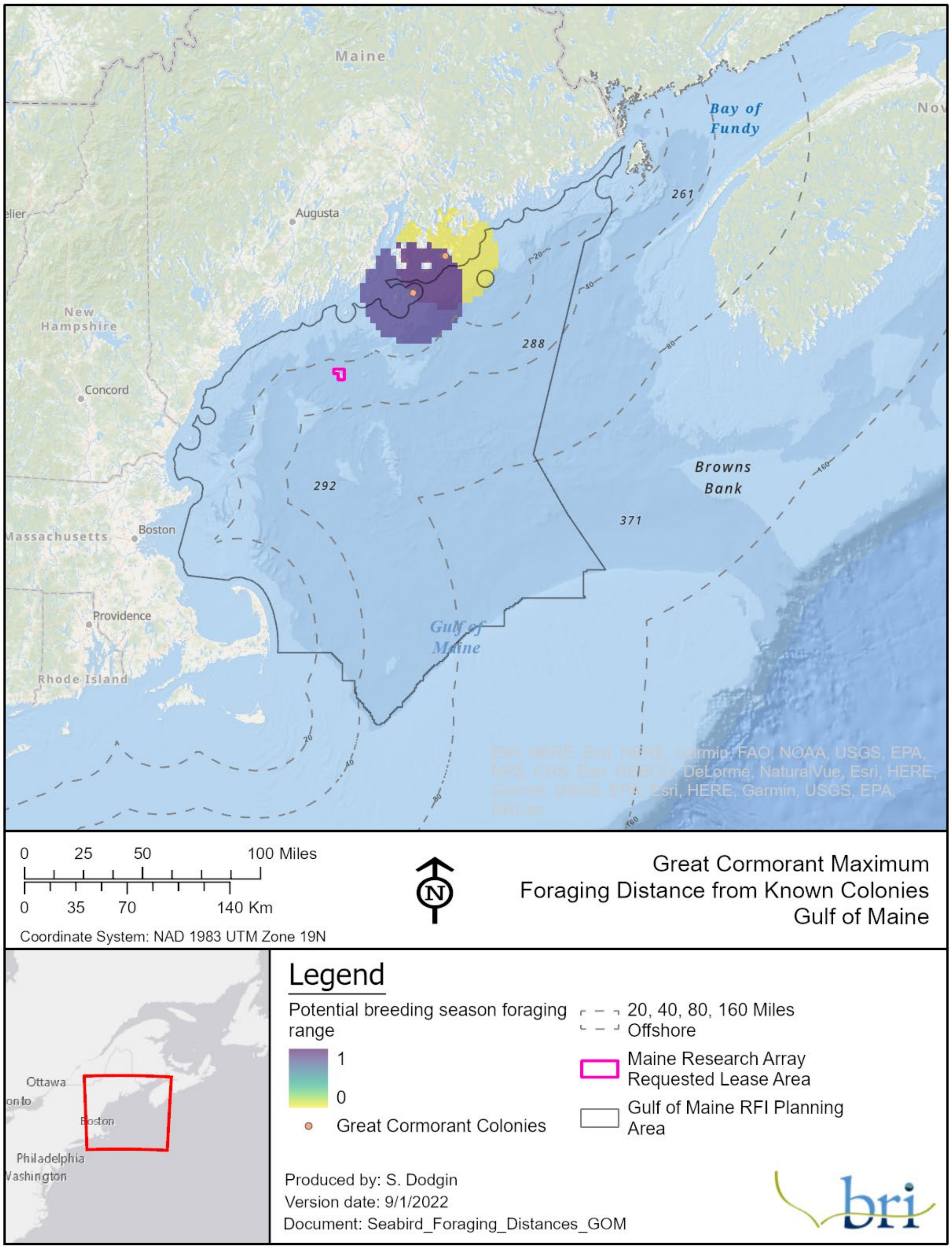

Figure 10. Foraging areas of importance for nesting Great Cormorants built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. Great Cormorants are listed as "threatened" by the State of Maine.

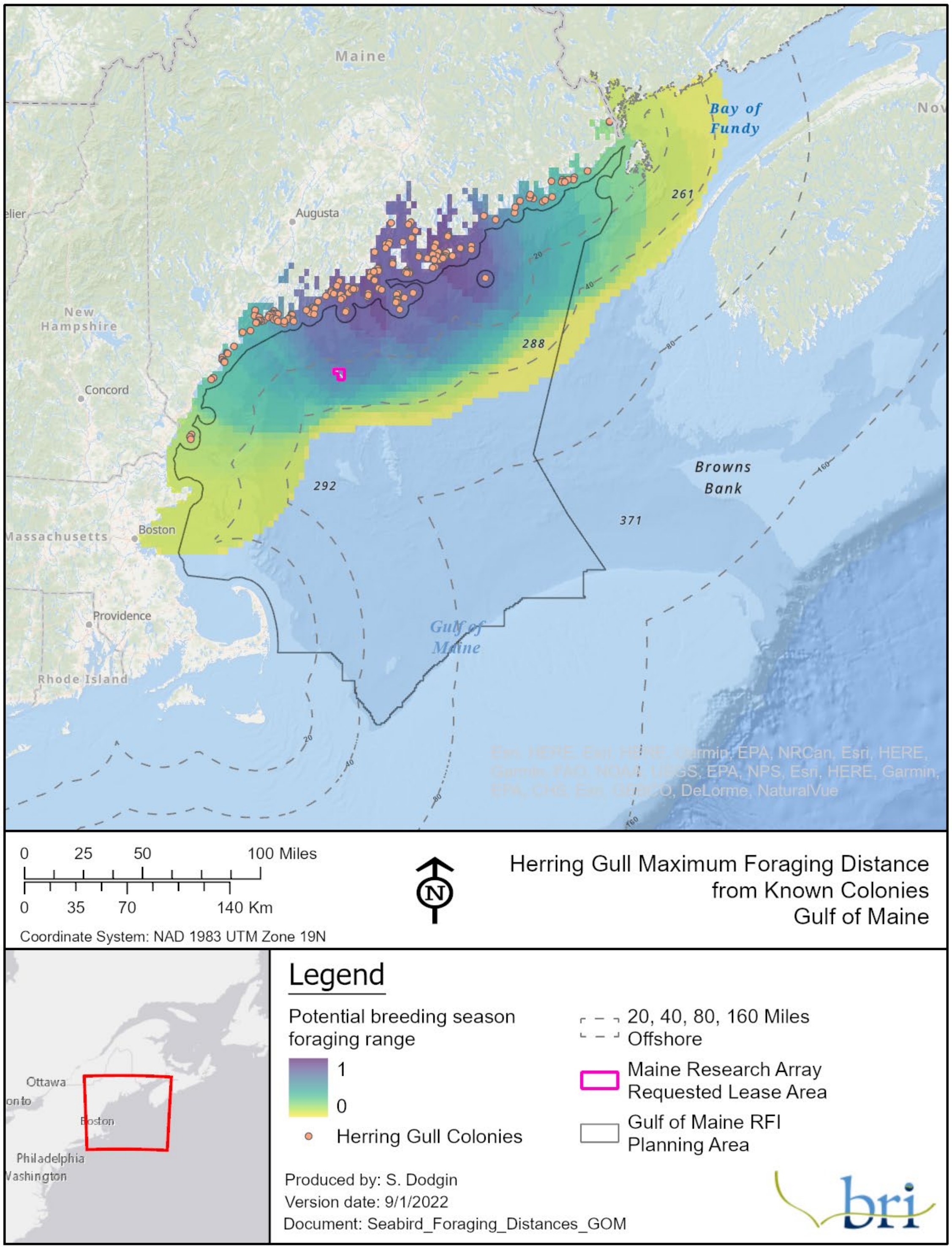

Figure 11. Foraging areas of importance for nesting Herring Gulls built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

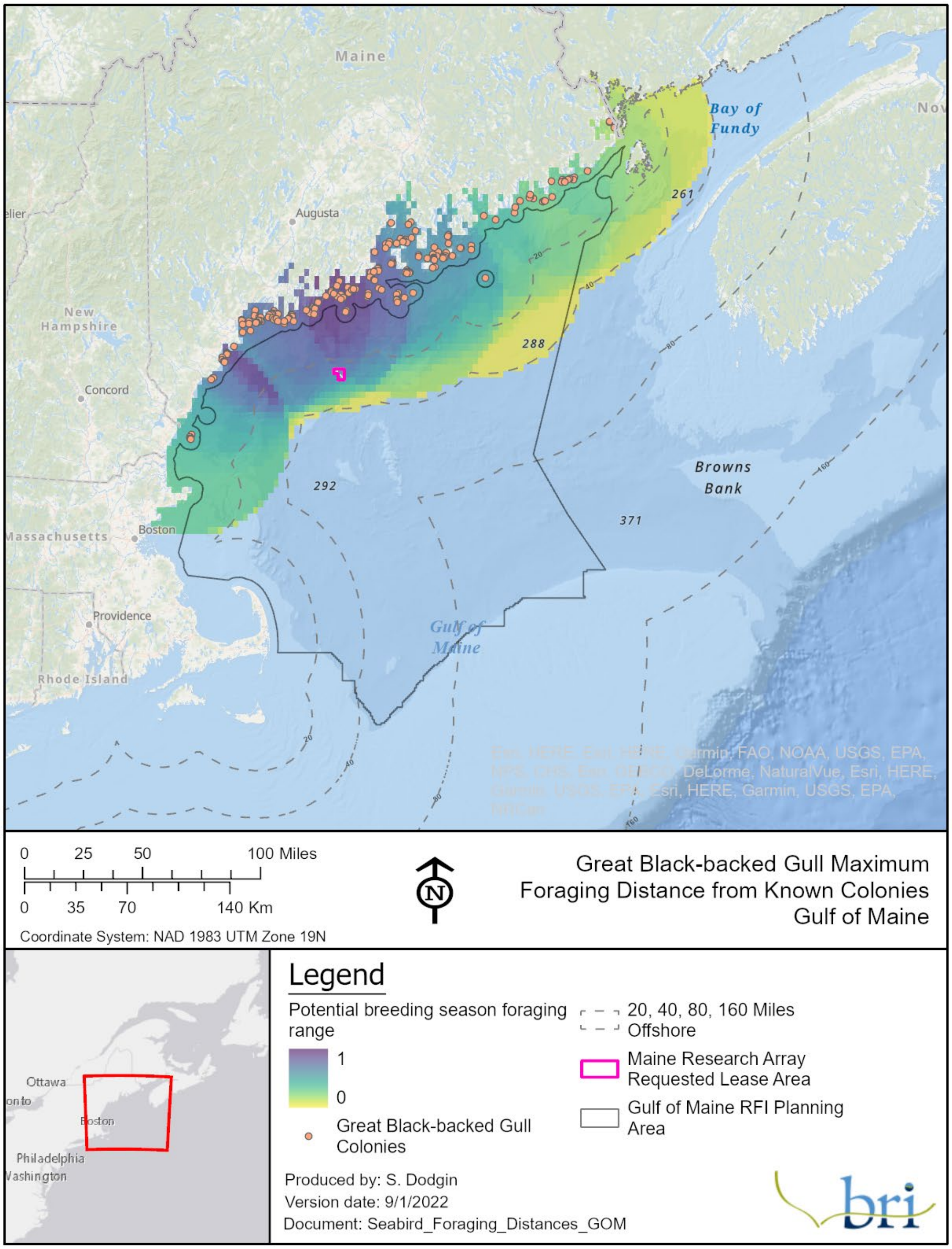

Figure 12. Foraging areas of importance for nesting Great Black-backed Gulls built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

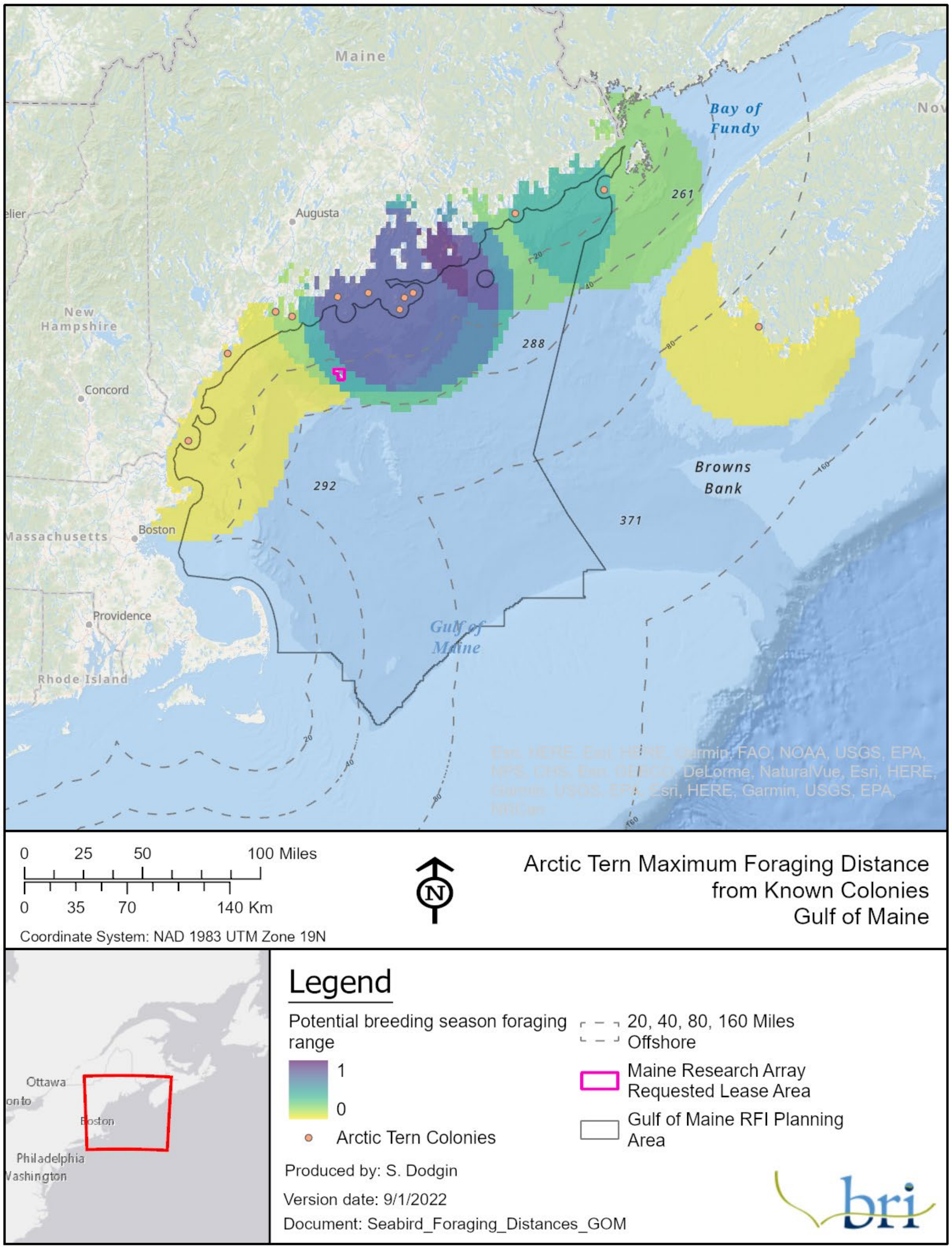

Figure 13. Foraging areas of importance for nesting Arctic Terns built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. The nesting sites for Arctic Terns in the Gulf of Maine represent all Arctic Tern breeding sites in the continental U.S., and Arctic Terns are listed as "threatened" by the State of Maine.

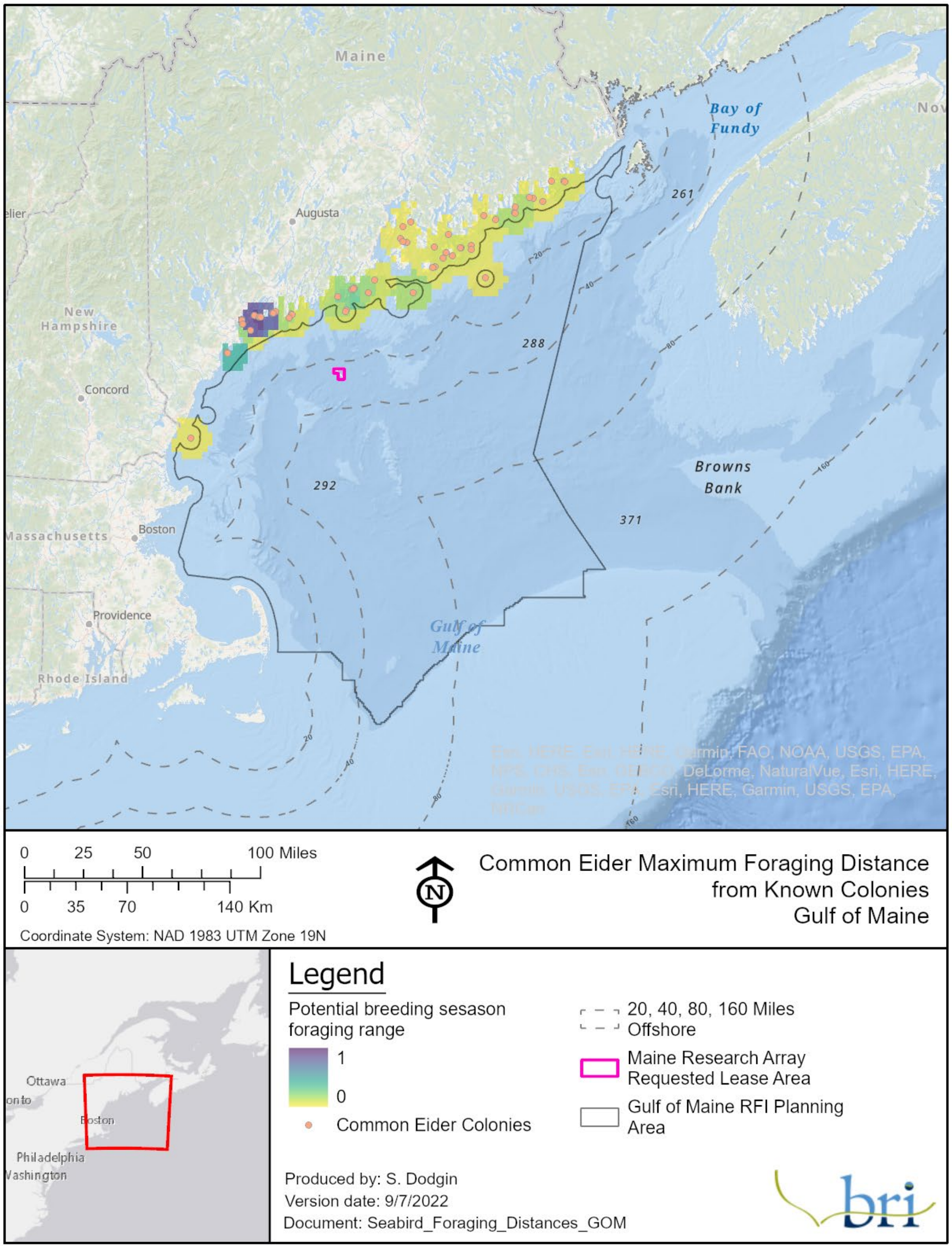

Figure 14. Foraging areas of importance for nesting Common Eiders built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

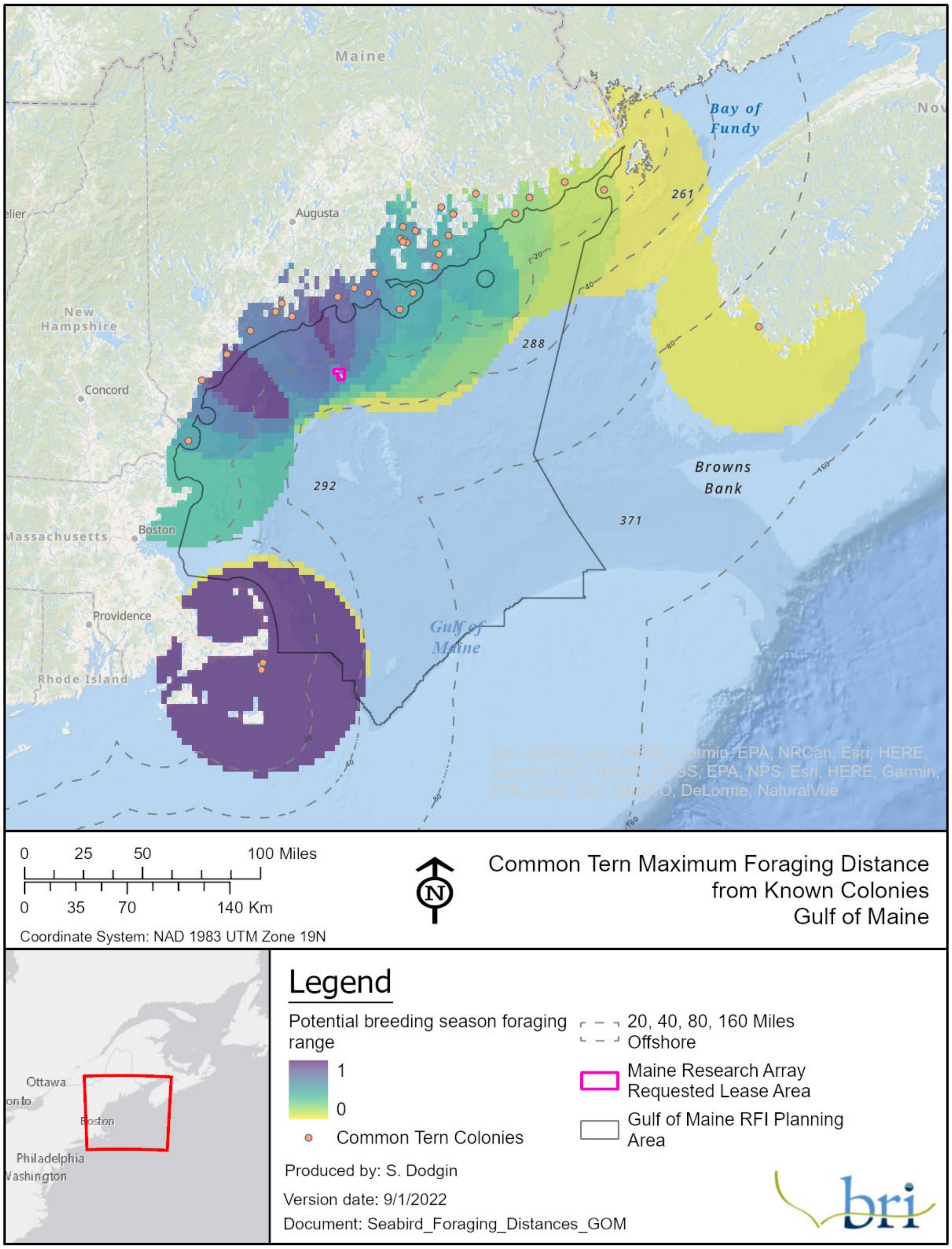

Figure 15. Foraging areas of importance for nesting Common Terns built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

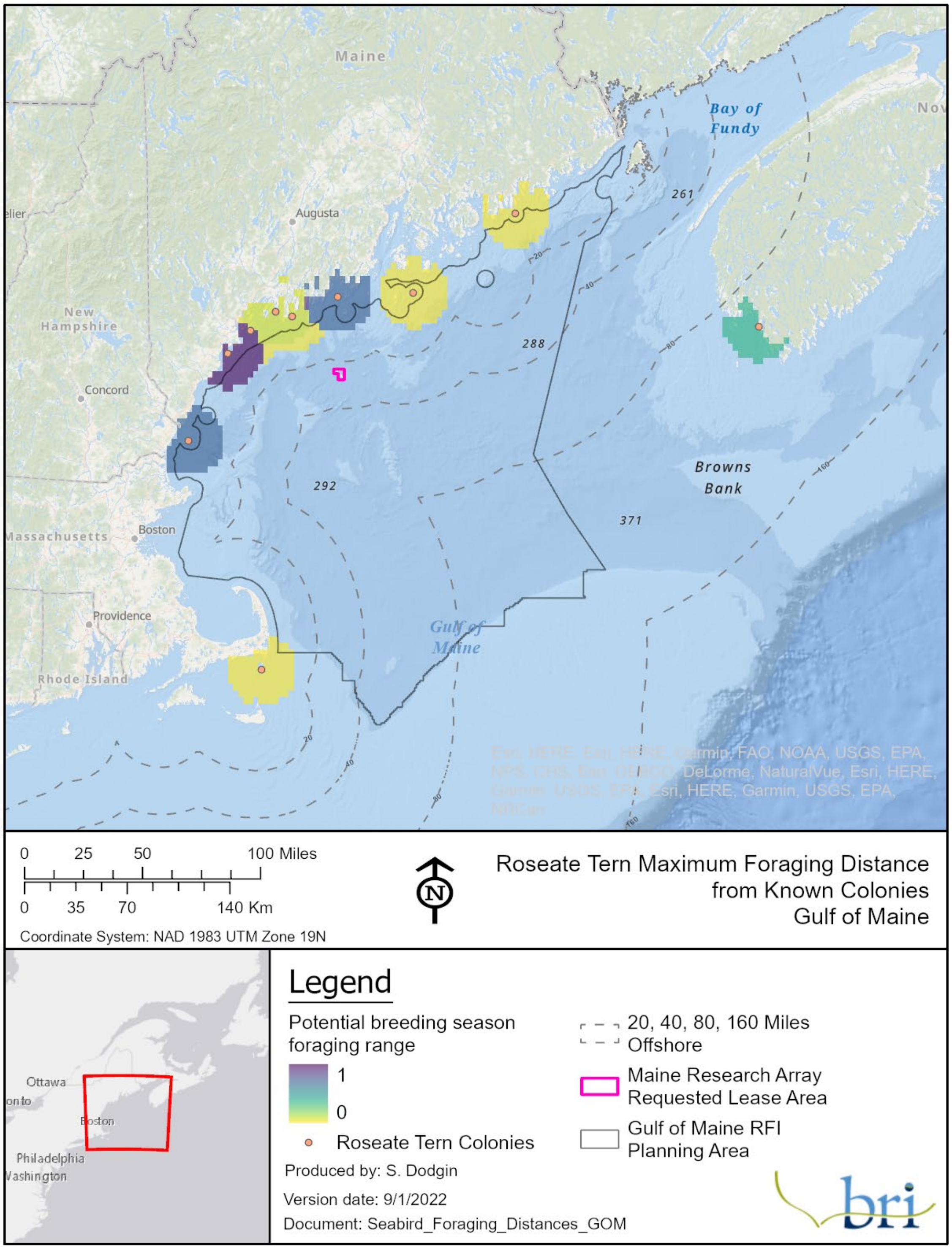

Figure 16. Foraging areas of importance for nesting Roseate Terns built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. Importantly, Roseate Terns are listed as “endangered” in the Endangered Species Act and by the State of Maine.

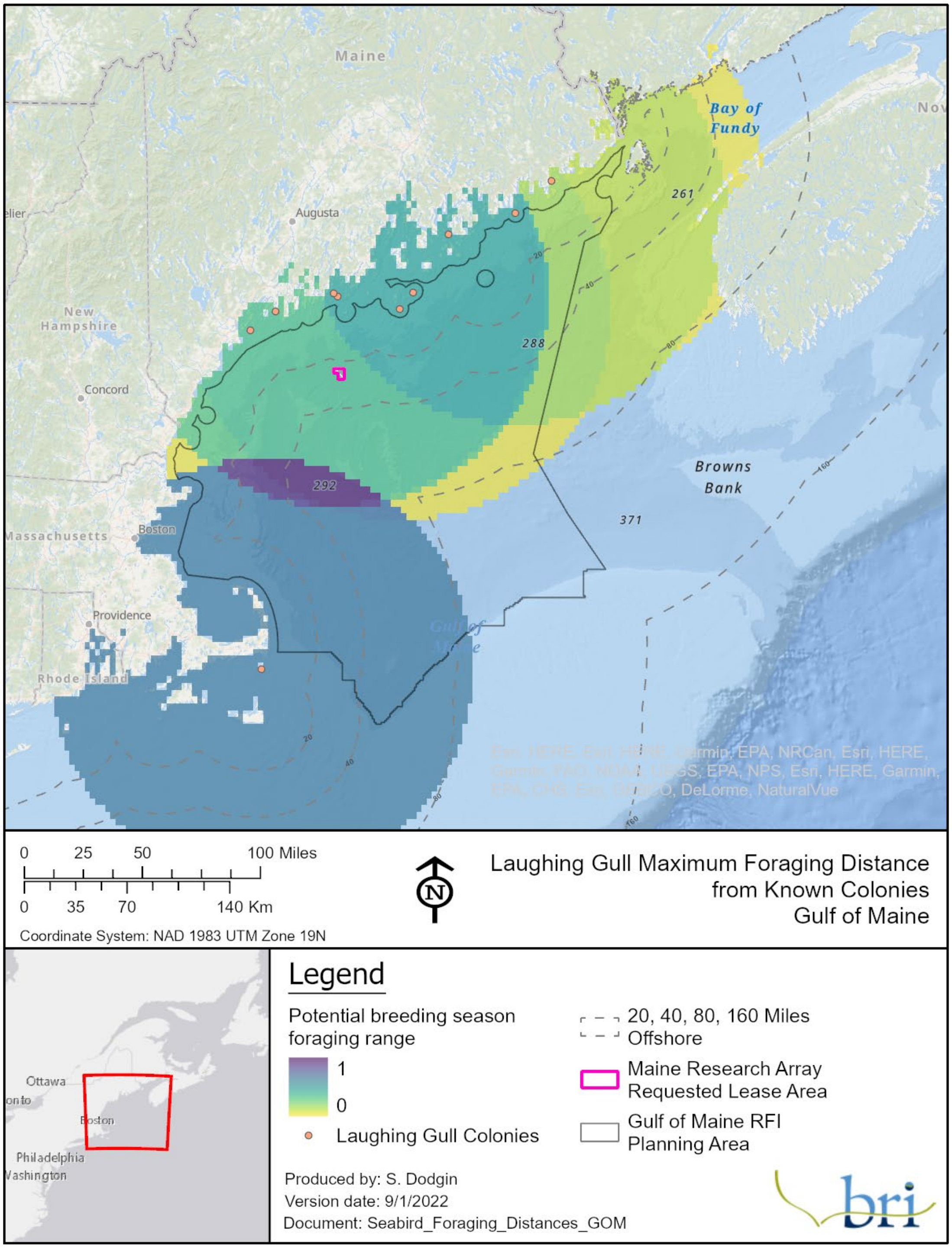

Figure 17. Foraging areas of importance for nesting Laughing Gulls built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. Of note, there are important nesting regions in Downeast and Midcoast Maine (particularly, Petit Manan Island, Matinicus Rock, and Eastern Egg Rock) that have a lower population than nesting sites near Cape Cod, but are still critical habitat for Laughing Gulls.

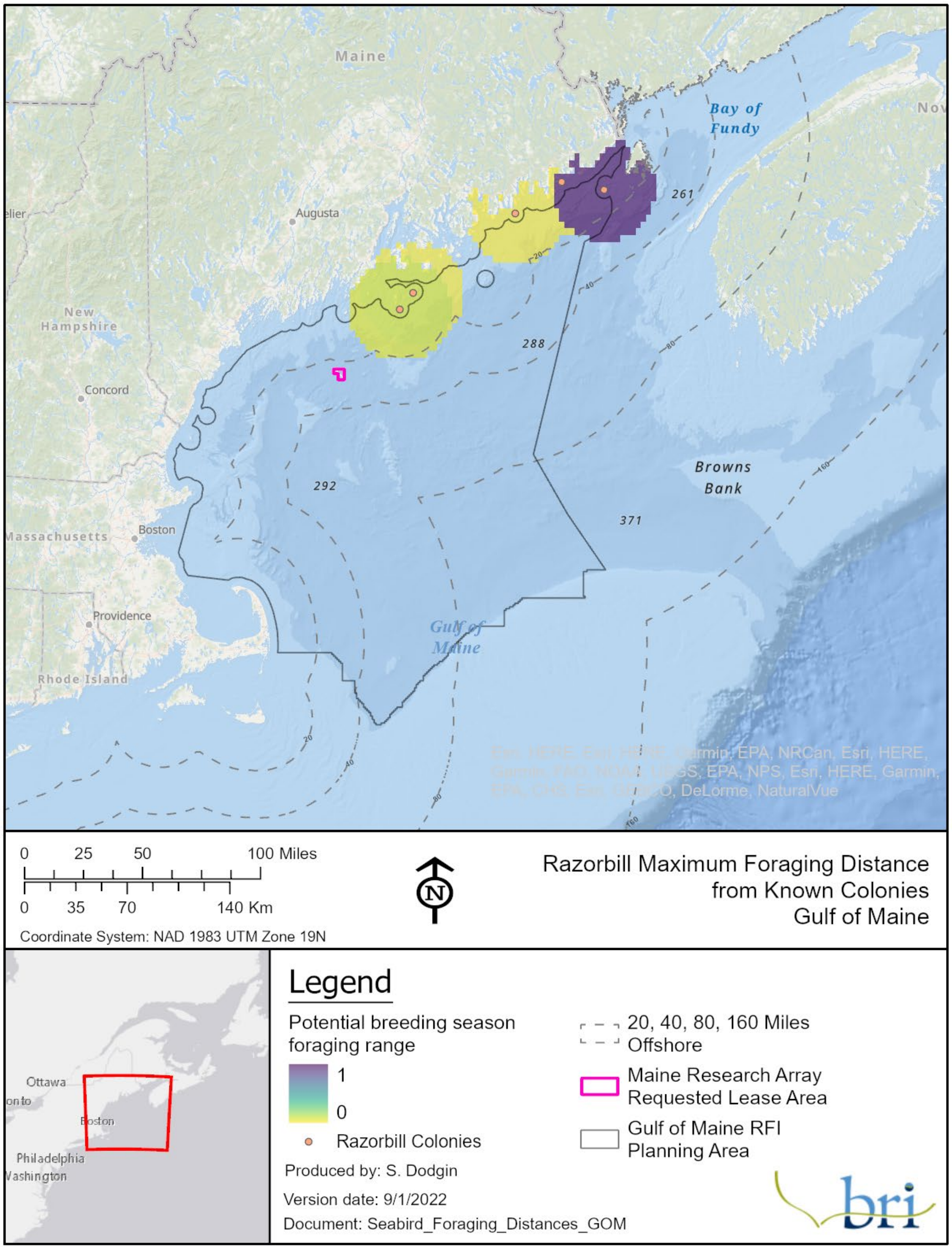

Figure 18. Foraging areas of importance for nesting Razorbills built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. The Maine Razorbill colonies are the only colonies in the U.S., and Razorbills are also listed as "threatened" by the State of Maine.

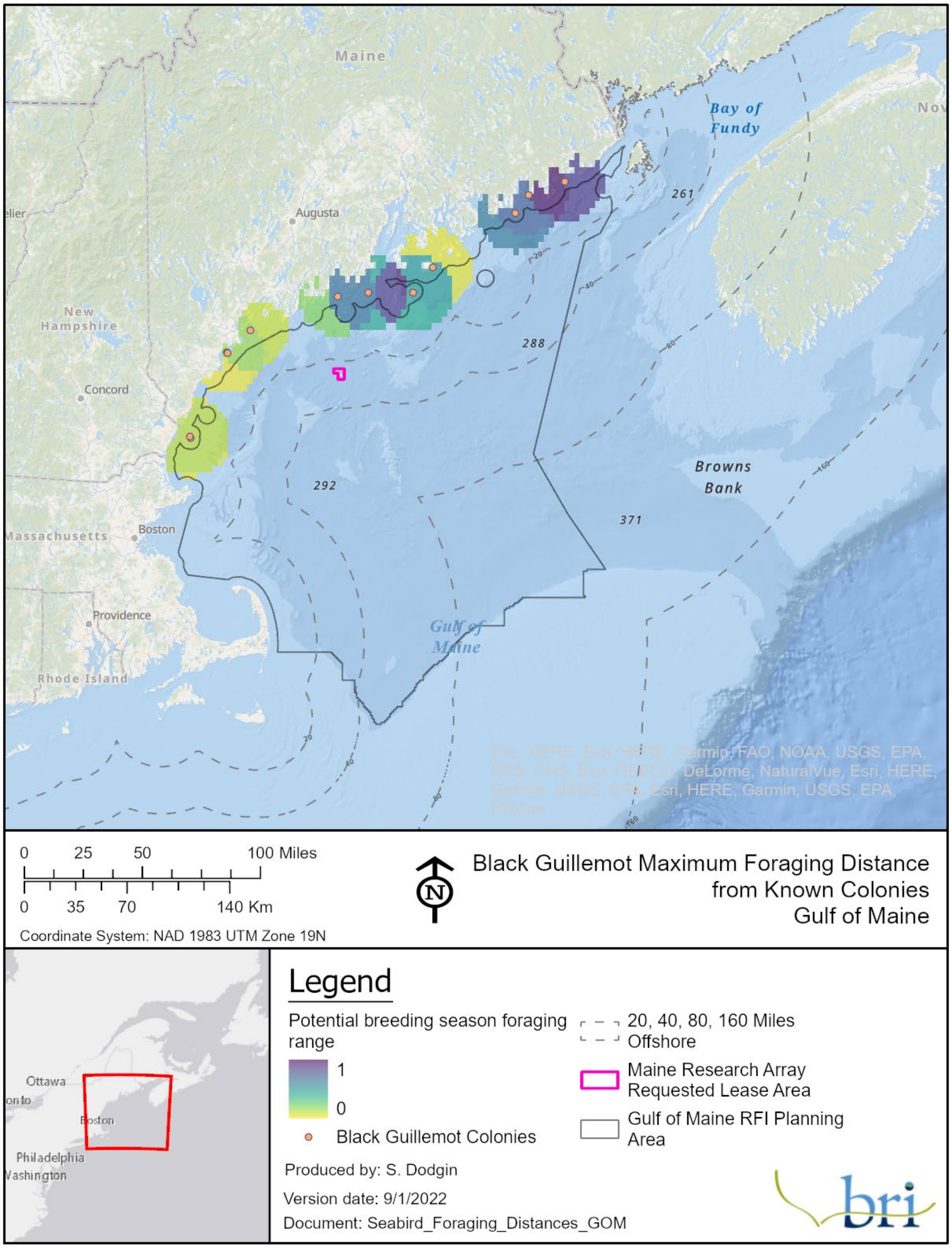

Figure 19. Foraging areas of importance for nesting Black Guillemont built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts. Though there are more than 160 nesting colonies for Black Guillemonts in the Gulf of Maine, the results presented here were limited to 16 colonies for which colony count data were available.

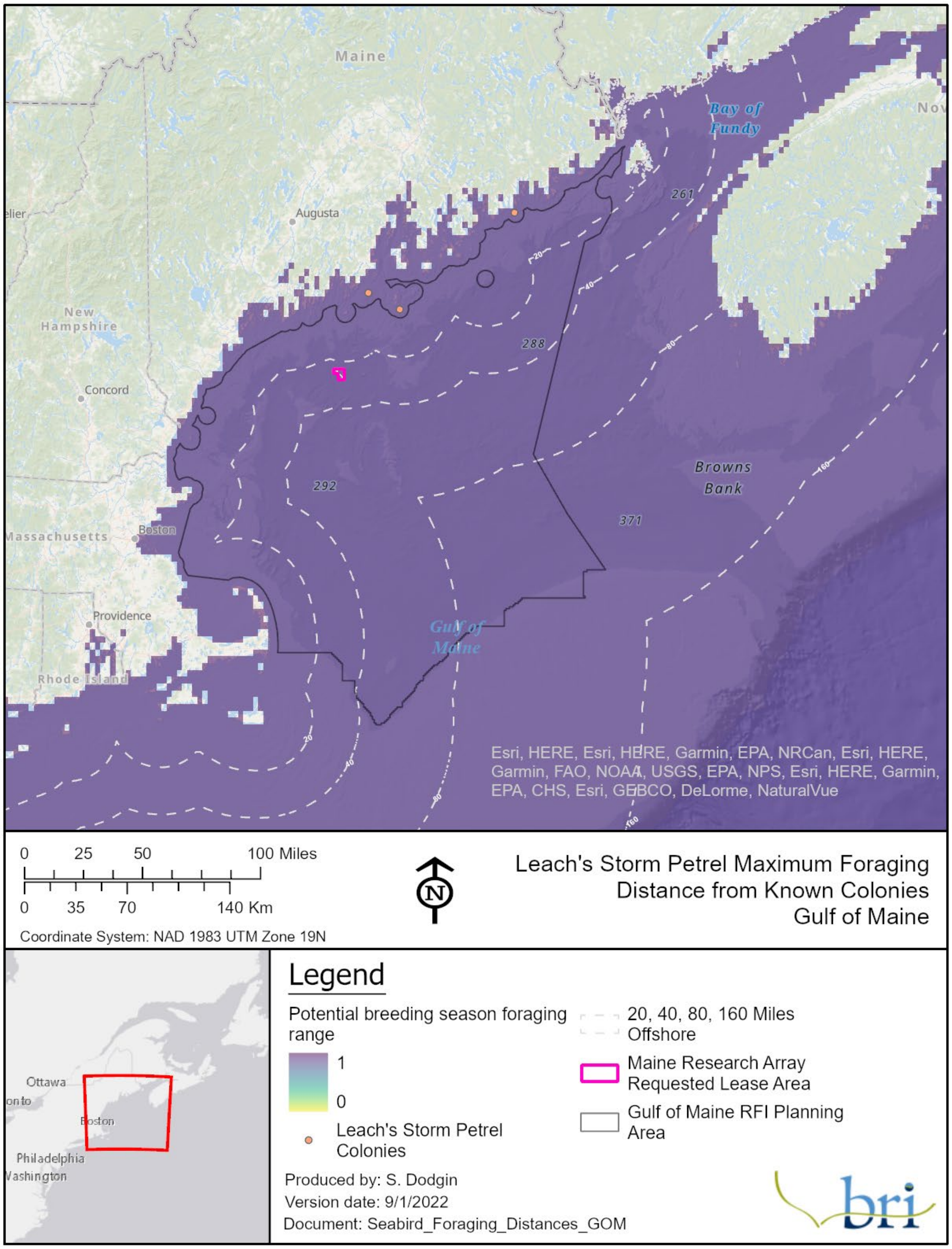

Figure 20. Foraging areas of importance for nesting Leach's storm petrel built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

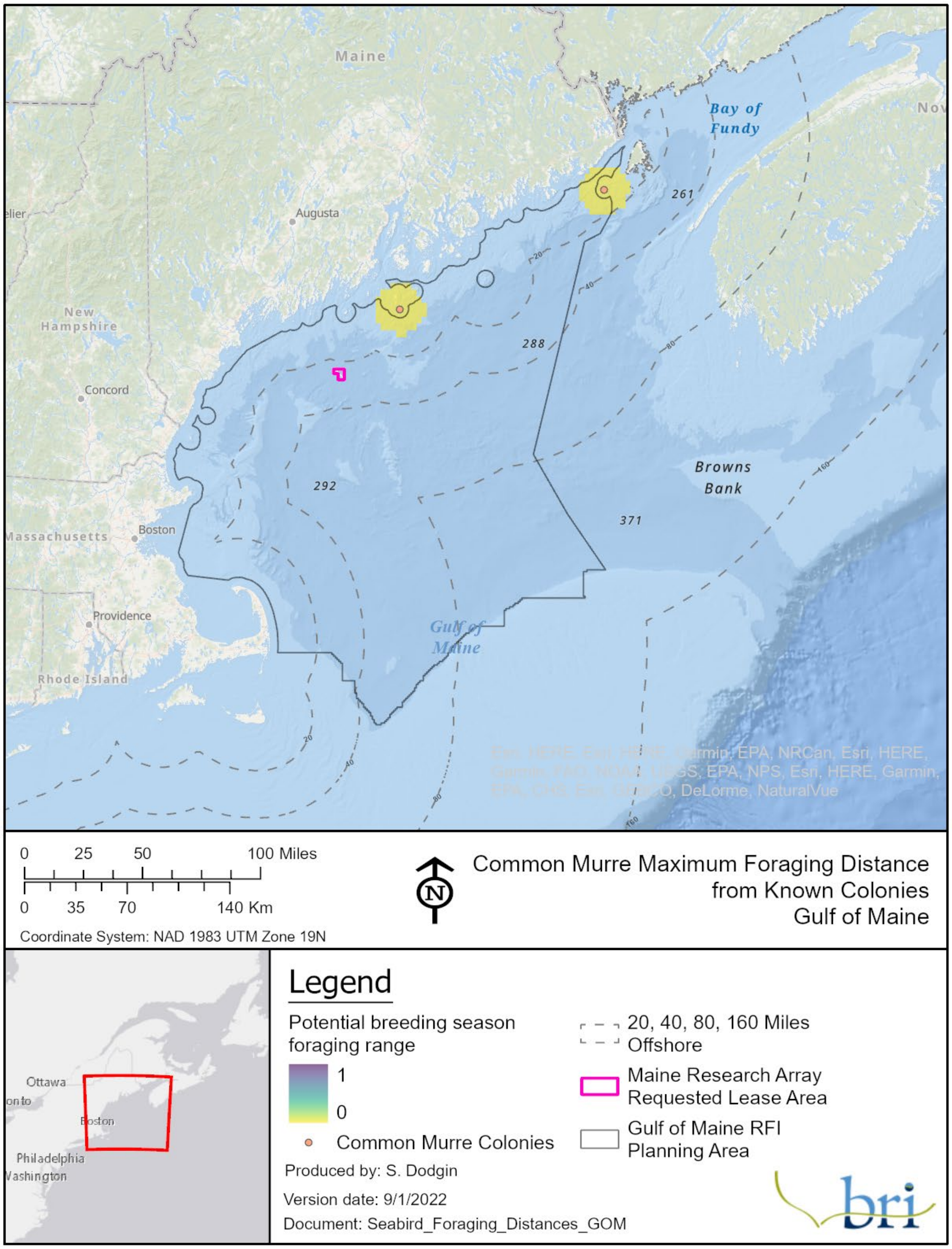

Figure 21. Foraging areas of importance for nesting Common Murres built using the maximum foraging distance for each species, weighted by the relative species-specific colony census counts.

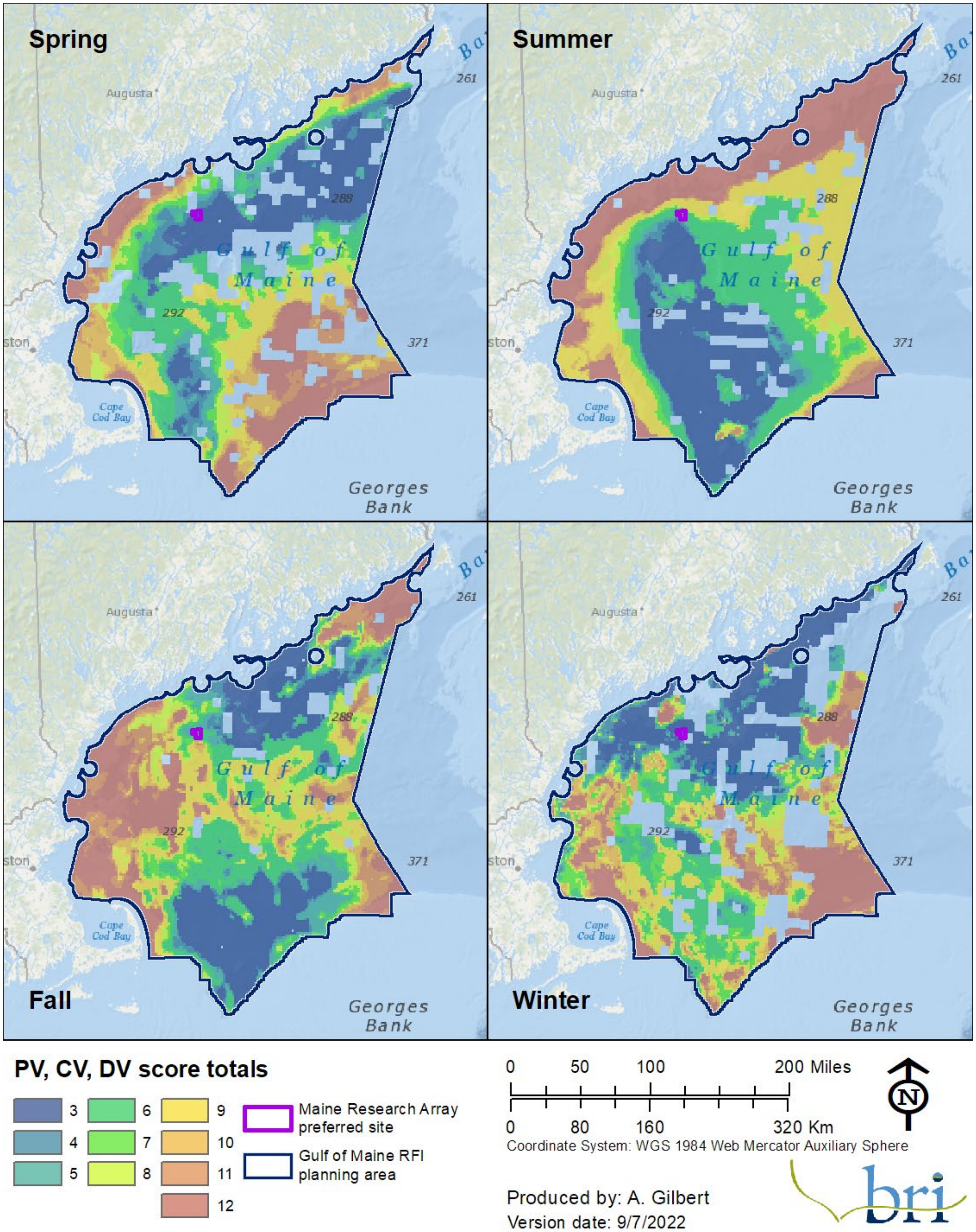

Figure 22. MDAT models weighted by population, collision, and displacement vulnerability for each season: spring, summer, fall, and winter. The Gulf of Maine RFI is indicated in orange and the preferred site for the research array is indicated in purple.

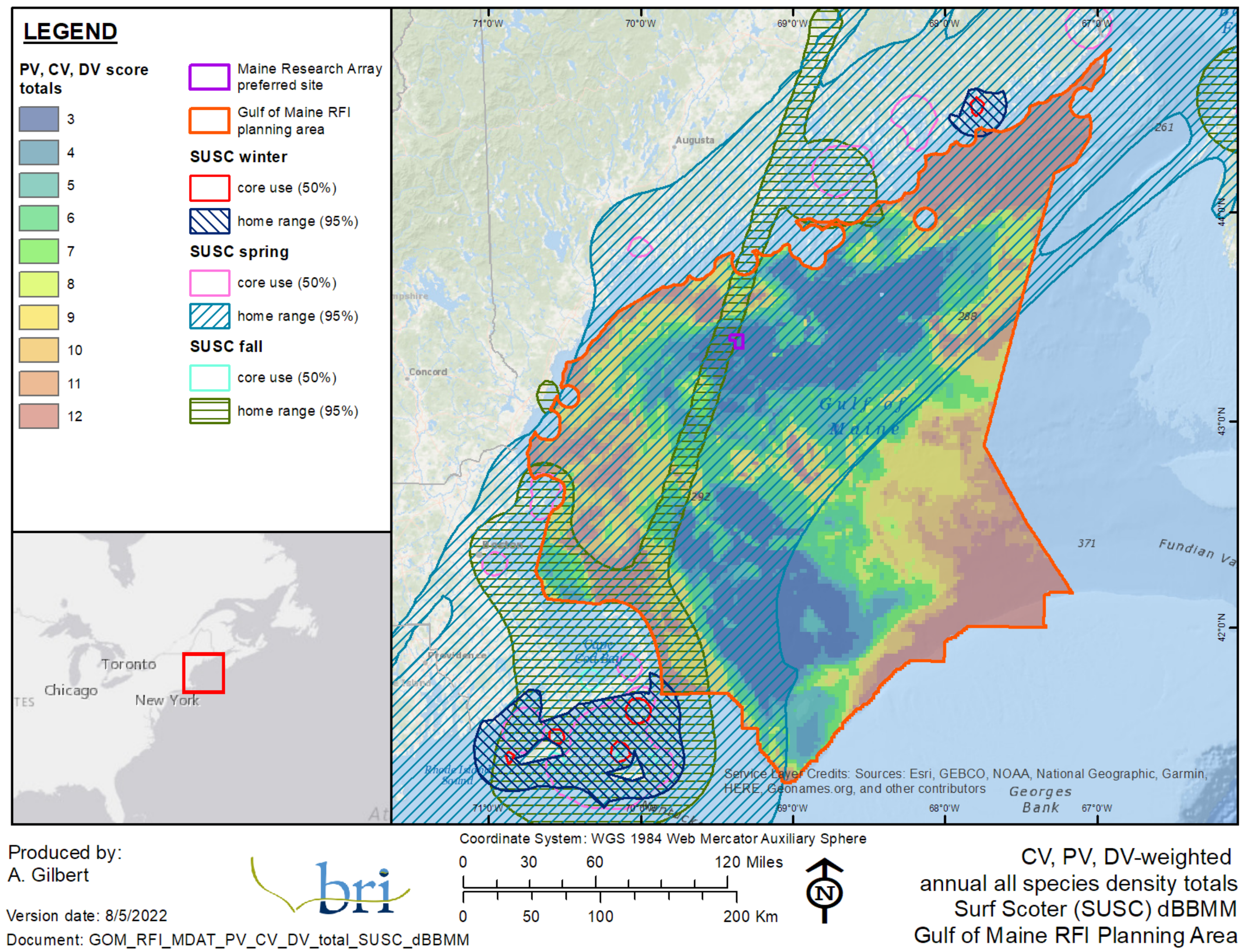

Figure 23. MDAT models weighted by population, collision, and displacement vulnerability with Surf Scoter core use (50%) and home range (95%) habitat indicated by season. The Gulf of Maine RFI is indicated in orange and the preferred site for the research array is indicated in purple. Note: the model was derived from individuals tagged in the mid-Atlantic and do not necessarily represent habitat use of individuals that reside in the Gulf of Maine region.

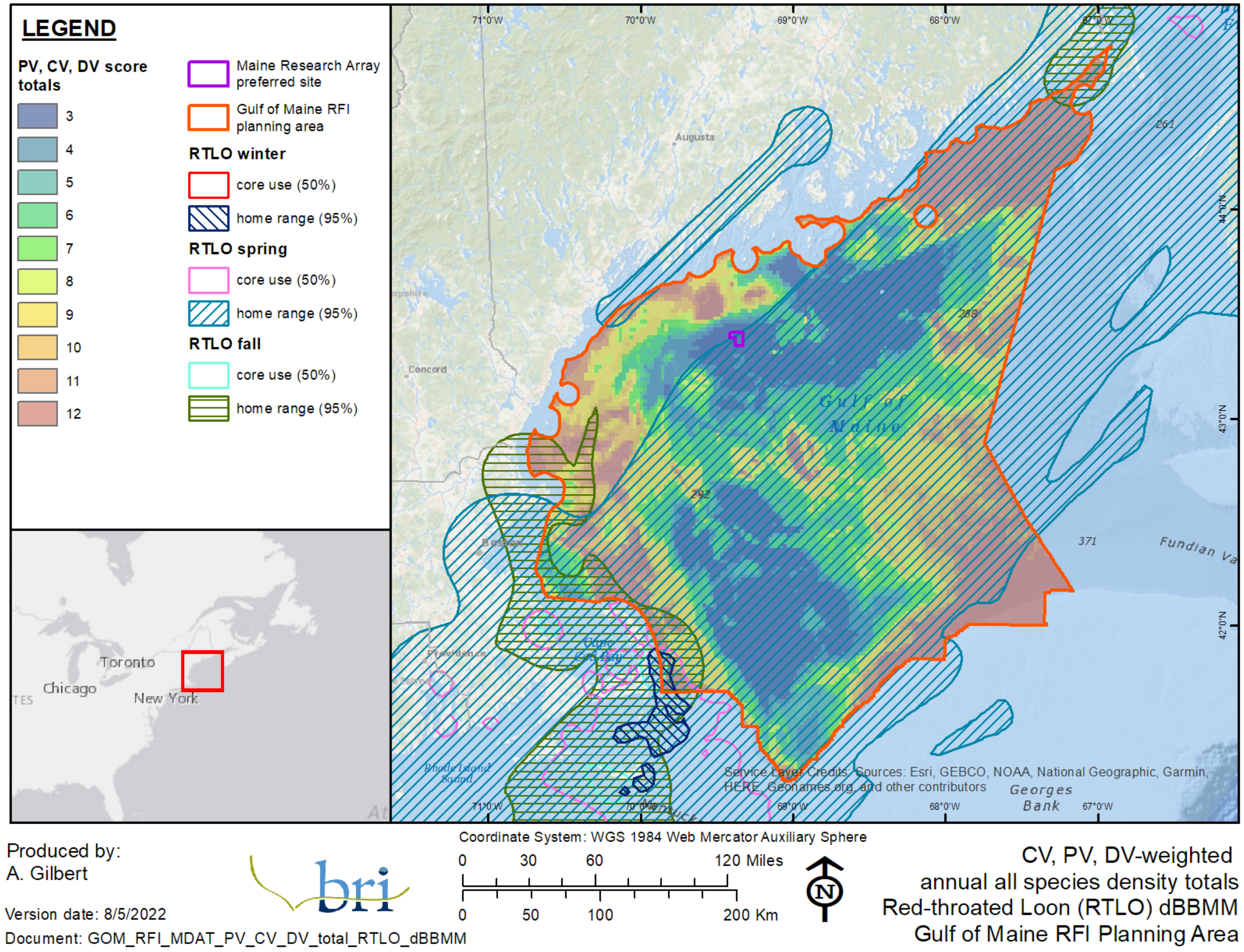

Figure 24. MDAT models weighted by population, collision, and displacement vulnerability with Red-throated Loon core use (50%) and home range (95%) habitat indicated by season. The Gulf of Maine RFI is indicated in orange and the preferred site for the research array is indicated in purple. Note: the model was derived from individuals tagged in the mid-Atlantic and do not necessarily represent habitat use of individuals that reside in the Gulf of Maine region.

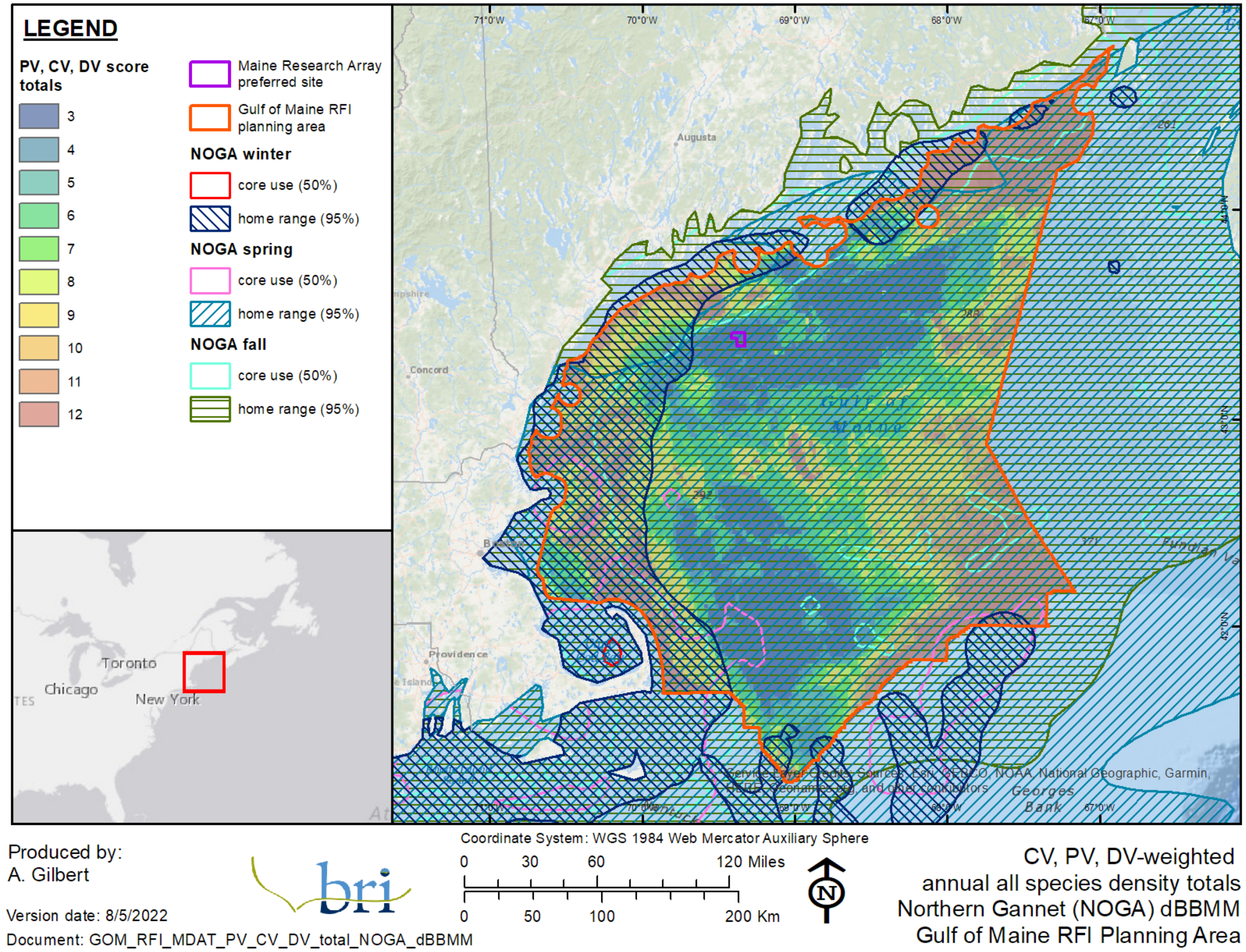

Figure 25. MDAT models weighted by population, collision, and displacement vulnerability with Northern Gannet core use (50%) and home range (95%) habitat indicated by season. The Gulf of Maine RFI is indicated in orange and the preferred site for the research array is indicated in purple. Note: the model was derived from individuals tagged in the mid-Atlantic and do not necessarily represent habitat use of individuals that reside in the Gulf of Maine region.

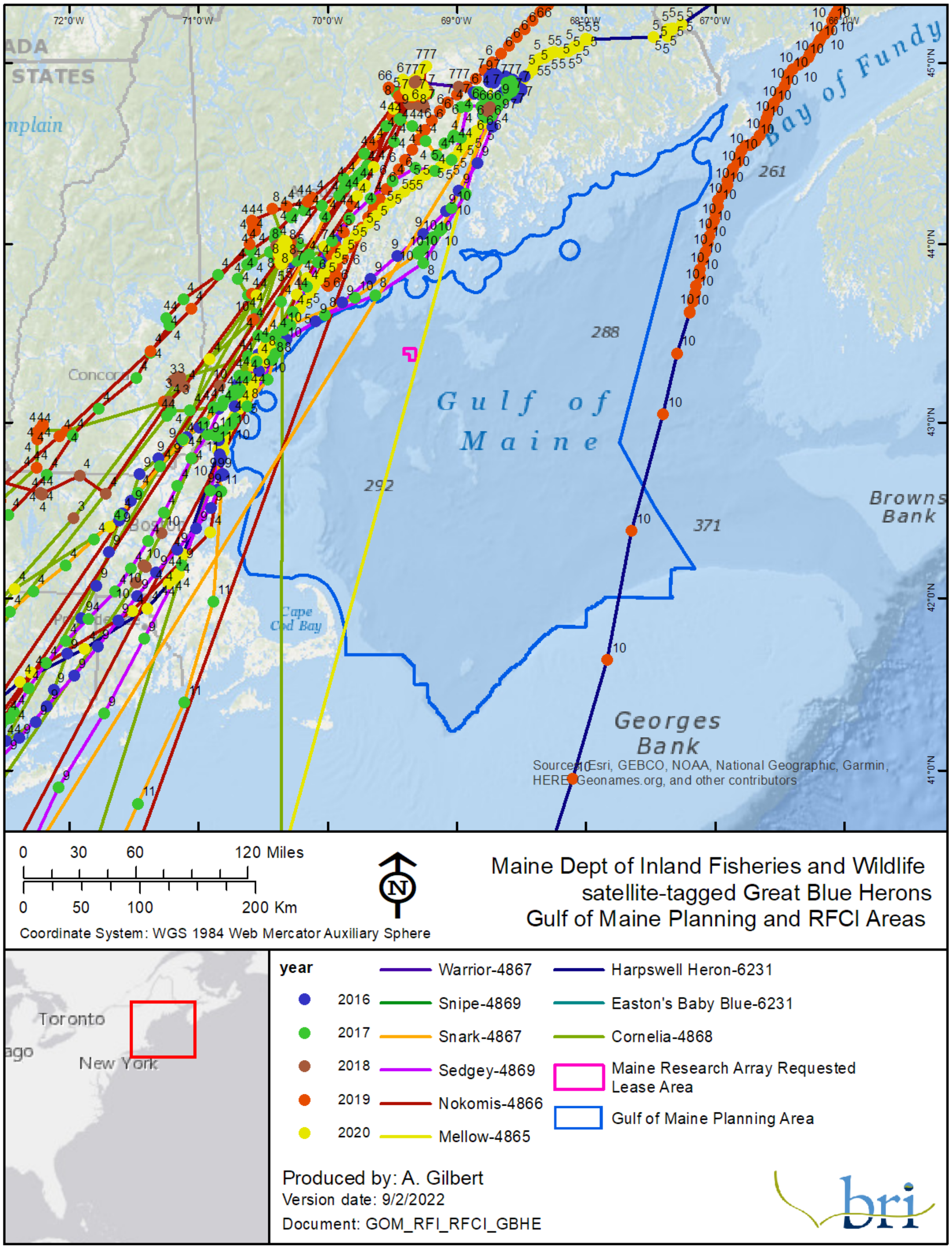

Figure 26. Great Blue Heron individuals (n=9) satellite tagged between 2016 and 2020. Line colors indicate individuals and point colors indicate year of tag. Numbers indicate the month of year of location transmission (i.e. "10" represents October). Since 2016, the Maine Department of Inland Fisheries and Wildlife (MDIFW) has been capturing Great Blue Herons each year in Maine and tracking their migrations with solar GPS satellite transmitters. The full dataset is available in the Movebank repository (https://movebank.org/)

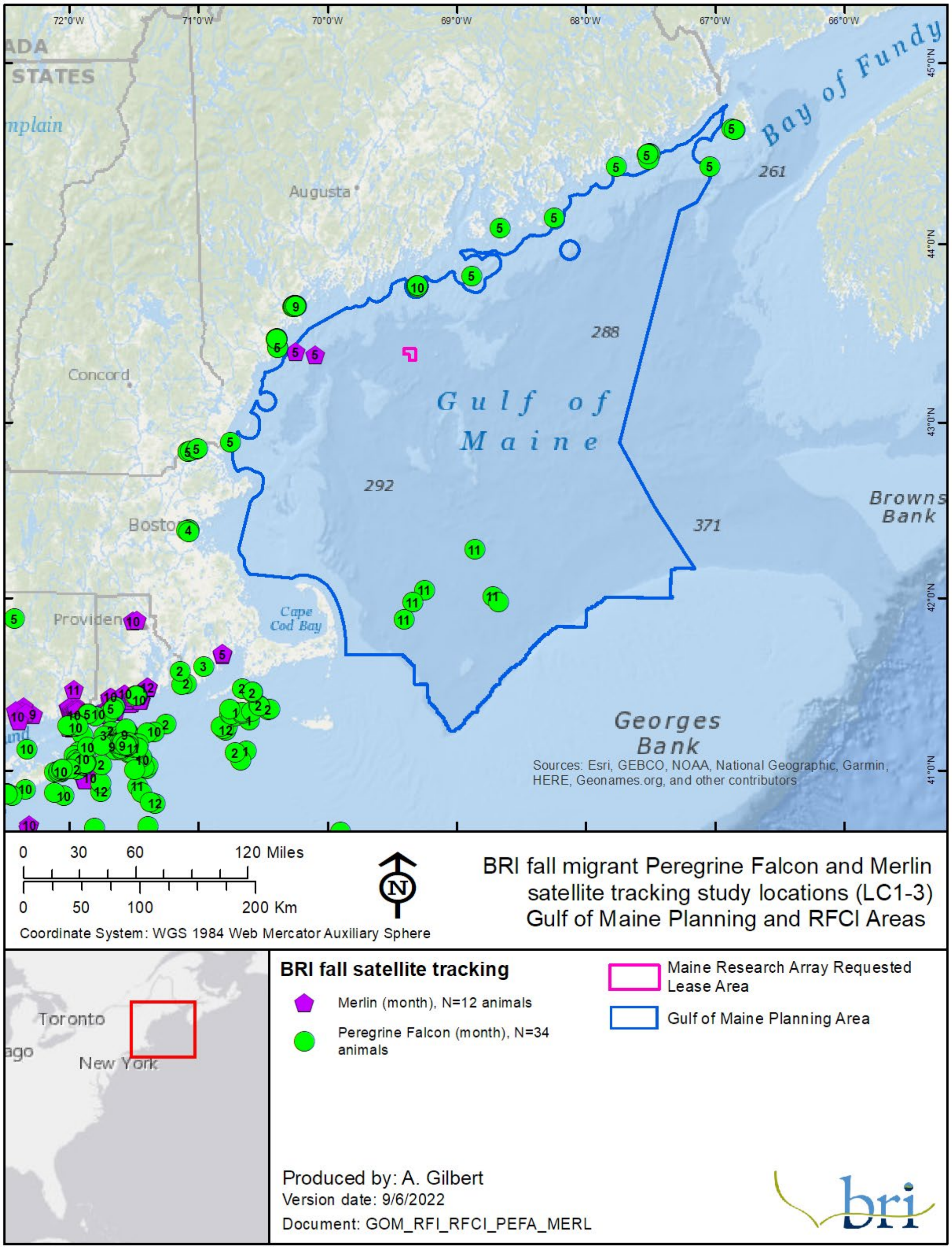

Figure 27. Fall migrant Peregrine Falcon and Merlin satellite tracking locations tagged at the Block Island Raptor Research Station at Block Island, Rhode Island; Monhegan Island, Maine; and Cutler, Maine. A total of 12 Merlins were tagged and 34 Peregrine Falcons were tagged. The month of transmission is indicated by the associated number for each transmission location.

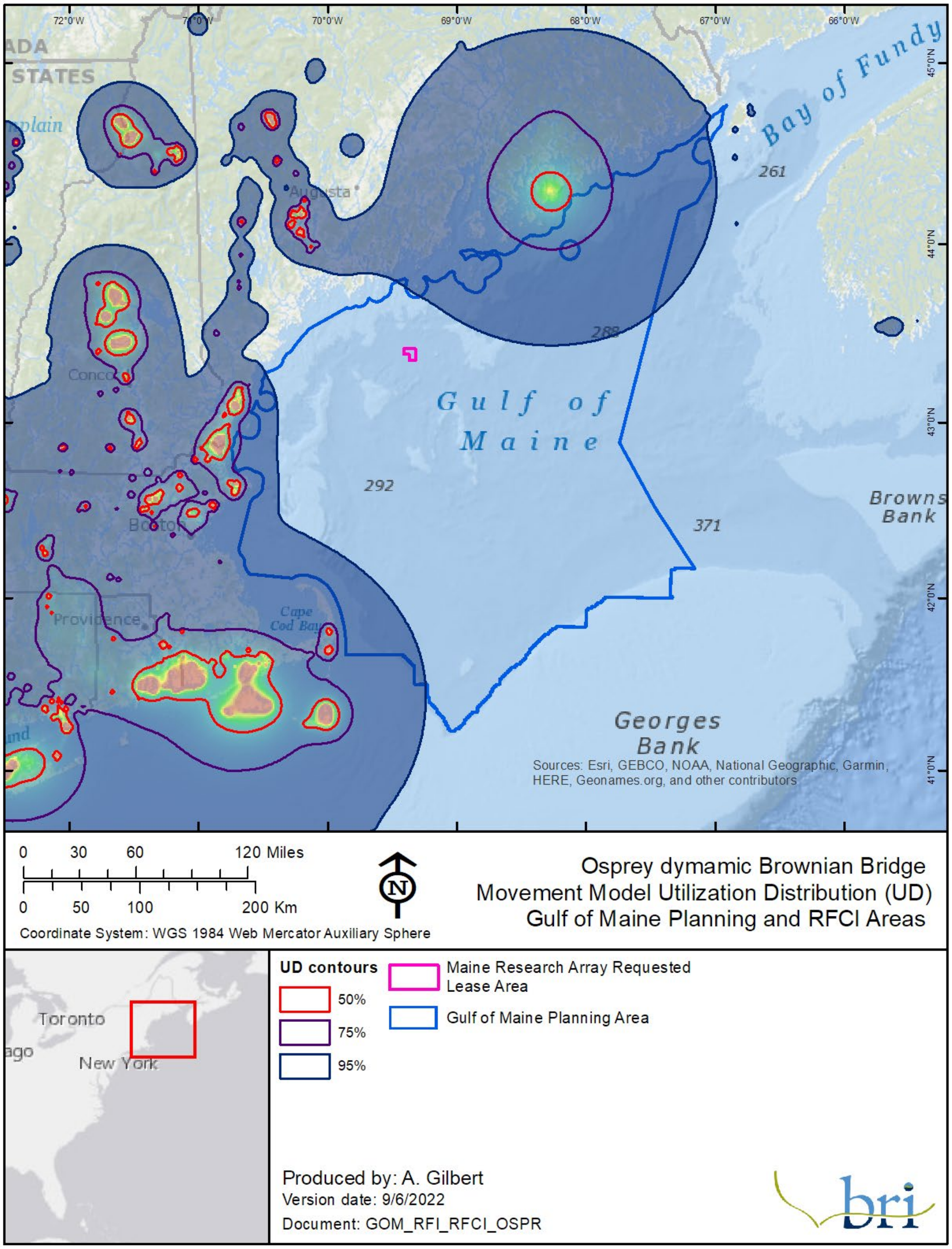

Figure 28. Osprey dynamic Brownian Bridge Movement Model utilization distributions for the Gulf of Maine planning area. Core habitat (red) and home range (blue shading) for Ospreys tagged between Chesapeake Bay and Northern New Hampshire. Note: no individuals were tagged in the GOM for this analysis.

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