ASSESSMENT OF SPATIAL OVERLAP OF FIXED FISHING GEAR AND RIGHT WHALES, *EUBALAENA GLACIALIS*, IN THE GULF OF MAINE

by

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Abstract

Right whale, *Eubalaena glacialis*, entanglement in fixed fishing gear remains one of the most crucial threats to the survival of the species today. Aerial surveys conducted by the National Marine Fisheries Service (NMFS) from 2002-2005 from the Gulf of Maine to the New York Bight recorded sighting events of right whales as well as fixed fishing gear buoys. These data were used to assess the presence or absence of spatial overlap between right whale sightings and fixed gear sightings to provide locations where whales most likely are encountering gear within the survey area. Preliminary results show persistent between-year overlap in spring, and within-year overlap in the summer, fall, and winter. This is the first study to utilize NMFS sightings of both right whales and fixed fishing gear. The resulting interaction zones can inform managers and possibly identify important areas for entanglement mitigation such as time area closures.

Introduction

The North Atlantic right whale, *Eubaleana glacialis*, (herein right whale) is a large baleen whale with adults averaging as much as 70 tons, and lengths up to 55 feet (NMFS 2005). First described by Otto Friedrich Müller in 1776 (Müller 1776), right whales were the first species of large whale hunted intensely by a predominantly Basque whaling fleet beginning in the sixteenth century (Aguilar 1986).

The Norwegians described intermittent takes of right whales from 1889 until as late as 1908 (Collett 1909). These “Nordkapers” (ice whales) were described as “fond of lying quietly on the surface of the water”, and, “on the whole easy to approach”. This unfortunate combination earned the whale its name, and by the early 19th century the population was in probable decline. Indeed, by 1820, renowned author and Captain W. Scoresby Jr. provided no mention, nor apparently even knew of, the animal (Wakeham 1914). The U.S. exploitation of North Atlantic right whales continued until the Convention for the Regulation of Whaling took effect in 1935, prohibiting harvest of right whales (NMFS 2005). Today, after 72 years of protection from whaling, the right whale shows no signs of recovery. Historic population estimates vary widely, with Gaskin (1991) giving a range of 12,000 to 15,000 individual animals. By the early 20th century, the population may have numbered as few as 50 animals (Reeves et al. 1994). The population estimate in 1994 was 295 individuals (Knowlton et al. 1994), with the International Whaling Commission supporting an estimate of 300 individuals in 2001 (Kraus et al. 2001). The most recent estimates range between 179 and 591 right whales (Moore 2006). Recent population assessments based on photographic identification of individual animals suggests a population decline of 2.4% (Caswell et al. 1999).

One of the two main factors impeding the recovery of the North Atlantic right whale is entanglement in fixed fishing gear (the other being collision with large ships). Seventeen years ago, scientists estimated that 57 percent of right whales exhibited evidence of an encounter with fishing gear, in the form of marks or actual gear (NMFS 2005). Nine years ago the estimate was revised to 62 percent of the population (Hamilton et al. 1998). Thus, two-thirds of this remnant population has been entangled at one time or another. The primary sources of entanglement are lobster pots and gillnets (Johnson et al. 2005). Entanglement is a relatively small contributor to known right whale mortality, estimated at 7 percent between 1970-1993 (Kenney & Kraus 1993). However, this figure only accounts for known mortality due to entanglement. Research indicates that many whales entangled in gear may die, and thus sink with the gear, without any detection (Kenney & Kraus 1993). Additionally, the behavior of entangled whales may be significantly altered. Entangled (or recently entangled) whales whale may be more susceptible to *other* causes of death, lending indirectly to the demise of the whale (either through difficultly foraging, susceptibility to infection from wounds left by the gear, etc.). Overall, entanglement is a serious conservation concern, reducing life spans and depressing population growth. Given the large amount of lobster pot and gillnet gear present in whale habitat in the Gulf of Maine, in 1994 the Federal Government through the National Marine Fisheries Service (NMFS) began to take action to reduce gear interactions.

Current regulations

NMFS classifies all commercial fisheries according to their potential to cause serious injury or incidental mortality to marine mammals using a three tiered system.

In 1997, after reviewing evidence of fishery entanglements, NMFS changed the classification of the Gulf of Maine and Mid-Atlantic lobster pot fisheries from Category III (fisheries with a small likelihood of incidental mortality and serious injury), to Category I (fisheries with a high likelihood of incidental mortality and serious injury, Appendix I).

As stated in the NMFS recovery plan for the North Atlantic right whale, "The ESA provides authority to the Secretary of Commerce for protecting most endangered marine species, including right whales. The National Marine Fisheries Service *has lead responsibility for developing and implementing a recovery program for this species*" (emphasis added, NMFS 2005). In addition to this, the Marine Mammal Protection Act (herein MMPA) explicitly states, "[Marine mammals] should not be permitted to diminish below their optimum sustainable population (MMPA 1972). Furthermore, the MMPA describes protections for "strategic stocks" of marine mammals, including right whales. These stocks are populations of marine mammals for which human-caused mortality exceeds the potential biological removal level (PBR, or the level beyond which mortalities begin to adversely affect the population), which has been set at zero for right whales (Waring et al. 2006).

Pursuant to Section 118 of the MMPA, Take Reduction Teams were established by NMFS to address fisheries takes of strategic stocks of marine mammals, including threatened and endangered species (MMPA 1994). Each Team's goal is to establish a Take Reduction Plan that within six months will reduce serious injury and mortality of marine mammals to a level below PBR, and in the longer term to a number approaching zero (MMPA 1972).

Due to interactions with four fisheries (Gulf of Maine/mid-Atlantic lobster pot, mid-Atlantic coastal gillnet, mid-Atlantic shark gillnet, and Gulf of Maine sink gillnet), and in accordance with the 1994 amendments to the MMPA, NMFS formed the Atlantic Large Whale Take Reduction Team (herein ALWTRT) in 1996 to address the incidental serious injury and mortality of three endangered species of whale: North Atlantic right whales, fin whales *(Balaenoptera physalus*), and humpback whales (*Megaptera novaeangliae,* NMFS 2005). An incomplete plan was forwarded to NMFS for review in early 1997. After consideration of the Team's recommendations, in April 1997 NMFS implemented eight specific provisions:

(1) Formation of a gear advisory group

(2) Research on potential fishing gear modifications to reduce entanglement

(3) A fisherman outreach and education program

(4) Expansion of the disentanglement network

(5) Hiring a large whale coordinator in Maine

(6) Continuation and refinement of the Northeast aircraft survey program

(7) Time/area closures

(8) Time/area specifics restrictions on gear deployment

Although the implementation of these provisions represented a major initiative by NMFS and the ALWTRT, the rate of entanglements did not decrease appreciably, and in 2000 the Humane Society of the United States (HSUS) sued NMFS for not adequately protecting right whales. The lawsuit stated that NMFS "[must] make immediate and substantive moves to protect the North Atlantic right whale from deaths and injuries that threaten the species' survival" (Right Whale News 2000).

The suit demanded, among other things, gear modification through research and development, restriction or closure of critical habitat, and a convening of a ship strike committee. In response, in January 2002, NMFS published three rules underlining the issues highlighted in the lawsuit: (1) to further modify fishing gear; (2) establish restricted areas based on predictable aggregations of right whales; (3) establish a system to restrict fishing in areas where unexpected aggregations of right whales are observed (NMFS 2005).

Protection zones, in which fishing is restricted to the use of modified gear, began in 1994 with the establishment of the Great South Channel Critical Habitat Area (GSC), and the Cape Cod Bay Critical Habitat area (CCB). The CHA and CCB were based on knowledge of right whale occurrences off New England (Hamilton & Mayo 1990), and were the first two management areas in the right whale's northern habitat to be established (Fig. 1, NMFS 2005). The CCB management area is active from January 1 – May 15, while the GSC is active from April 1 – July 31 (Federal Register 67, 2002). Seasonal Area Management (SAM) areas East and West were added (in response to rule 2, above) in 2002 and restricted gear deployment in areas of predictable northern right whale habitat. SAM west is active from March 1 through April 30, and SAM east is active from May 1 through July 31 (Fig. 1, Federal Register 67, 2002). Finally, Dynamic Area Management zones (DAMs) were added (also in 2002) in response to rule 3. DAM zones are triggered by a report of three or more right whales within an area of 75-nm^2 or less, and are approximately 30-km^2 in area (example, Fig. 2, Clapham and Pace 2001). DAMs restrict gear in the same manner as the SAMs, and any DAM zone remains in effect for a minimum period of

15 days or longer if it is shown that the aggregation persists (Federal Register 67, 2002).

Overall, however, current management measures have been ineffective in reducing the frequency of right whale entanglement. Thus, the present study examines direct co-occurrences of fishing gear and right whales (dealing with provision 2, above), highlighting spatial and temporal overlap between fisheries and right whales in the Gulf of Maine. By identifying areas of overlap, this study will provide the National Marine Fisheries Service with information on where encounters occur, and at a higher spatial and temporal resolution than has previously been possible. The areas identified as highly overlapping warrant intense consideration of stricter controls on which gears can be fished, or an outright moratorium on the use of fixed fishing gear in the overlapping zones.

Profile of the Gulf of Maine

The Gulf of Maine is a partially enclosed shallow oceanic basin whose landward side is defined by the slope of the North American coastline and seaward by submarine banks (Figs. 3, 4, Brooks 1994). The Gulf consists of three main nearshore basins: George's Basin, Jordan Basin, and Wilkinson Basin. The Gulf of Maine features strong tidal currents and a generally counterclockwise gyre throughout the basin (Brooks 1985). Inflow of oceanic waters enter the Gulf in the Northeast Channel, minimally in spring and peaking in early summer (Ramp et al. 1985). Basins inside the Gulf collect this denser ocean water, where it contributes to upper-trophic gyres in George's and Jordan Basins (Brooks 1985). Wilkinson Basin exhibits a southwestward flow (Vermersch & Beardsley 1979), and in years with higher than average fresh water influx from rivers and runoff, the Jordan Basin gyre may weaken or reverse (Brown & Irish 1992). Summer winds from the southwest produce upwelling across the Gulf of Maine, and denser, saltier waters will typically flow into adjoining basins (Brooks 1987). Summer months exhibit a three tier structure in which fresh water runoff forms at the surface, with a colder, thicker layer below, and the Maine "bottom water", a year-round layer of saltier and denser waters, at the benthos (Brooks 1985). Water exits predominantly along the northern edges of George's Bank, and secondly through the Great South Channel (Brooks 1985). The combination of turbulent mixing within the Gulf of Maine had yielded, up until the past few decades, one of the most productive fisheries in the world (Pauly & Maclean 2003).

Profile of the U.S. lobster industry

Correia et al. (2006) divided the management of lobsters in the western Atlantic into three geographic subunits based on distribution and abundance: the Gulf of Maine, George's Bank, and Southern New England. This study will focus on the Gulf of Maine and George's Bank fisheries. The largest portion of landings (74% from 1981 to 2003) come from the Gulf of Maine. Southern New England reported 21% of landings from the same time frame, and the George's Bank fishery reported 5% (Correia et al. 2006). Correia et al. (2006) describe the bulk of the Gulf of Maine fishery landings as comprised of inshore (herein referred to as the inshore fishery), while George's Bank fishing effort as mainly offshore (herein referred to as the offshore fishery). Permitting for lobsters has remained relatively steady over the 23 years of data reported, with a median of 11,884 permit holders (Correia et al. 2006). In recent years, technological advances in RADAR, SONAR, GPS, and boat design have resulted in a substantial increase in fishing efficiency (Miller 1995). Inshore traps are typically fished with a single buoy attached to one or two traps, termed fishing a single or single double, or in a trawl, where between six and ten traps are fished on a single line (Figs. 5, 6, Anderson & Anderson 1999). Offshore strings of up to 40 traps are not uncommon (Bisack 2003).

The inshore lobster fishery predominantly consists of smaller, day-trip vessels from Maine, Massachusetts, and New Hampshire (Correia et al. 2006). The number of traps fished in inshore waters has increased from approximately 2.4 million traps in 1982 to 3.6 million traps in 2003 with an average of 2.3 million traps (Fig. 7).

The offshore fishery is composed mainly of fishermen from Massachusetts and Rhode Island. The fleet is comprised of larger vessels than the inshore fishery, typically making multi-day trips (Correia et al. 2006). A policy of voluntary reporting, as well as poor resolution of reports received has lead to inaccurate estimates of offshore fishing effort (Correia et al. 2006). Correia et al. (2006) used Massachusetts effort data as an index of offshore fishing effort, finding an average of 44,000 traps fished in 2006 (Fig. 8).

Profile of the U.S. gillnet industry

The Northeast multispecies sink, or bottom-tended, gillnet fishery extends from Maine to North Carolina. Gillnet gear typically fished in the Gulf of Maine is composed of monofilament mesh suspended between a floating line (the head rope) and a sinking line (Fig. 9, Waring et al. 1996). Gillnets are fished in groups in which as many as 12 nets are strung together, stretching from 600 feet to 2 miles (Waring et al. 2005). Each net is typically three hundred feet in length by eleven feet in height. In 2002, there were 361 fishermen with active permits (Waring et al. 2005).

Target species include Pollock (*Pollachius vivrens*), cod (*Gadus morhua*), flatfish (order *Pleuronectiformes*), and monkfish (genus *Lophius*, Waring et al. 1996).

Methods and materials

From 1998 to the present, aerial surveys for right whales have been conducted by the Northeast Fisheries Science Center in Woods Hole, Massachusetts. The purpose of these surveys is to locate right whales within the Gulf of Maine (Fig. 10), and subsequently alert ships to right whale locations. Surveys were conducted from a double observer platform (Fig. 11). Approximately 243,000 kilometers of trackline, resulting in 845 right whale sighting events, were surveyed from 2002-2005. In addition, locations of generalized “fixed gear unspecified” were also noted. In total, 1066 individual fishing gear sighting events were recorded. The years 2002-2005 were selected for analysis based on data completeness and overall integrity (Cole 2005).

While on survey, whale locations were recorded at their exact positions using a software system linked to a GPS unit aboard the aircraft, along with environmental conditions such as glare, cloud cover, Beaufort Sea State, and the overall quality of the survey conditions. Johnson et al. (2005) found that any fishing line in the water column poses a risk of entanglement, so identification to gear type (i.e. trap or gillnet) was not attempted. Fixed gear sightings were aggregated based on the amount of gear observed into three qualitative groupings: *sparse*, *moderate*, and *dense*. In general, *sparse* indicated singular or occasional pieces of gear seen along a transect; *moderate* indicated more-or-less regular observations of fishing gear, and *dense* indicated constant gear sightings such that a count of the individual pieces would be impractical. To calculate the magnitude of fixed gear sighted, these qualitative values were assigned quantitative relative density values of 1, 2, and 3 respectively.

Gear sightings data, right whale sightings data, and comprehensive information on survey effort were then tabularized and graphed by season/year and by season (i.e. spring 2002, 2003, etc. as well as just "spring") and imported into ArcGIS 9.0 as shapefiles. All files were aggregated into 5-km, 15-km and 30-km grid cells using *Hawth's tools* polygon in polygon analysis function for the whale and gear files (point files), and the sum line lengths in polygons function for the trackline data (line file). The 5-km grid cells were chosen based on the Effective Strip Width (ESW) of the aerial surveys as determined by use of the *Distance* 5.0 software system. The probability of detection for a right whale degraded to below 50% at 2.8-km for one side of the platform, or roughly 5-km from both sides of the platform, which is the standard by which ESW is evaluated (Buckland et al. 2001). The probability of detection did not change when multiple covariate distance sampling techniques including the environmental conditions listed above were used (Figs. 12-15). During aggregation events, it is thought that right whales will, in general, stay within a rough 30-km area for at least two weeks. This cell size, therefore, provides adequate protection for right whales within those two weeks (Clapham & Pace 2001), and was chosen as a candidate resolution for analysis. 15-km grid cells were chosen as an intermediate size. After initial examination, 30-km grid cells were selected as an appropriate resolution to continue the analysis because the resolution provides a robust generalization of the gear sighted (the 5-km and 15-km gear sightings aggregated well into the 30-km), as well and incorporating likely whale movements over extended periods of time.

Files were then converted to raster grids of the same dimensions, and both the whale sighting data and the gear sighting data were divided by the trackline data files to reflect relative effort (gear/km surveyed, whales/km surveyed). These effort corrected files were then filtered to find cells that contained both gear and whale sightings. The gear data in this study used presents itself in a manner that can be easily misunderstood. The number recorded in a cell is not the number of individual pieces of gear sighted. It is an index, as mentioned above, summing the amount of "sparse", "moderate", and "dense" gears sighted. The numbers shown on Figs. 16-33 is this number divided by number of kilometers of trackline flown.

Results

33 of 4060 cells (.81%) contained both fishing gear and right whales during the four year time frame.

Overlap occurred during the spring in all four years (Figs. 16-19, overview, Fig. 20). Some of these overlaps were found in only one year (indicated by the green cells in Fig. 20), while others were persistent through two years (indicated by the yellow cells in Fig. 20). In one cell, persistent multi-year overlap occurred in three of the four years studied (indicated by the red cell in Fig. 20).

Areas of overlap occurred less frequently in summer, with a total of six identified, and no persistent multi-year overlaps (Figs. 21-24 overview, Fig. 25). Fall contained the least overlap (Figs. 26-29, overview, Fig. 30).

Surveys during the winter months have only recently been conducted, with 2004 and 2005 marking the first years of year-round coverage of the study area (overview, Fig. 33). Winter 2004 contained one overlap (Fig. 31). Winter 2005 indicated four overlaps (Fig. 32).

Rates for whale sightings/km averaged .03669/km over all seasons, and gear density/km averaged .01062/km over all seasons. Fig. 34 highlights the average relationship from season to season throughout the four year time frame. Right whale sightings decreased from spring to summer, while fixed gear sightings increased. From summer to fall, both right whale sightings and fixed gear sightings decreased at roughly the same rate, and from fall to winter, both right whale and fixed gear sightings increased, though fixed gear sightings increased at a higher rate.

Discussion

There were few areas of consistent overlap between fixed fishing gear and right whales in the survey area. Overlapping areas were uncommon in summer, fall, and winter, and individual cell overlaps did not occur more than once from year to year. The offshore fishery (George's Bank) in the spring presents the most striking example of overlap, with one area in particular exhibiting right whale/gear overlap in three out of the last four years. This area is surrounded by zones where overlap occurred less frequently, but in two cases occurred twice in the same area in different years (yellow cells in Fig. 20). This suggests that although there is only one three-year overlap, an addition of more data may reveal more co-occurrence. It should be noted that from 2002 to 2005, the number of total gear sightings increased. This is probably due to increasingly robust data collection and spatial coverage within the SAS team's survey methods, rather than an increase in fishing effort.

Variation in overlap during the year can be explained in part by the seasonal migration of right whales. Generally speaking, during the spring months, right whales are found south of Cape Cod in the vicinity of the Great South Channel (Fig. 35). In the summer right whales occur north into the Bay of Fundy, and east into Canadian waters (Fig. 36). In autumn right whales are typically found north of Cape Cod in the Gulf of Maine (Fig. 37). Winter months were surveyed for the first times in 2004 and 2005, and thus any conclusions drawn from these data must be tentative, but data suggest that during this time right whales can be found in and around Cape Cod Bay (Fig. 38).

To address which fisheries might be affected by restriction of fishing effort in areas of persistent overlap, a review of Massachusetts lobster fishing records was performed. From 2001 to 2004, there was little fishing in January, February, and March (Figs. 39-42, Dean et al. 2002, 2004, 2005, 2006), contributing a per year average of 1.6% to the total pounds of lobster landed. Additionally, the area of persistent overlap (Fig. 47) lies within statistical reporting area 18. Area 18 contributes only a small percentage to the total poundage of lobster taken in the Gulf of Maine (Figs. 43-46), at an average of 3% per year. If fishing efforts were reduced within area 18, and more specifically in the areas identified as overlapping, the economic effect would be negligible to the lobster industry as a whole, as well as facilitate an immediate reduction in the likelihood of entanglement.

Conclusion

There are only between 179 and 591 north Atlantic right whales remaining (Moore 2006). While the problem of shipstrike is the focus of much current management (NOAA 2006), entanglement remains a daunting problem. Disentanglement teams do not address the heart of the issue; they are a solution to a symptom, not the problem, as it were. As long as there is not sufficient willpower in both NMFS as well as the federal and state legislatures to address entanglement directly, it will continue to threaten the right whale. It is NMFS' responsibility to conserve and rehabilitate the right whale, and although the agency is addressing some problems, gear continues to pose an unabated threat. A closure or severe curtailment of fishing in areas demonstrating right whale/fixed gear overlap *year* after *year* after *year* (red area in Fig. 20) may be a first step in addressing gear entanglement. It is evident from this study that both fixed fishing gear as well as right whales are present during the spring in the same zone of the Great South Channel. Although the area itself covers 900 square miles of ocean, this zone represents a very small portion of the lobster fishing grounds. Lobster are not fished heavily during the months of most overlap, and additionally, only a small percentage of all lobster caught are caught within the proposed closure area. A closure of the red zone identified in Fig. 20 would ensure that there is no chance of entanglement with relatively little economic harm to the lobster industry as a whole. Alternatively, restricting the area to experimental fishing gear may also be feasible, if the area is designated for research of alternative fishing gears, such as pop-up buoys, break-away links, and lines or nets that degrade with time. Whatever the type of gear, it must be proven whale safe before deployment. Ultimately, the issue is one of political will. As with all things environmental, a focusing event may be needed before the issue of entanglement of all endangered whales is taken seriously. It would do the environment, as well as the Nation, a great disservice only to see the right whale as a shining example of what *not* to do.

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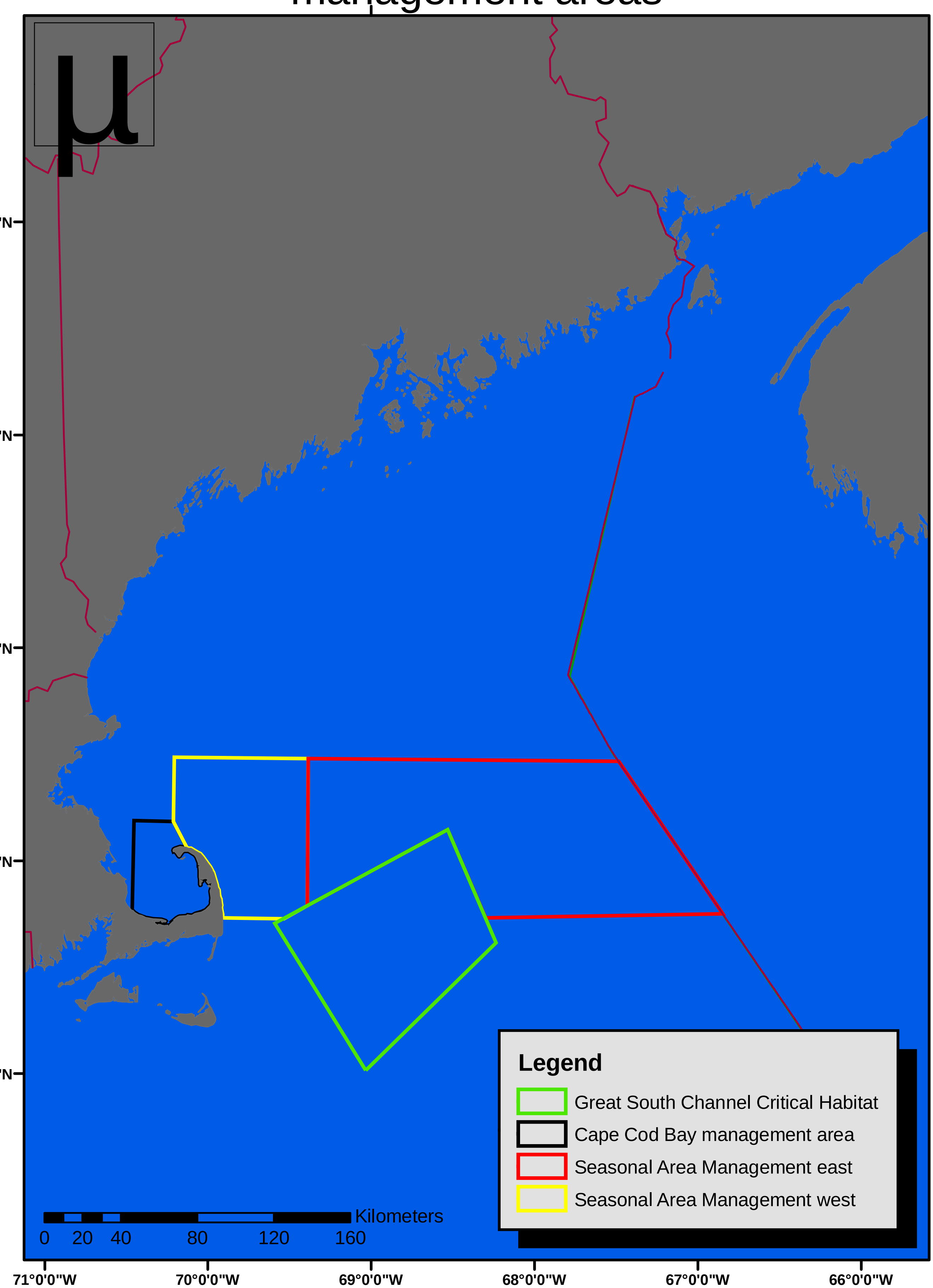
Appendix 1: fishery categories (quoted from NMFS 2005 at IH-4)

Category I fishery means a commercial fishery determined by the Assistant Administrator to have frequent incidental mortality and serious injury of marine mammals. A commercial fishery that frequently causes mortality or serious injury of marine mammals is one that is by itself responsible for the annual removal of 50 percent or more of any stock's potential biological removal level. *Category II fishery* means a commercial fishery determined by the Assistant Administrator to have occasional incidental mortality and serious injury of marine mammals. A commercial fishery that occasionally causes mortality or serious injury of marine mammals is one that, collectively with other fisheries, is responsible for the annual removal of more than 10 percent of any marine mammal stock's potential biological removal level and that is by itself responsible for the annual removal of between 1 and 50 percent, exclusive, of any stock's potential biological removal level. *Category III fishery* means a commercial fishery determined by the Assistant Administrator to have a remote likelihood of, or no known incidental mortality and serious injury of marine mammals. A commercial fishery that has a remote likelihood of causing incidental mortality and serious injury of marine mammals is one that collectively with other fisheries is responsible for the annual removal of: (1) Ten percent or less of any marine mammal stock's potential biological removal level, or (2) More than 10 percent of any marine mammal stock's potential biological removal level, yet that fishery by itself is responsible for the annual removal of 1 percent or less of that stock's potential biological removal level.

Fig. 1: Right whale northern management areas



Map author: Brendan Hurley
Map created: 4/18/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 2: Example from December 2002 DAM zone
(http://www.maine.gov/dmr/rm/whale/Dec19_zone.pdf)

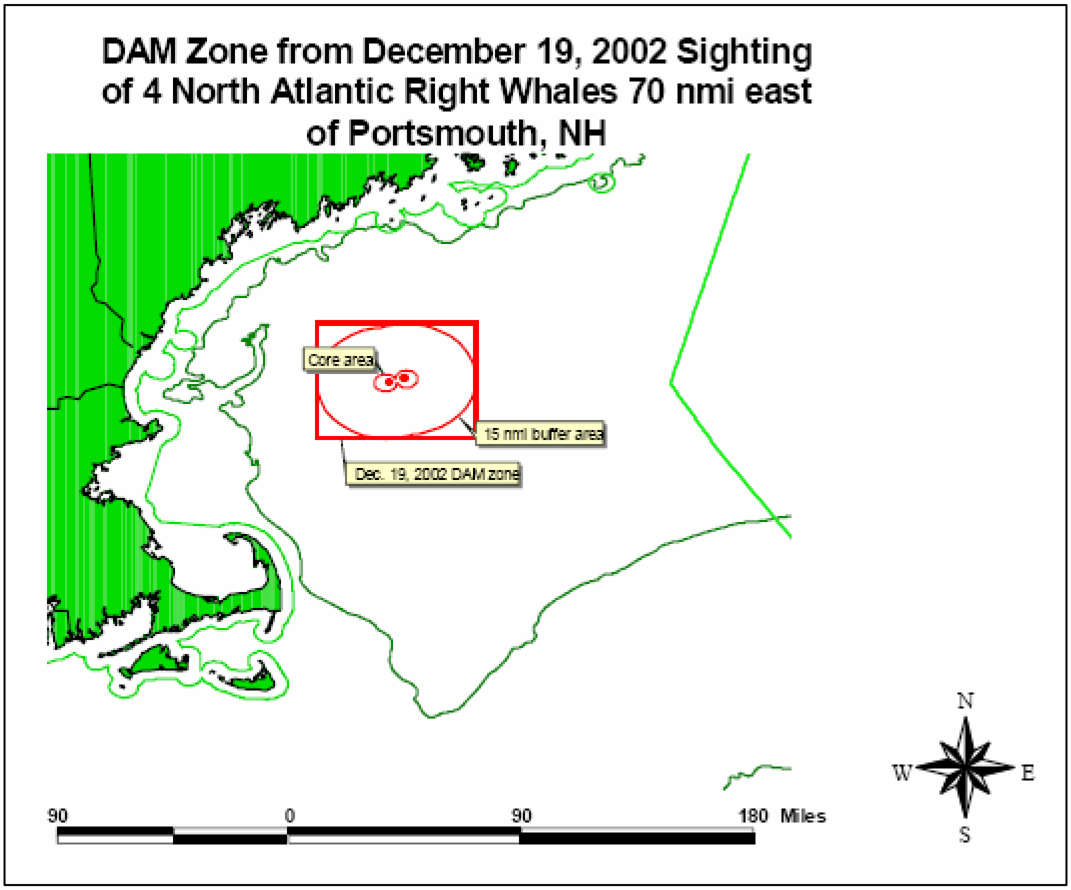
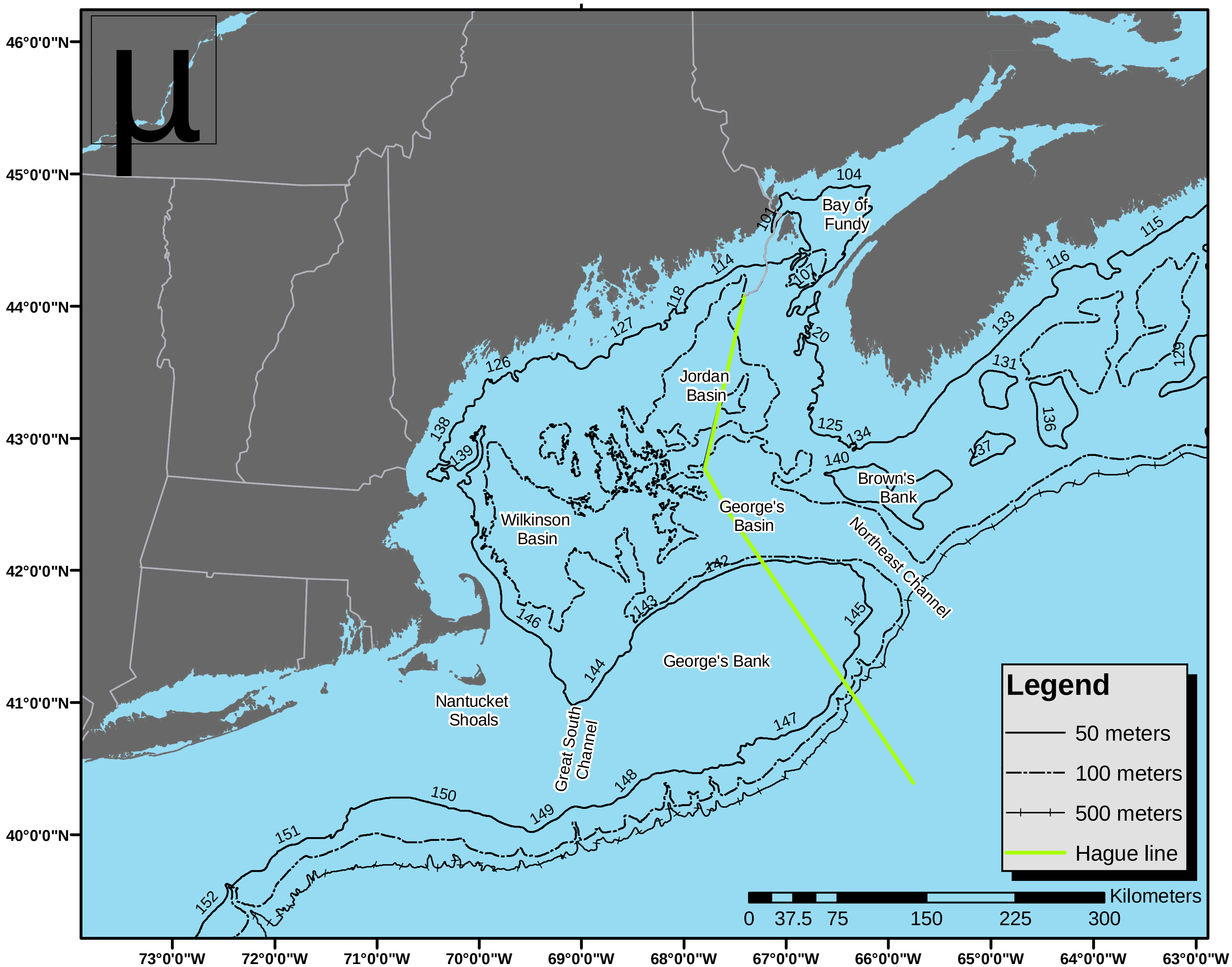
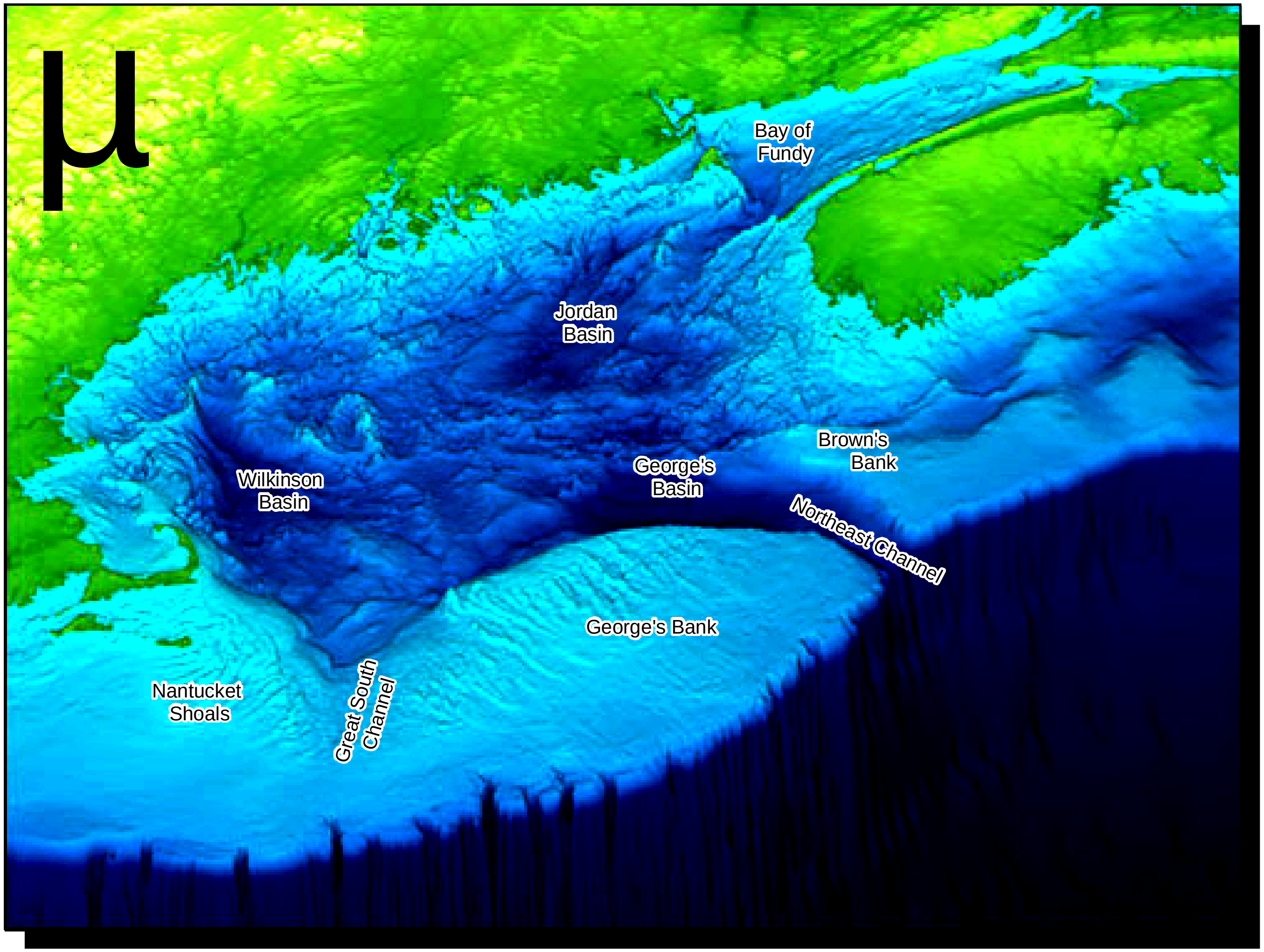


Fig. 3: Gulf of Maine physical features



Map author: Brendan Hurley
Map created: 3/13/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 4: three-dimensional bathymetry of the Gulf of Maine



Bathymetry exagerated 75 times times to show benthic features
source: http://www.gomoos.org/aboutgulfme/

Figure 5: single double lobster pot

(Adapted from Anderson & Anderson 1999)

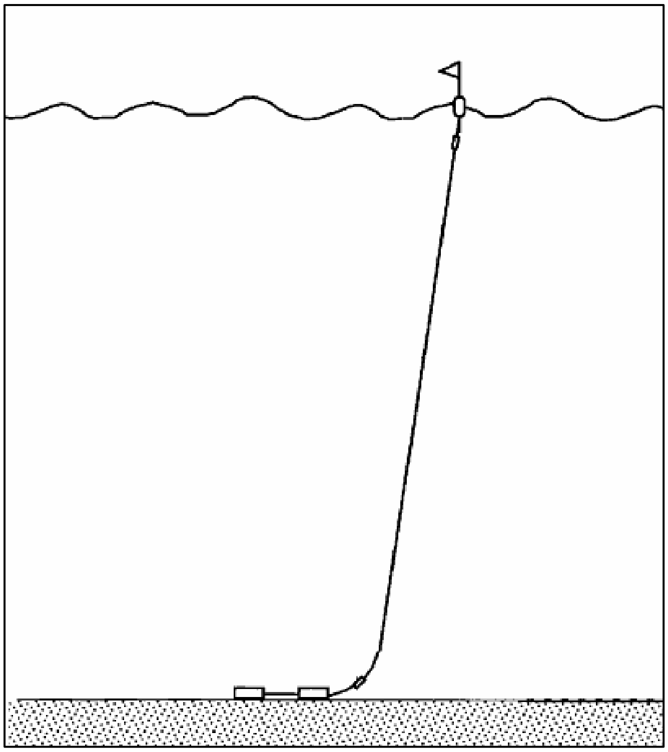


Figure 6: Lobster pot trawl

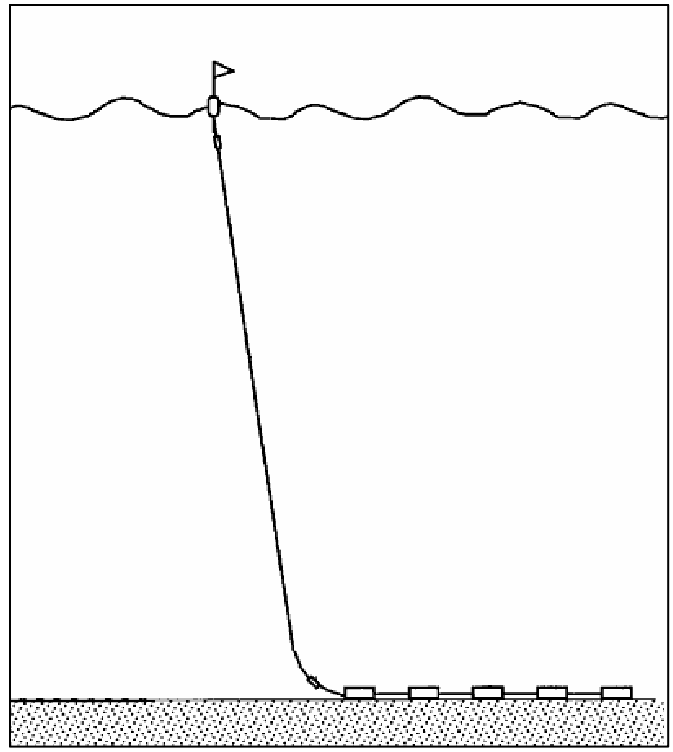


Figure 7: Number of traps reported fished in the Gulf of Maine

(Correia 2006)

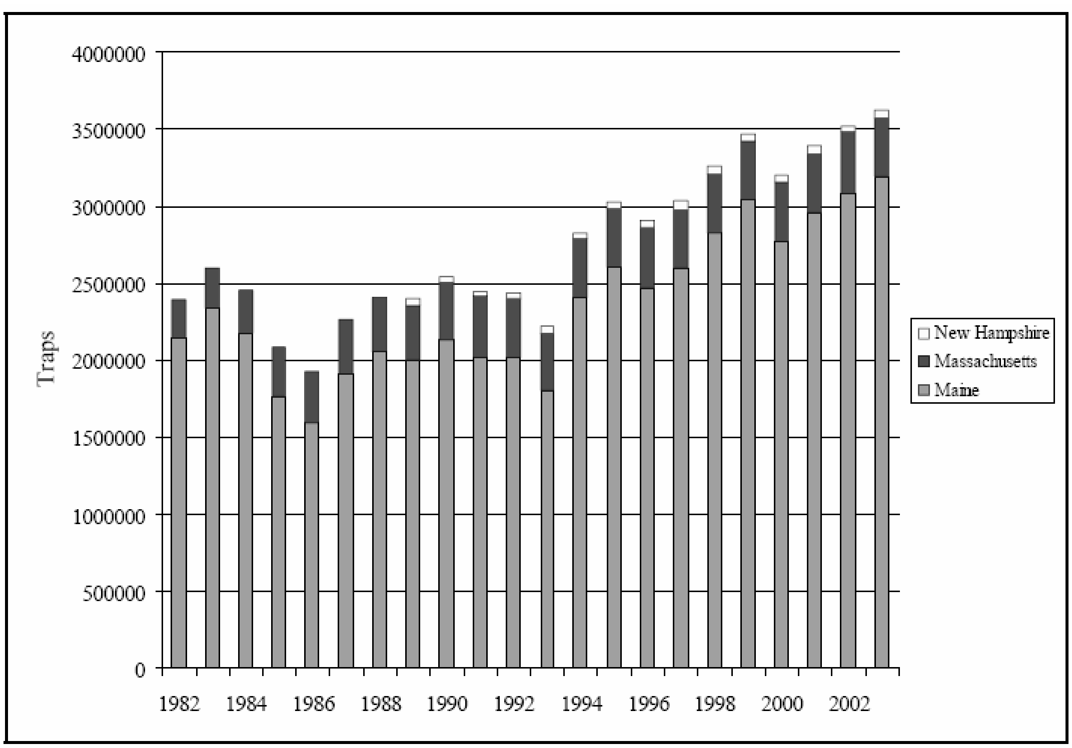


Figure 8: Number of traps reported fished on George's Bank with Massachusetts as an index (Correia 2006)

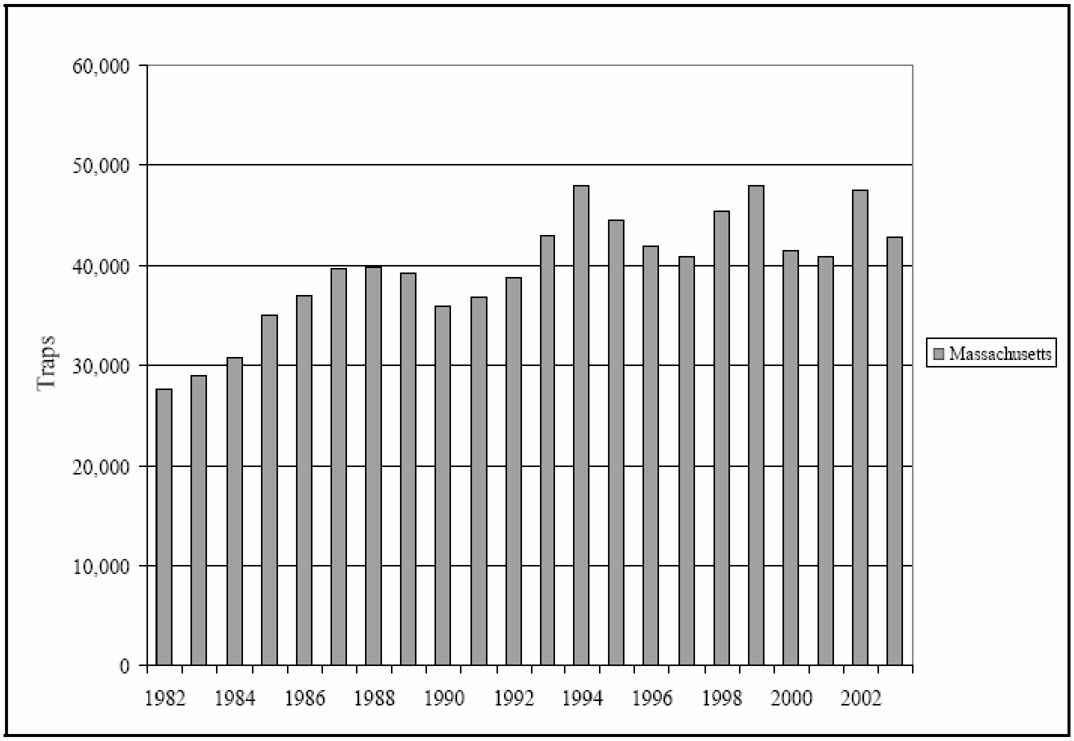
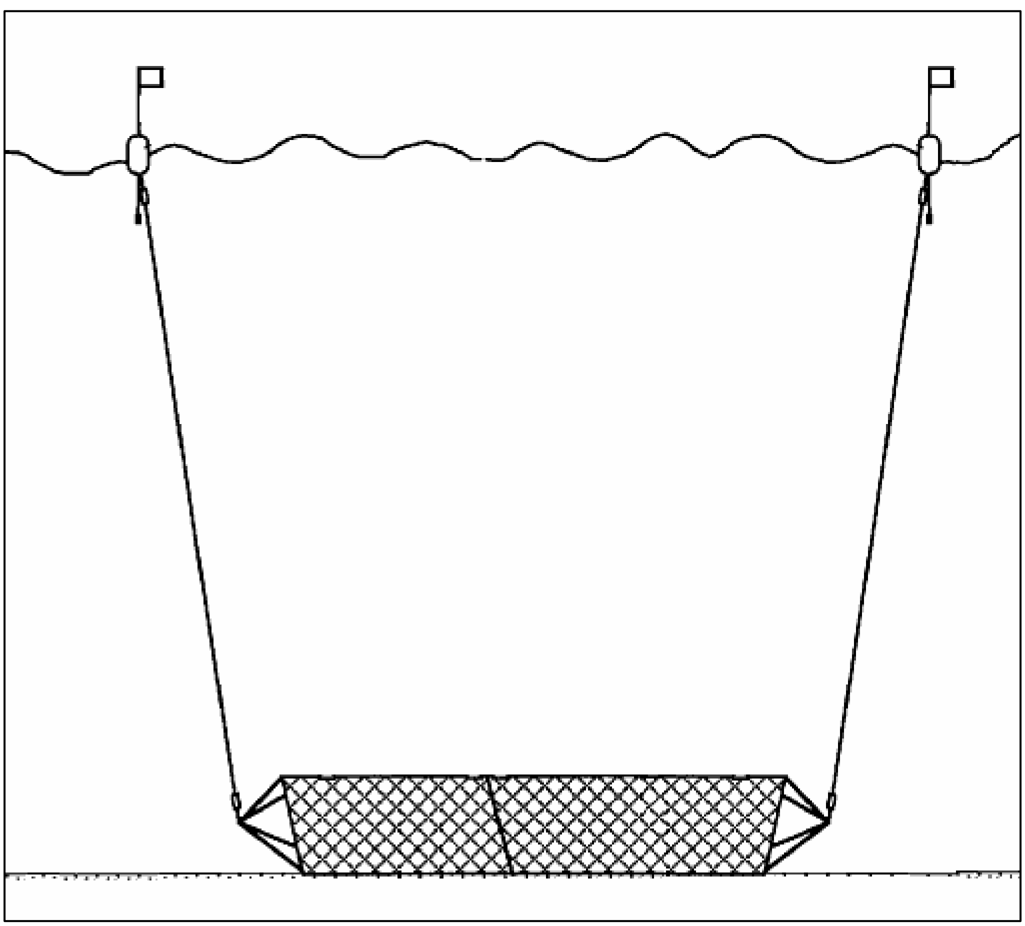
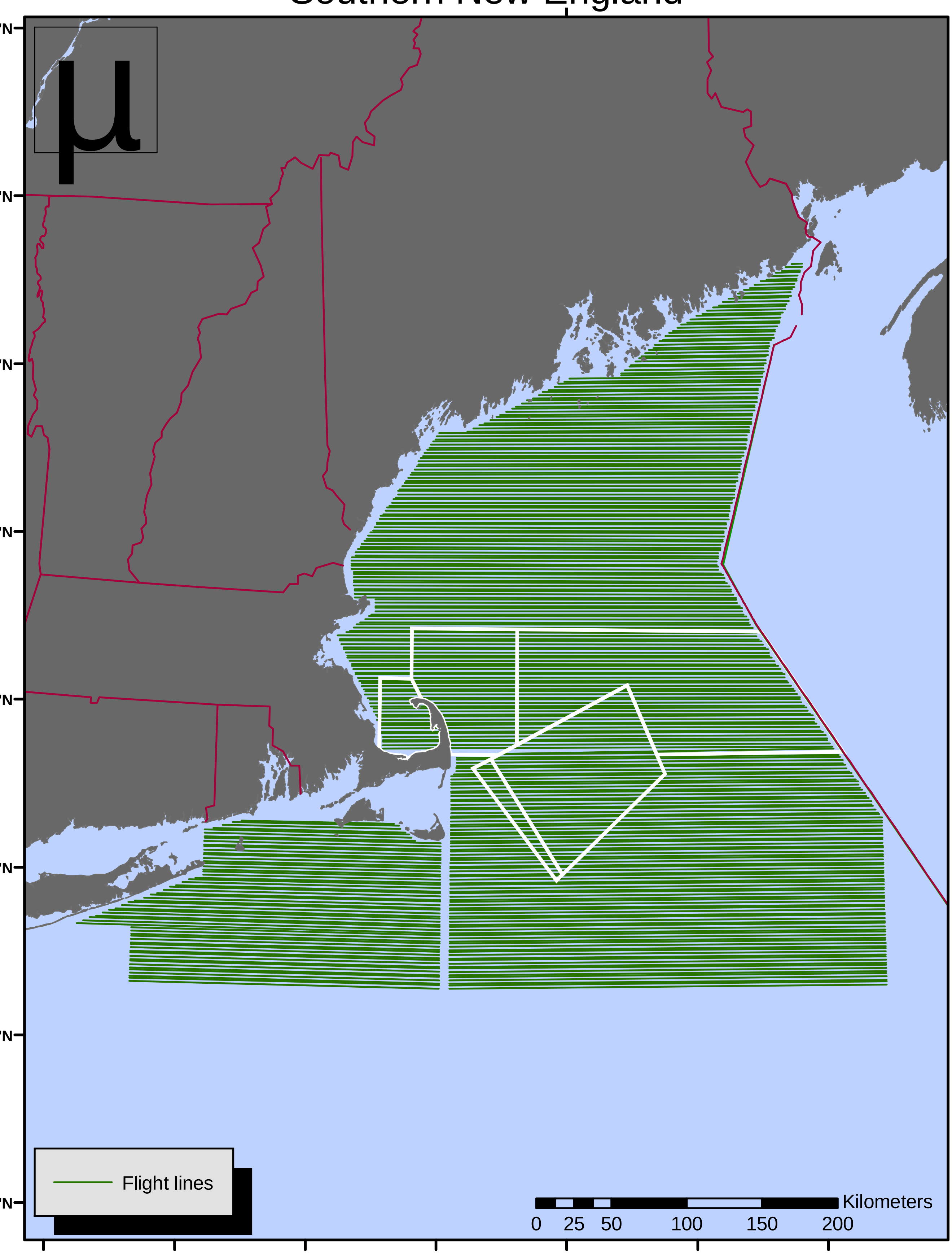


Figure 9: A typical gillnet set



Adapted from Anderson
Anderson (1999)

Fig. 10: National Marine Fisheries Service survey lines- Gulf of Maine, George's Bank, Southern New England



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 11: De Havilland DHC-6 Twin Otter, Series 300

Fig. 12: Detection probability with variable glare

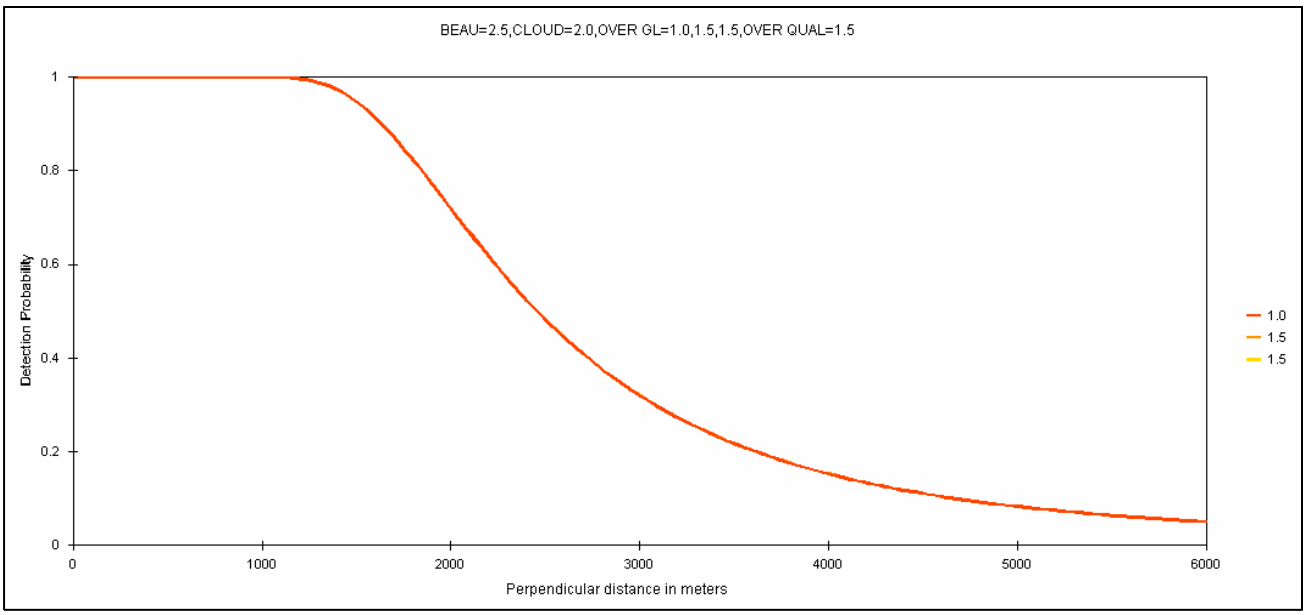


Fig. 13: Detection probability with variable cloud cover

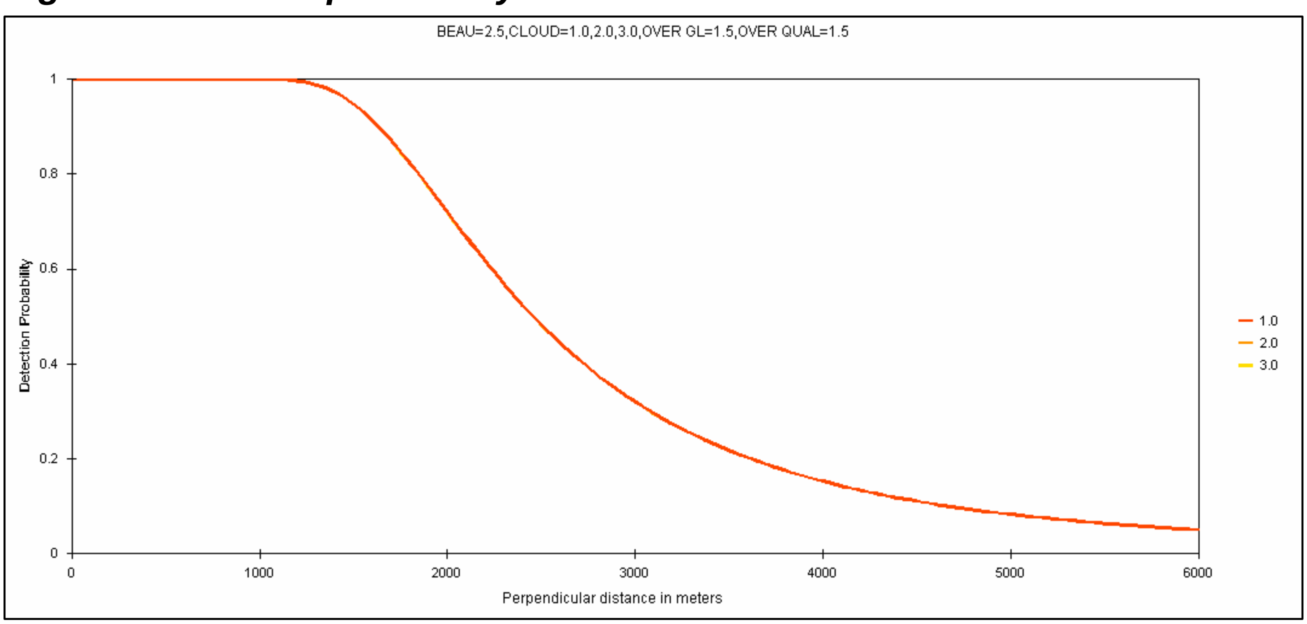


Fig. 14: Detection probability with variable Beaufort Sea State

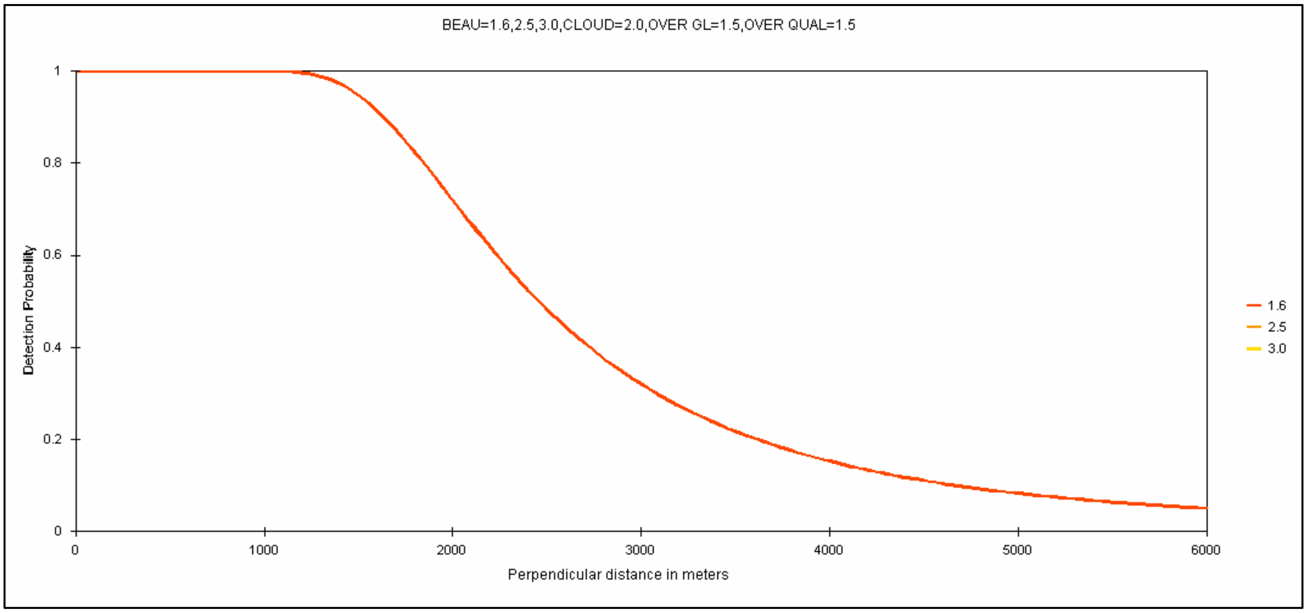


Fig. 15: Detection probability with variable overall quality

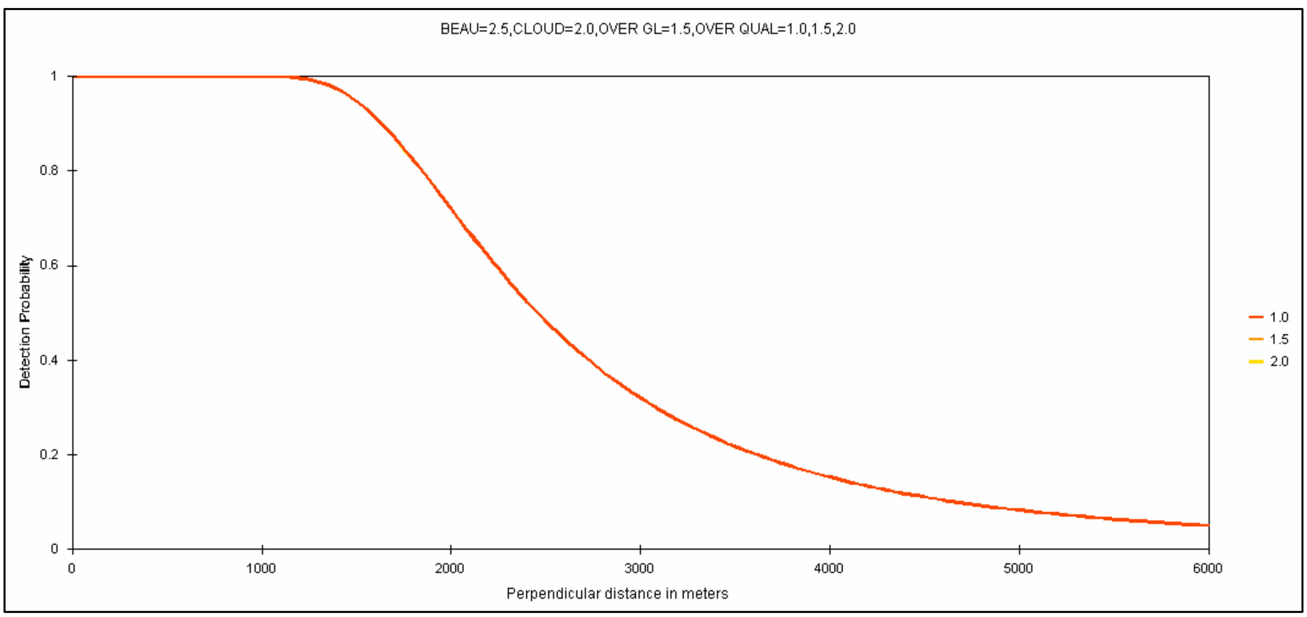
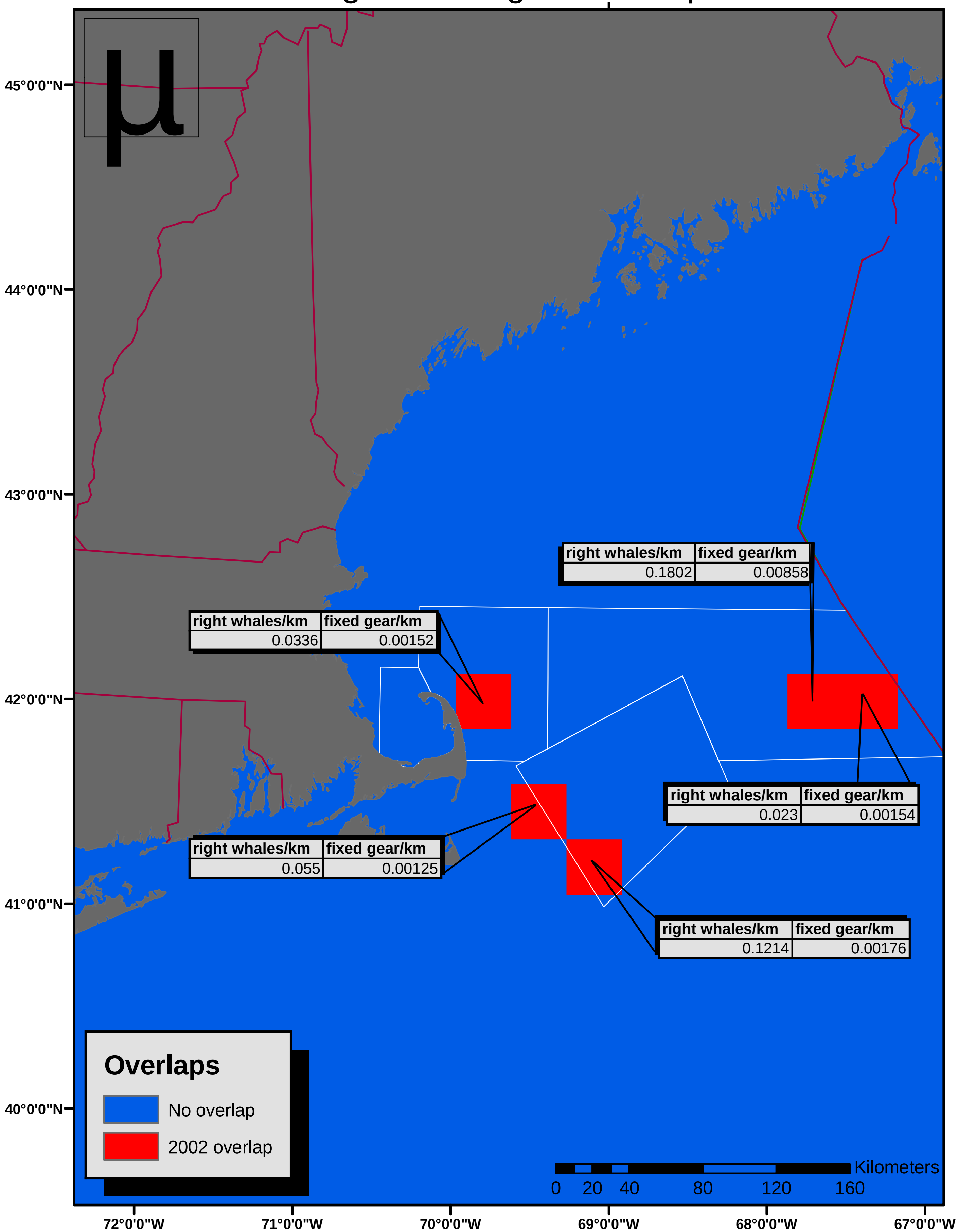
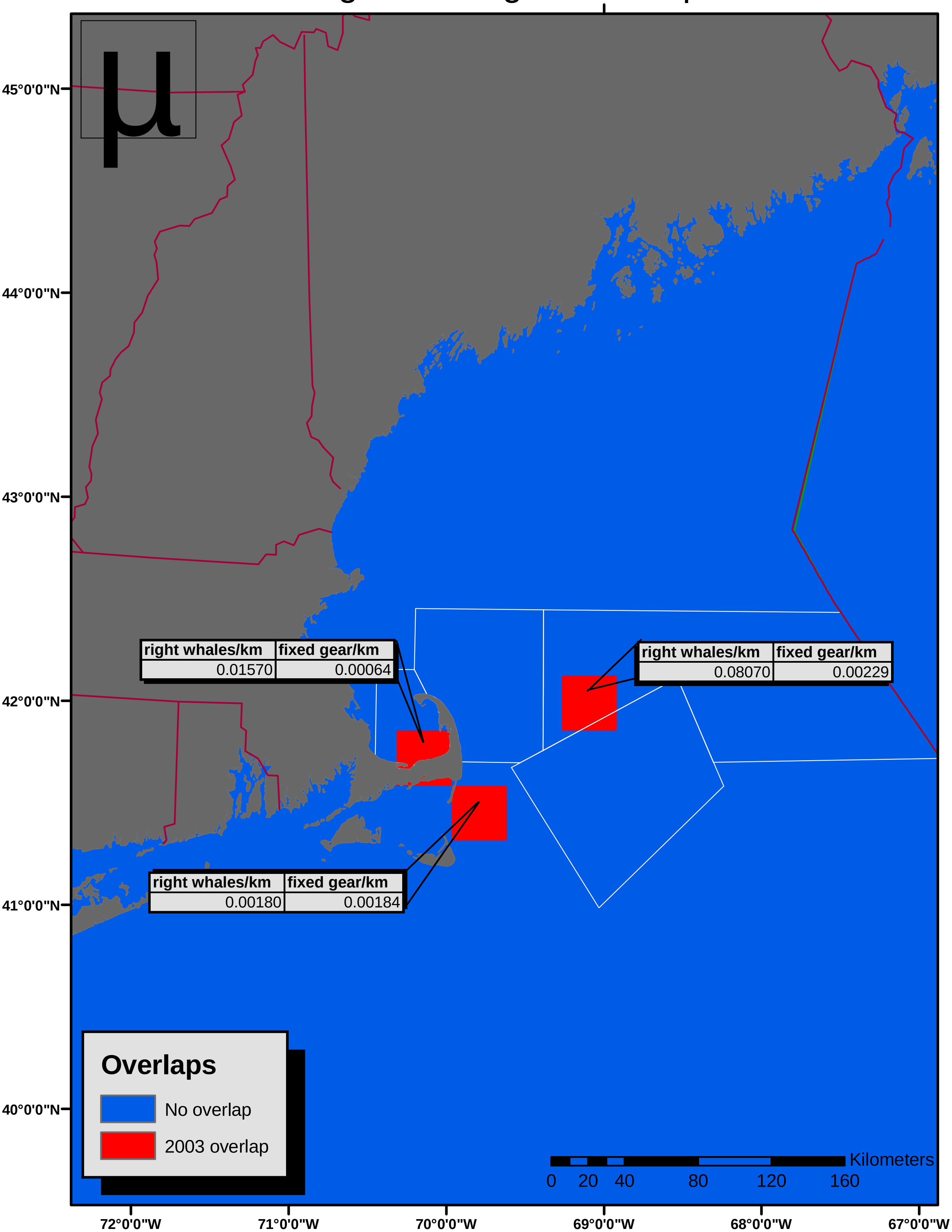


Fig. 16: 30km grid cells, Spring 2002 right whale/gear overlap



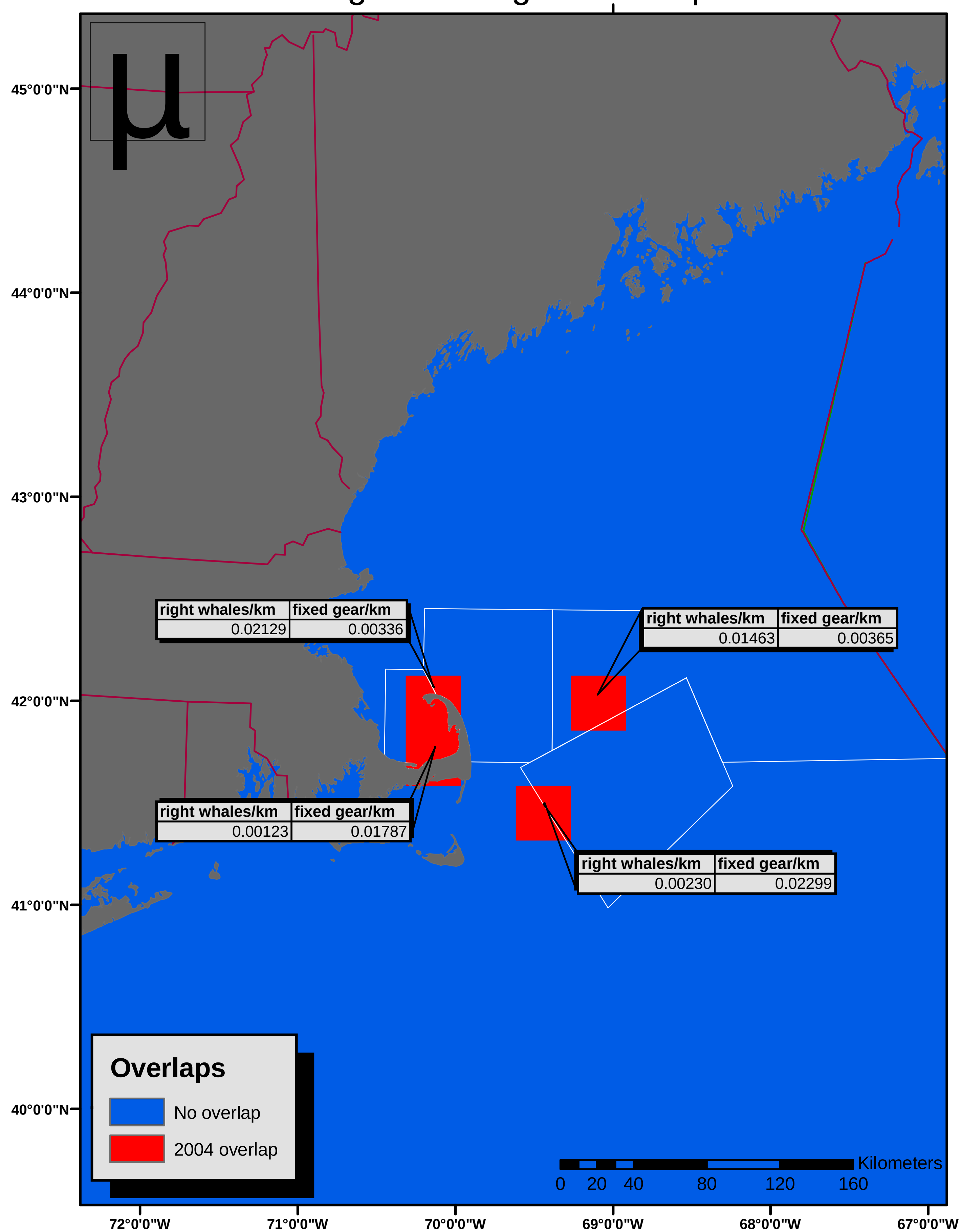
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 17: 30km grid cells, Spring 2003 right whale/gear overlap



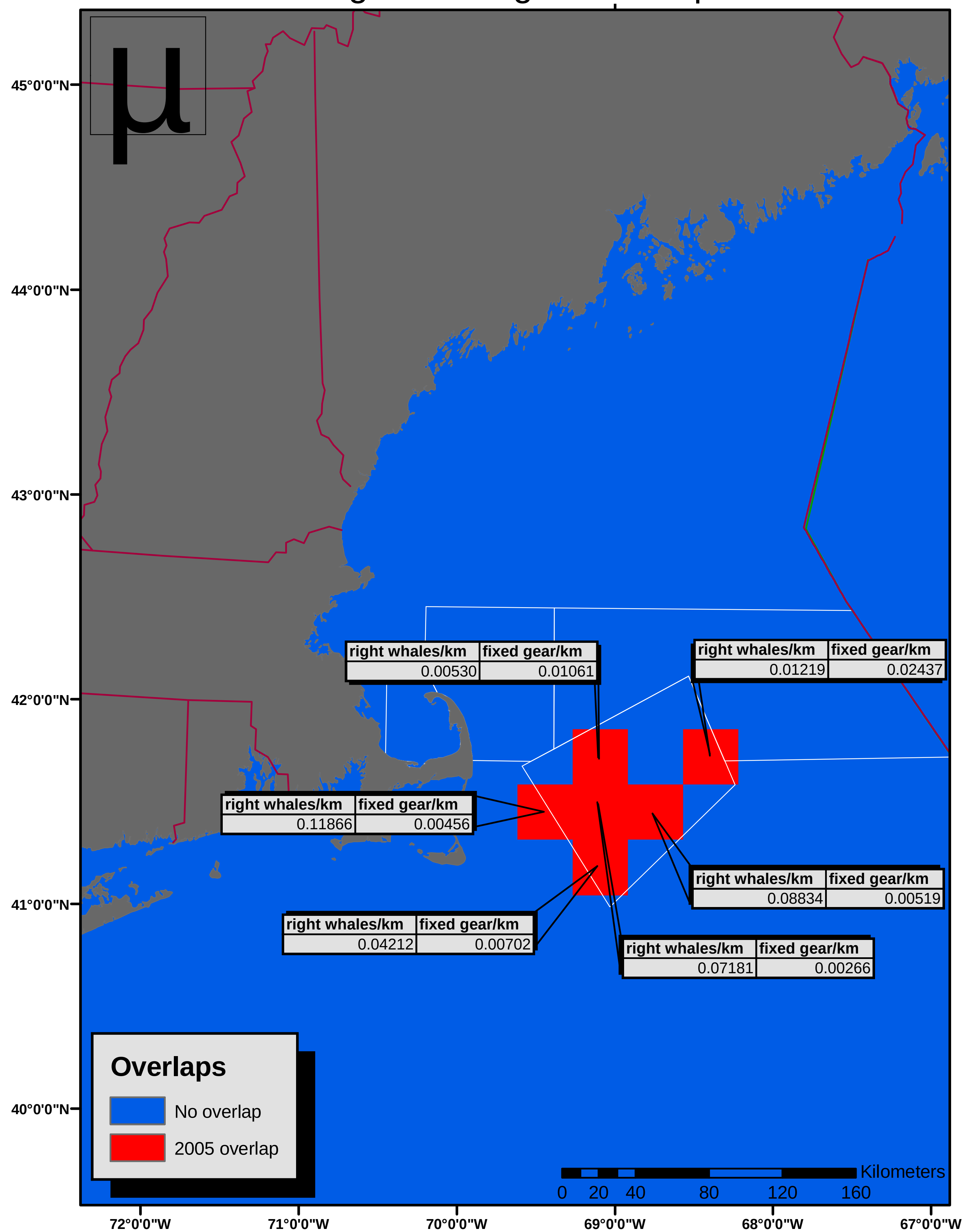
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 18: 30km grid cells, Spring 2004 right whale/gear overlap



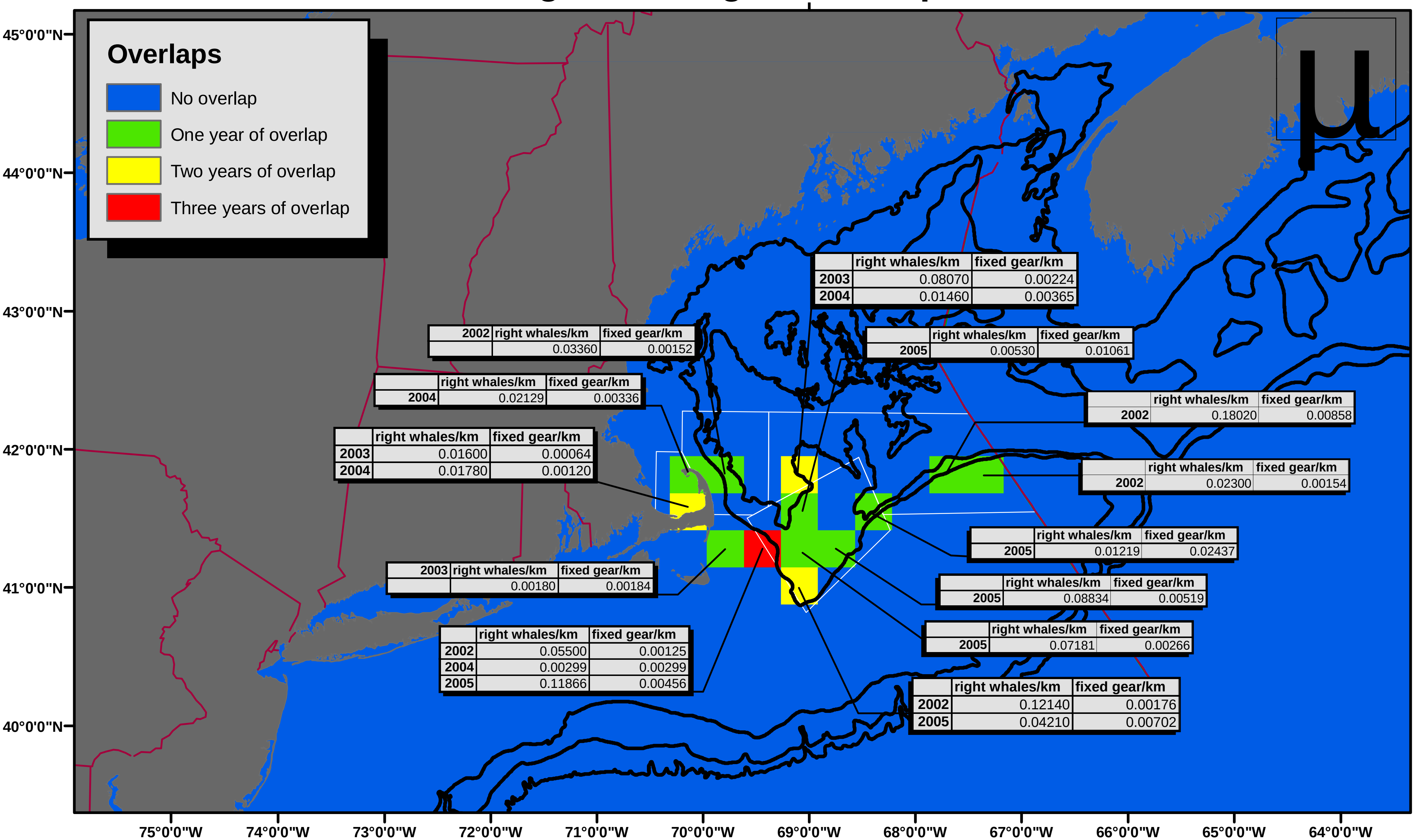
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 19: 30km grid cells, Spring 2005 right whale/gear overlap



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

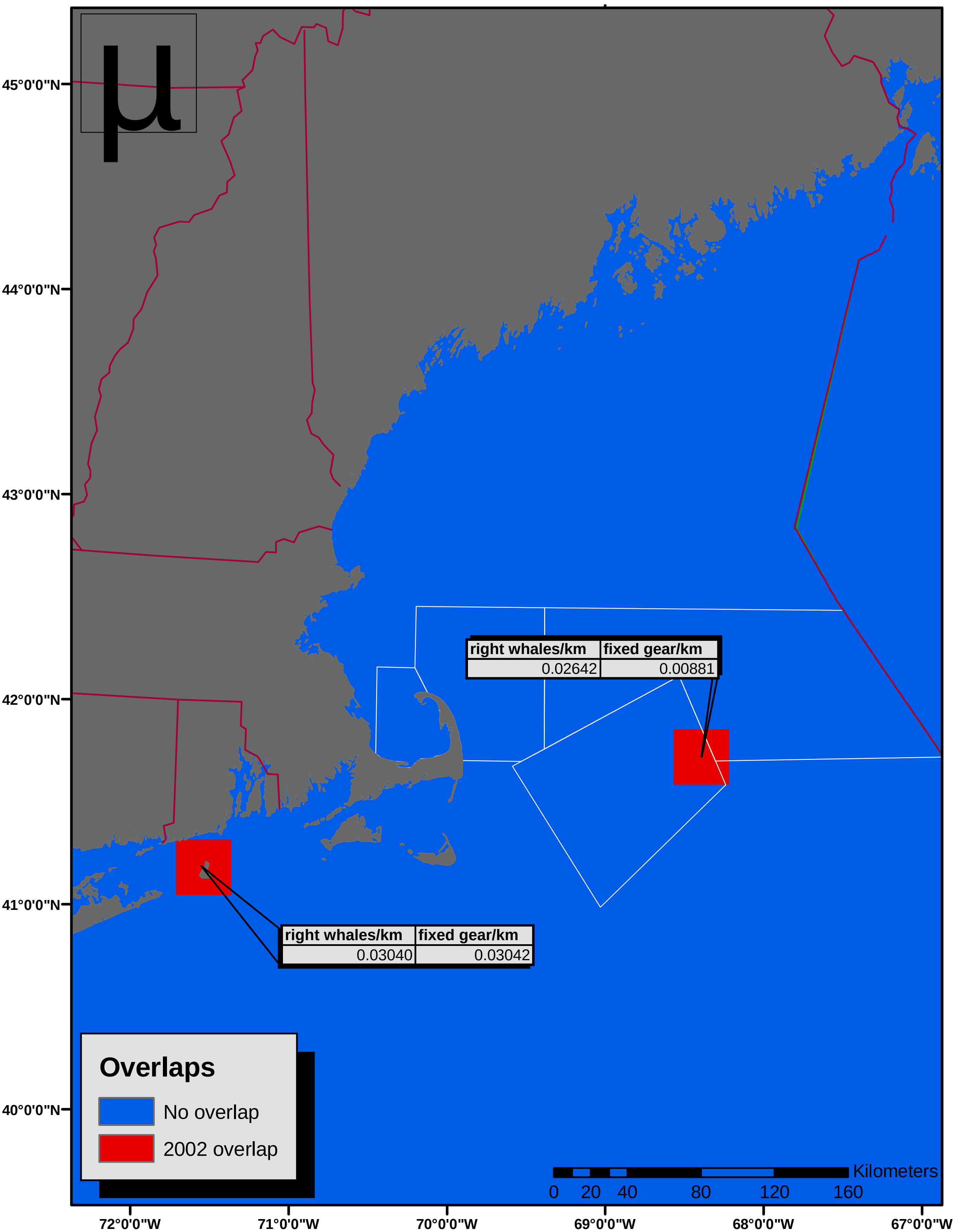
Fig. 20: 30km grid cells, overall spring right whale/gear overlap



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

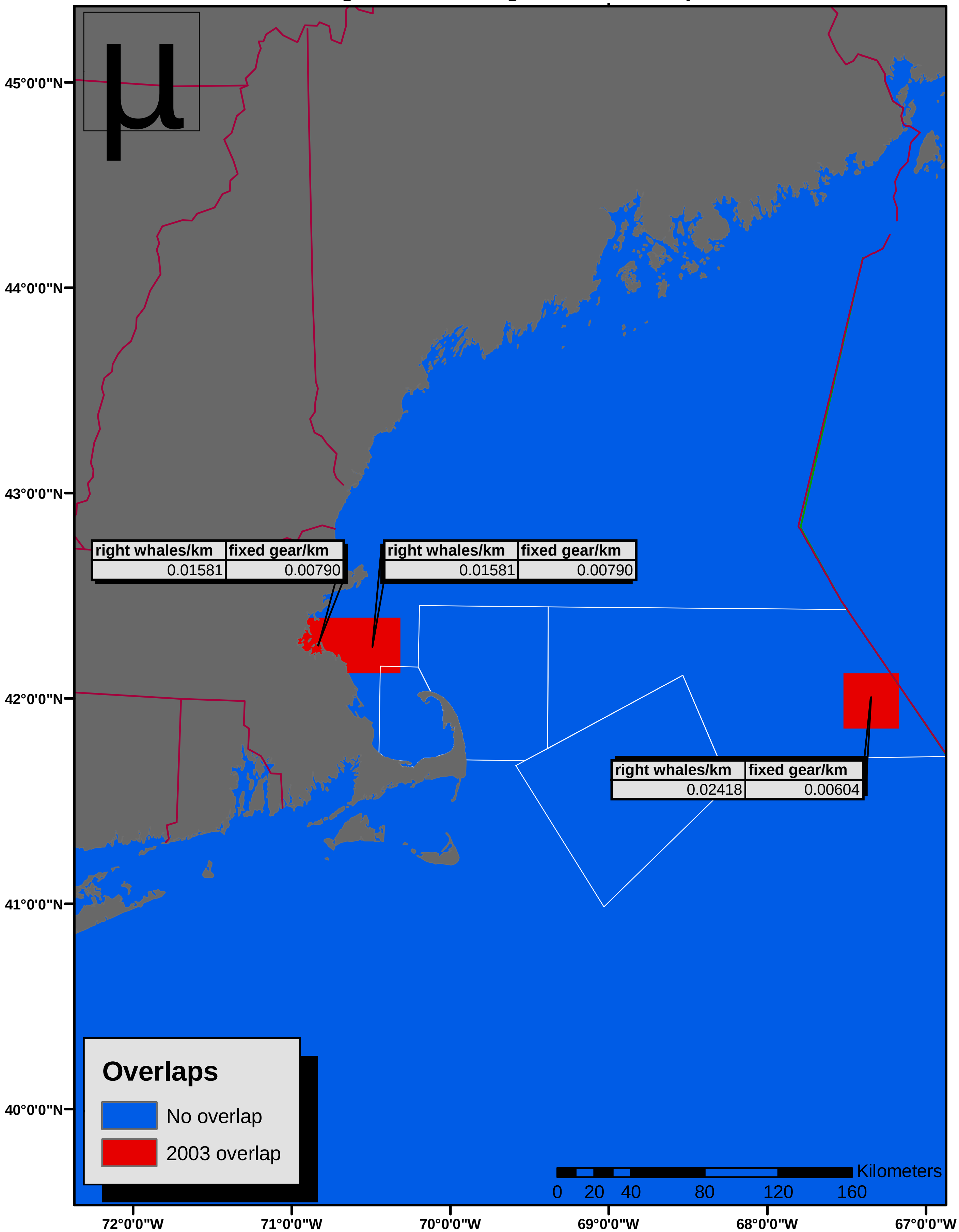
Kilometers
0 30 60 120 180 240

Fig. 21: 30km grid cells, Summer 2002
right whale/gear overlap



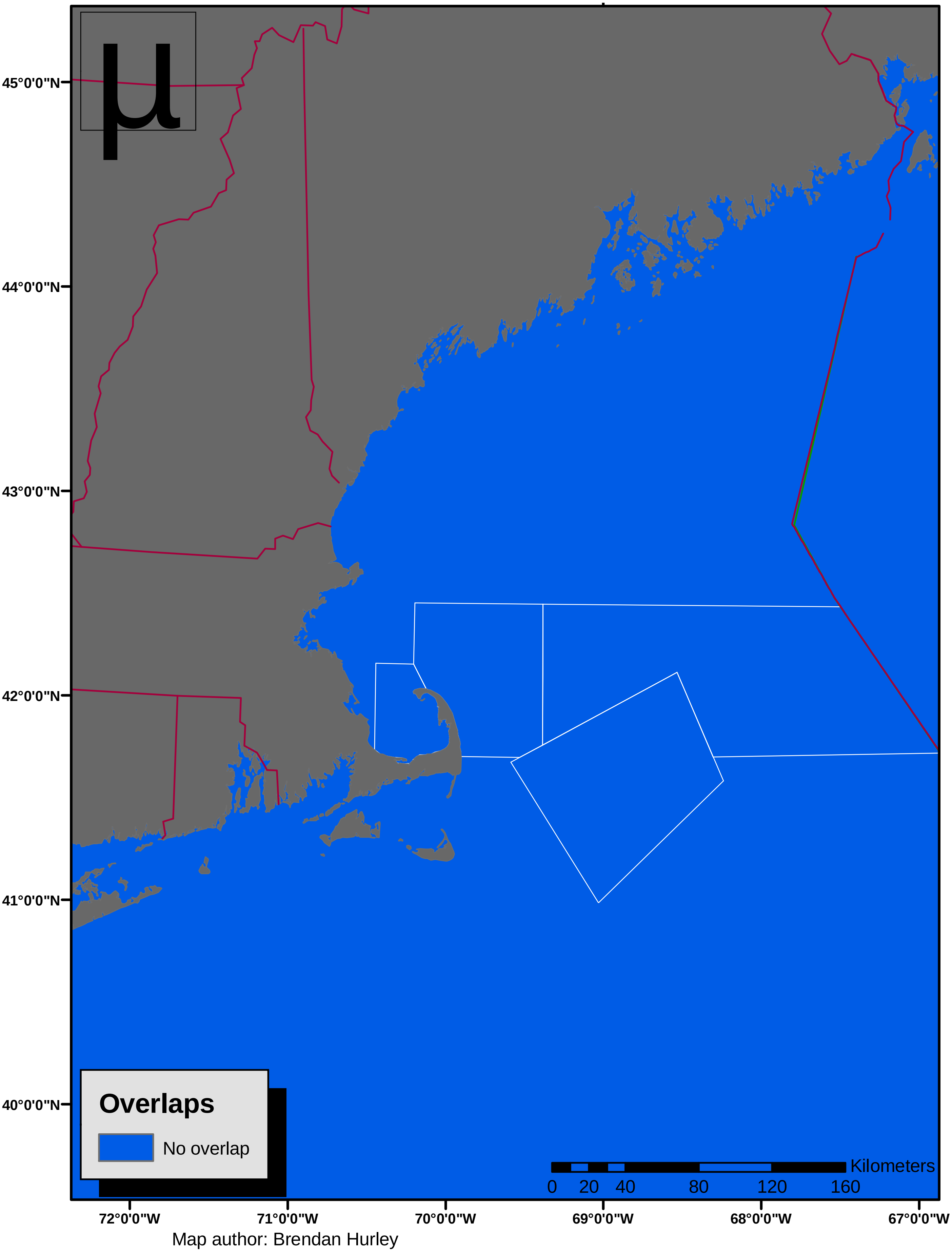
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 22: 30km grid cells, Summer 2003 right whale/gear overlap



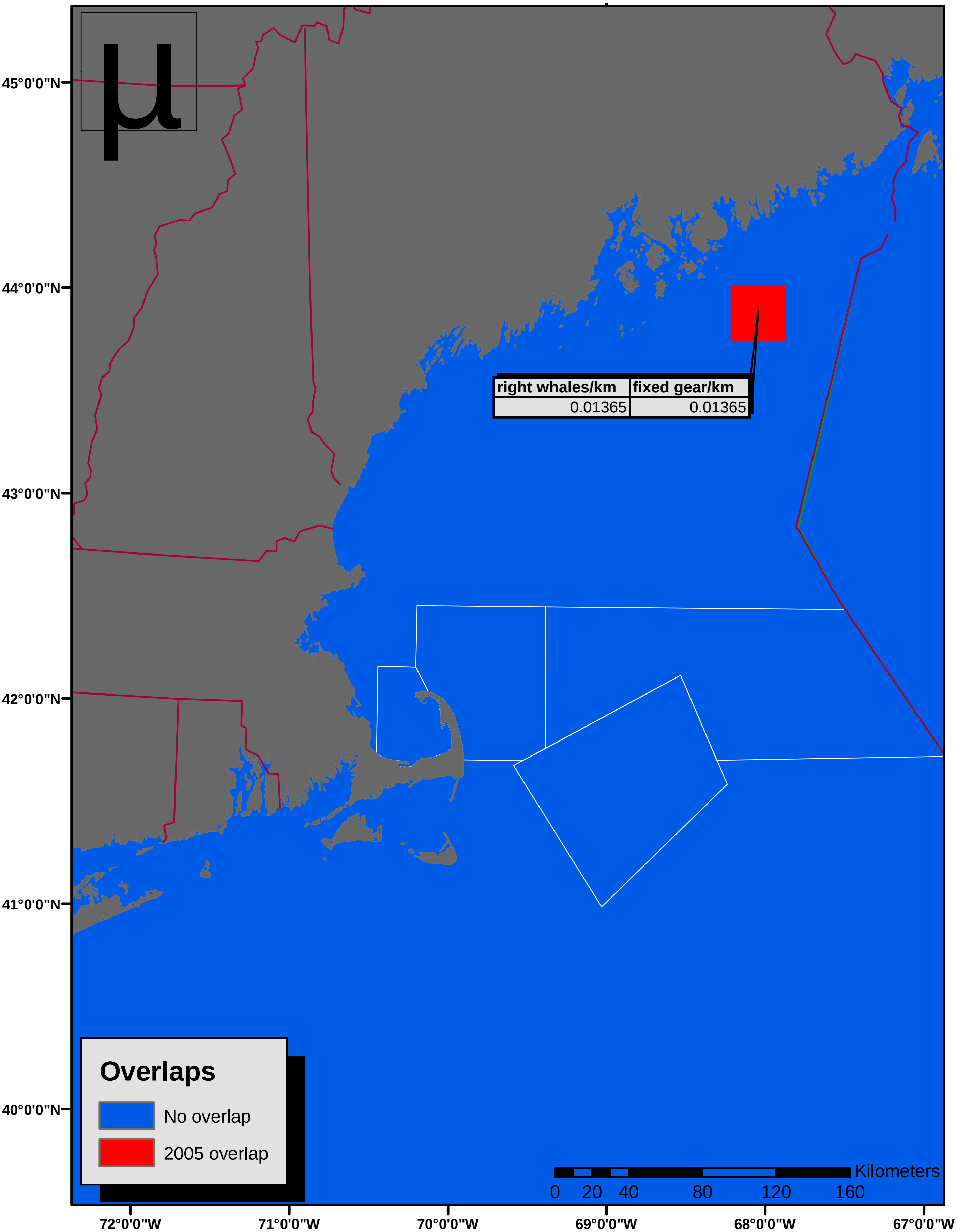
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 23: 30km grid cells, Summer 2004 right whale/gear overlap



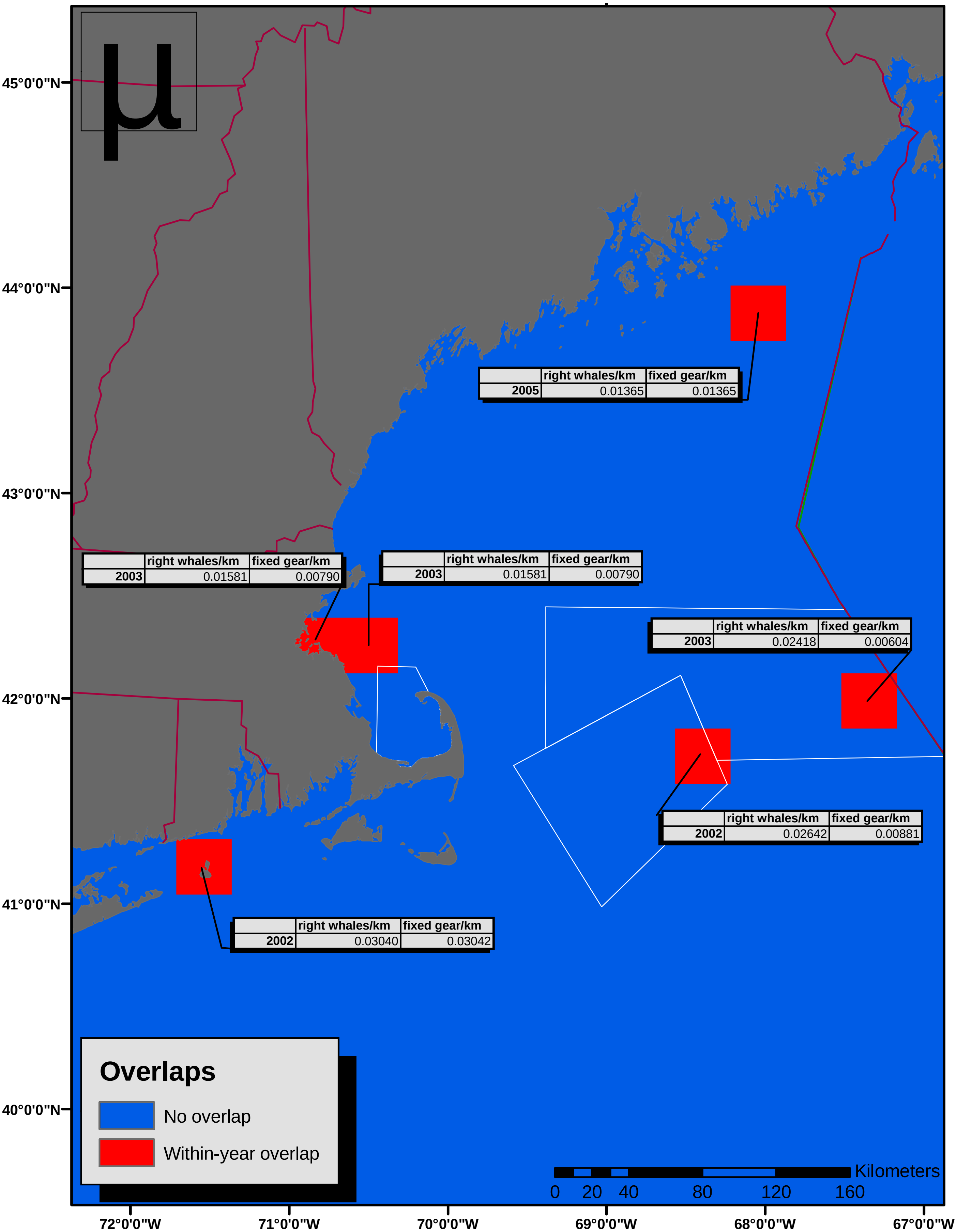
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 24: 30km grid cells, Summer 2005 right whale/gear overlap



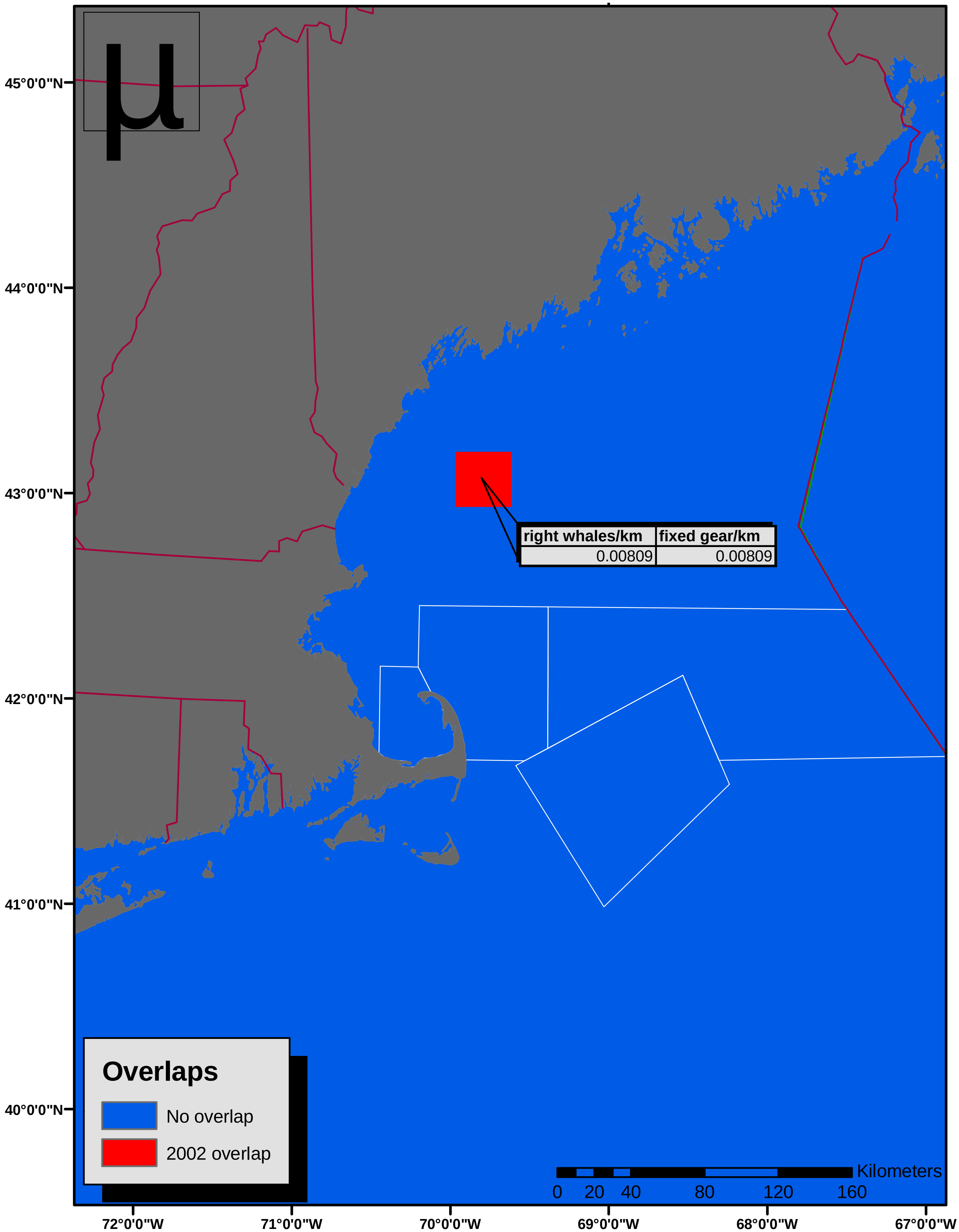
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 25: 30km grid cells, overall summer right whale/gear overlap



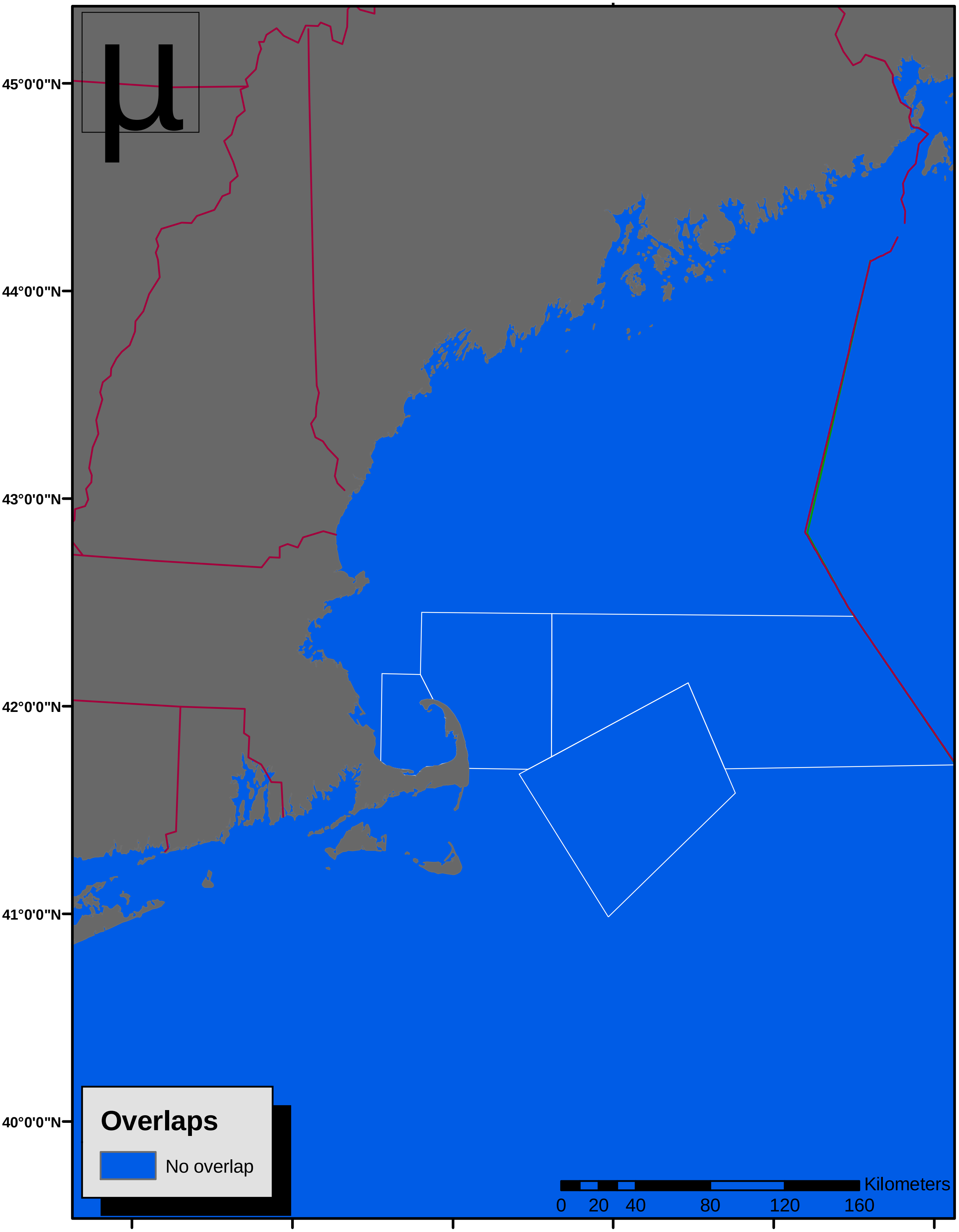
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 26: 30km grid cells, Fall 2002
right whale/gear overlap



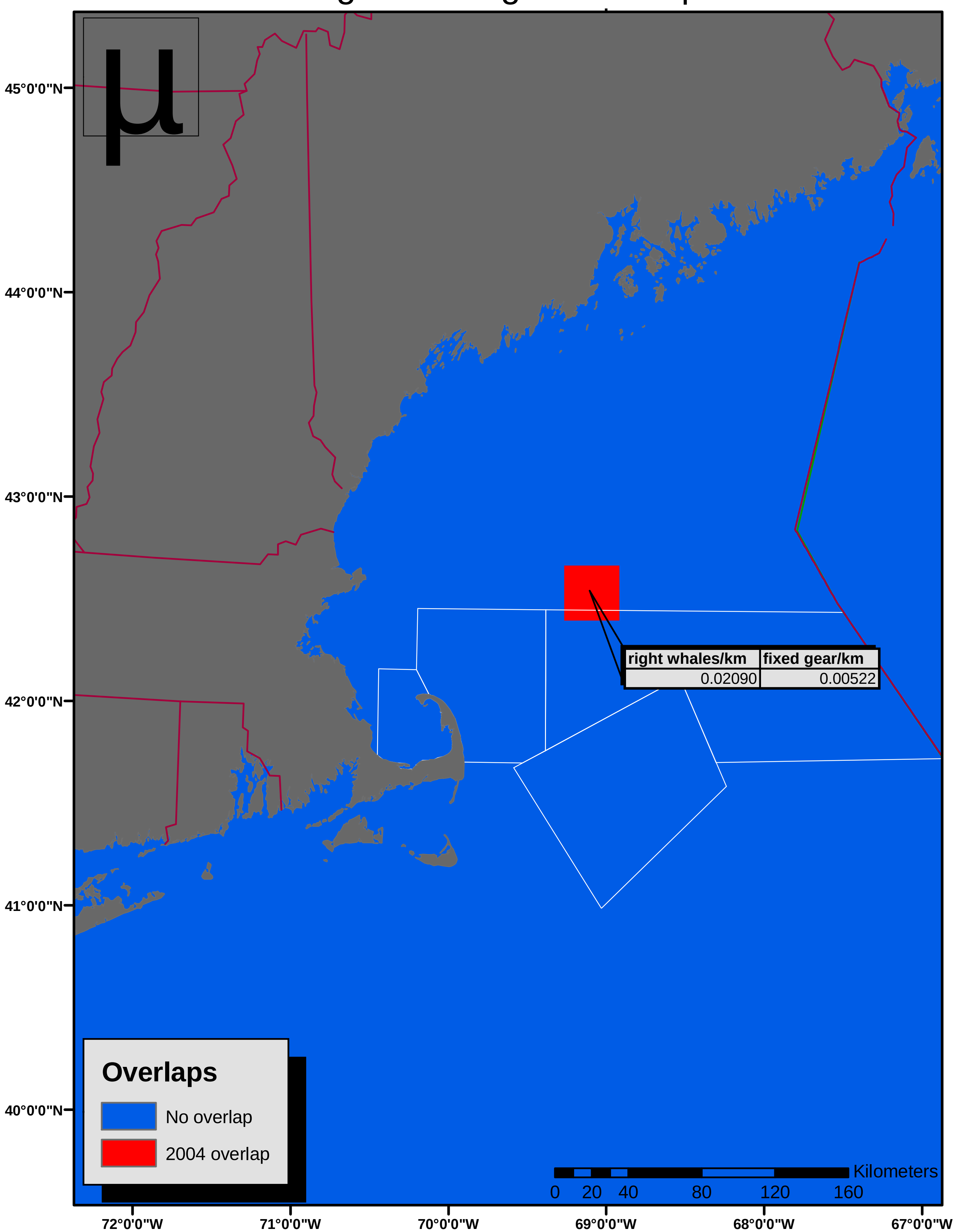
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 27: 30km grid cells, Fall 2003
right whale/gear overlap



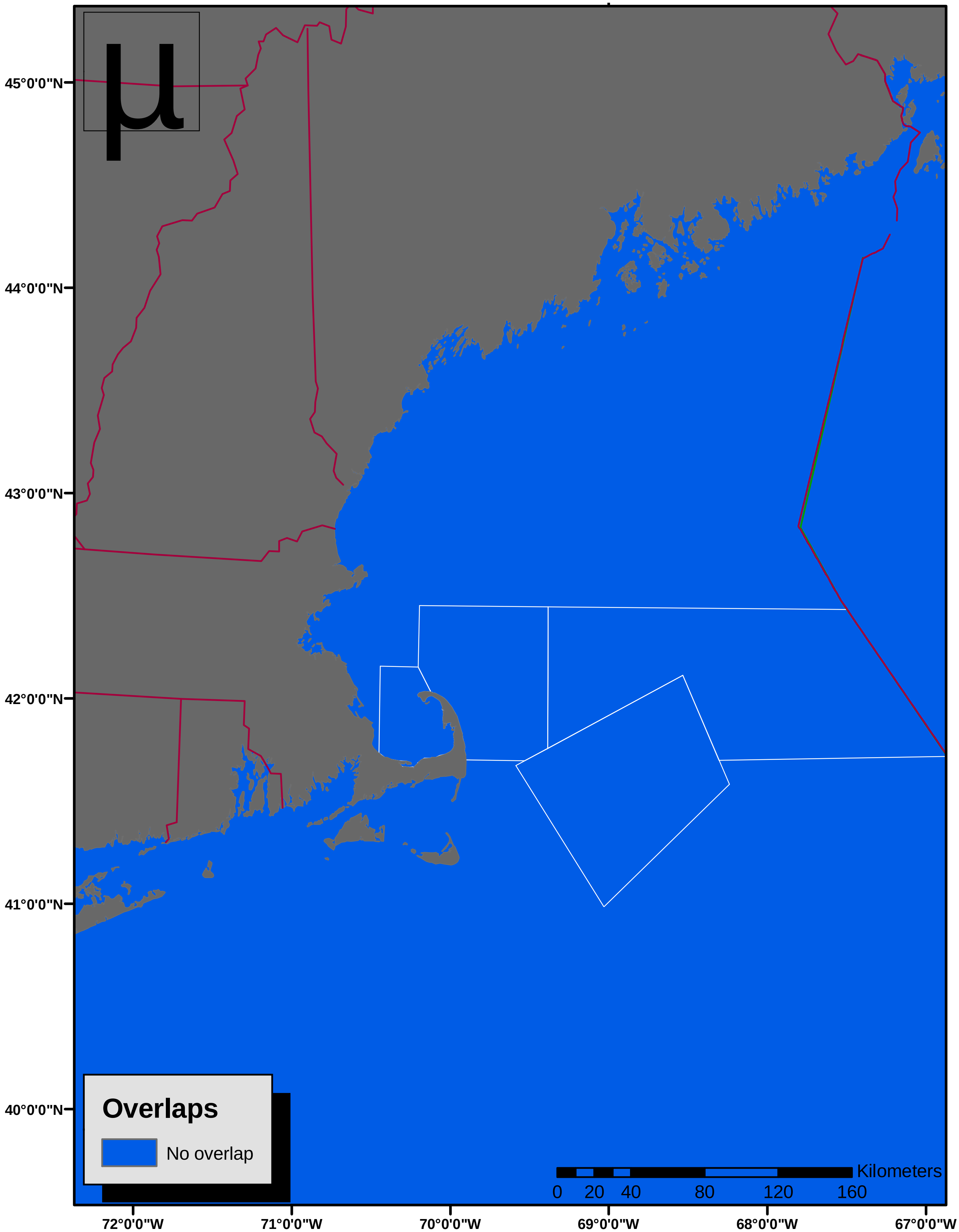
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 28: 30km grid cells, Fall 2004
right whale/gear overlap



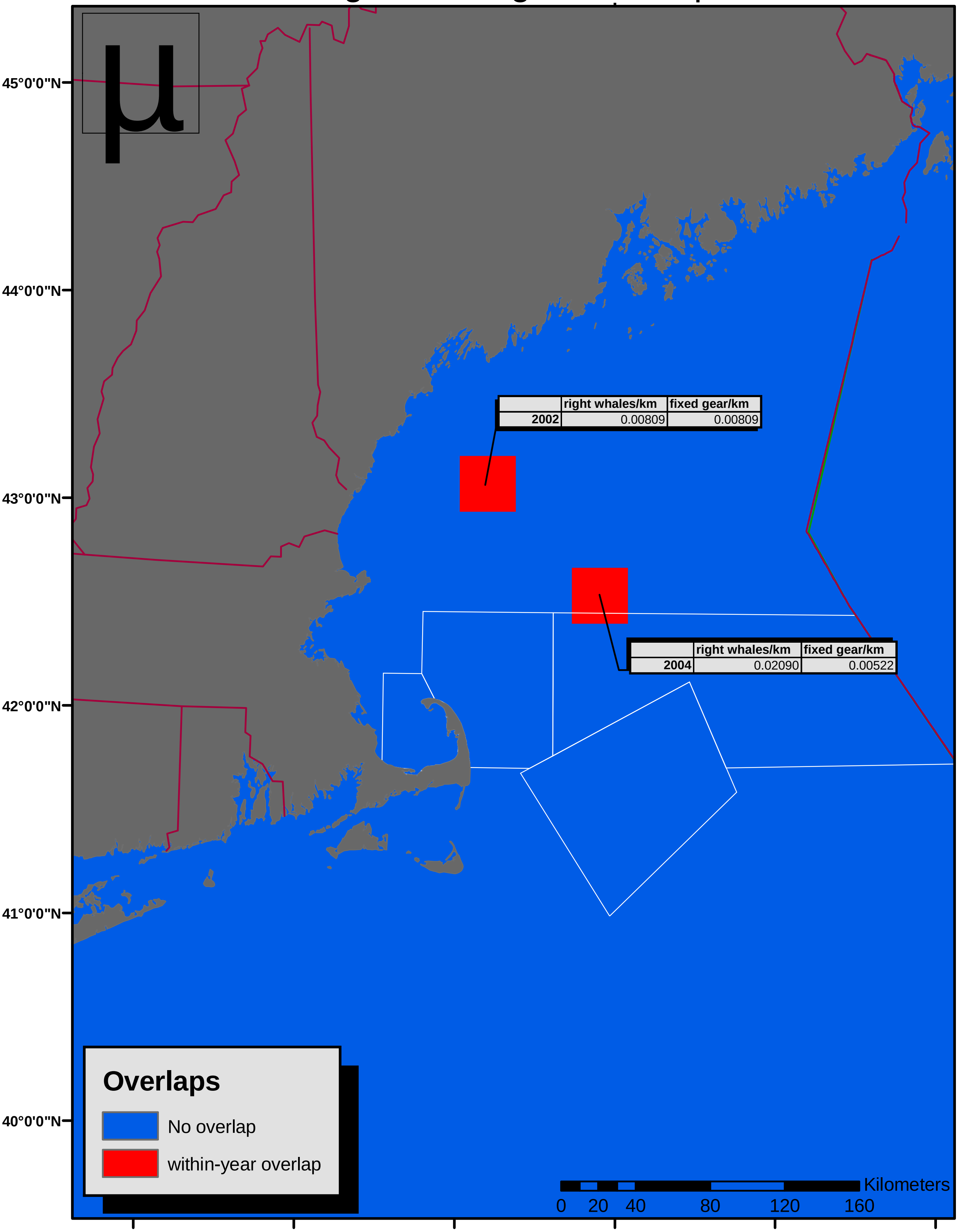
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 29: 30km grid cells, Fall 2005
right whale/gear overlap



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 30: 30km grid cells, overall fall right whale/gear overlap

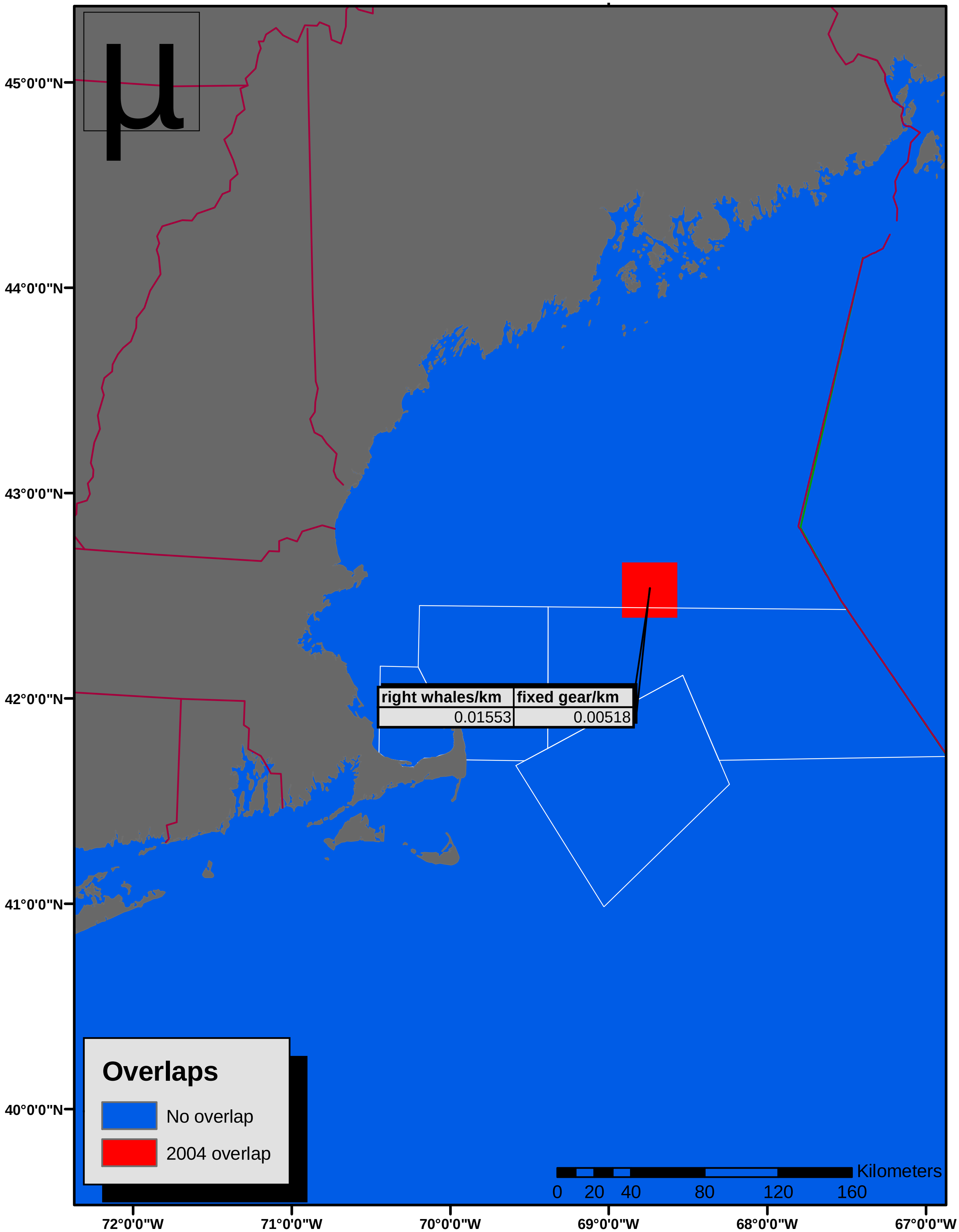


Map author: Brendan Hurley

Map created: 2/26/07

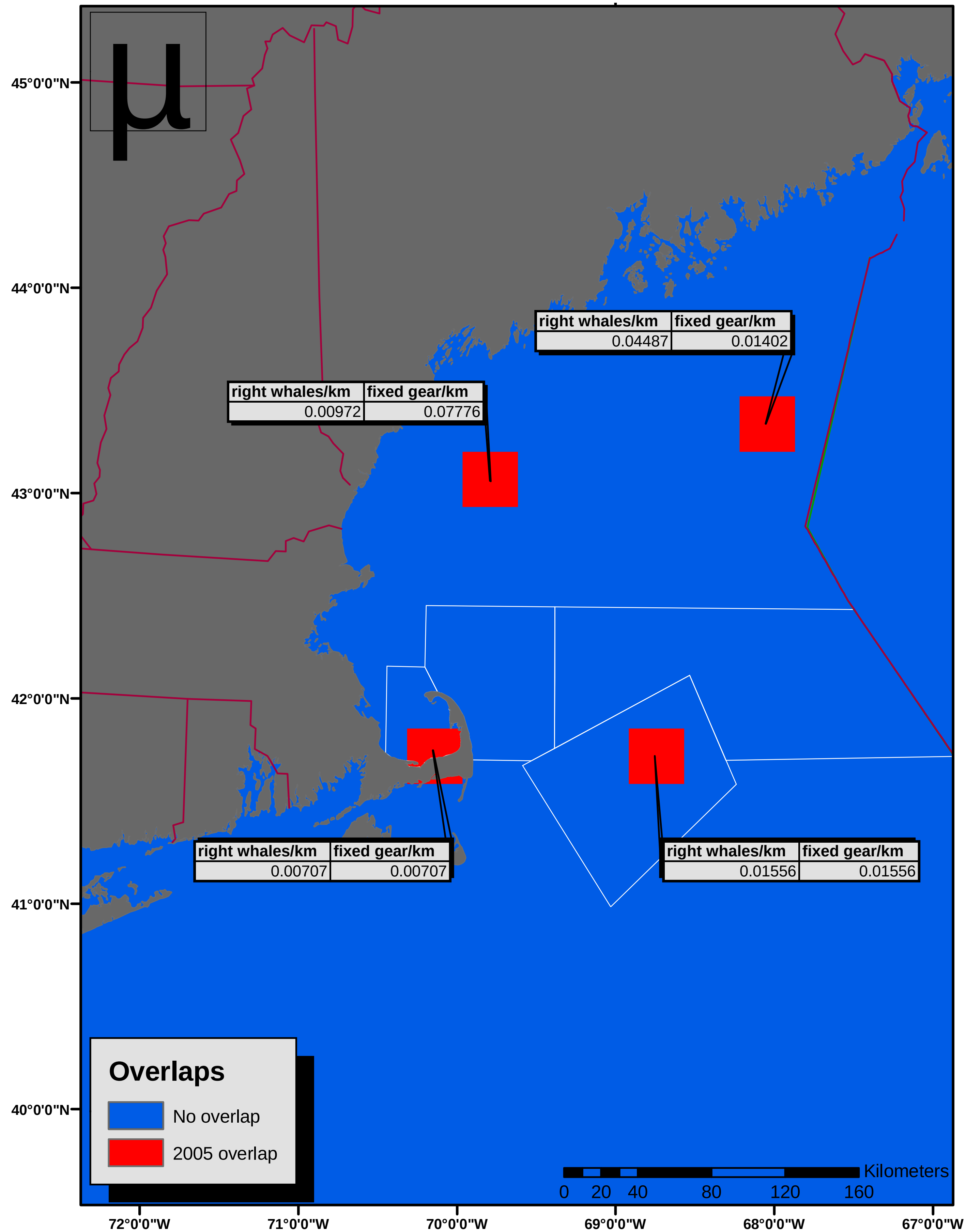
Projection: Universal Transverse Mercator, zone 19N

Fig. 31: 30km grid cells, winter 2004 right whale/gear overlap



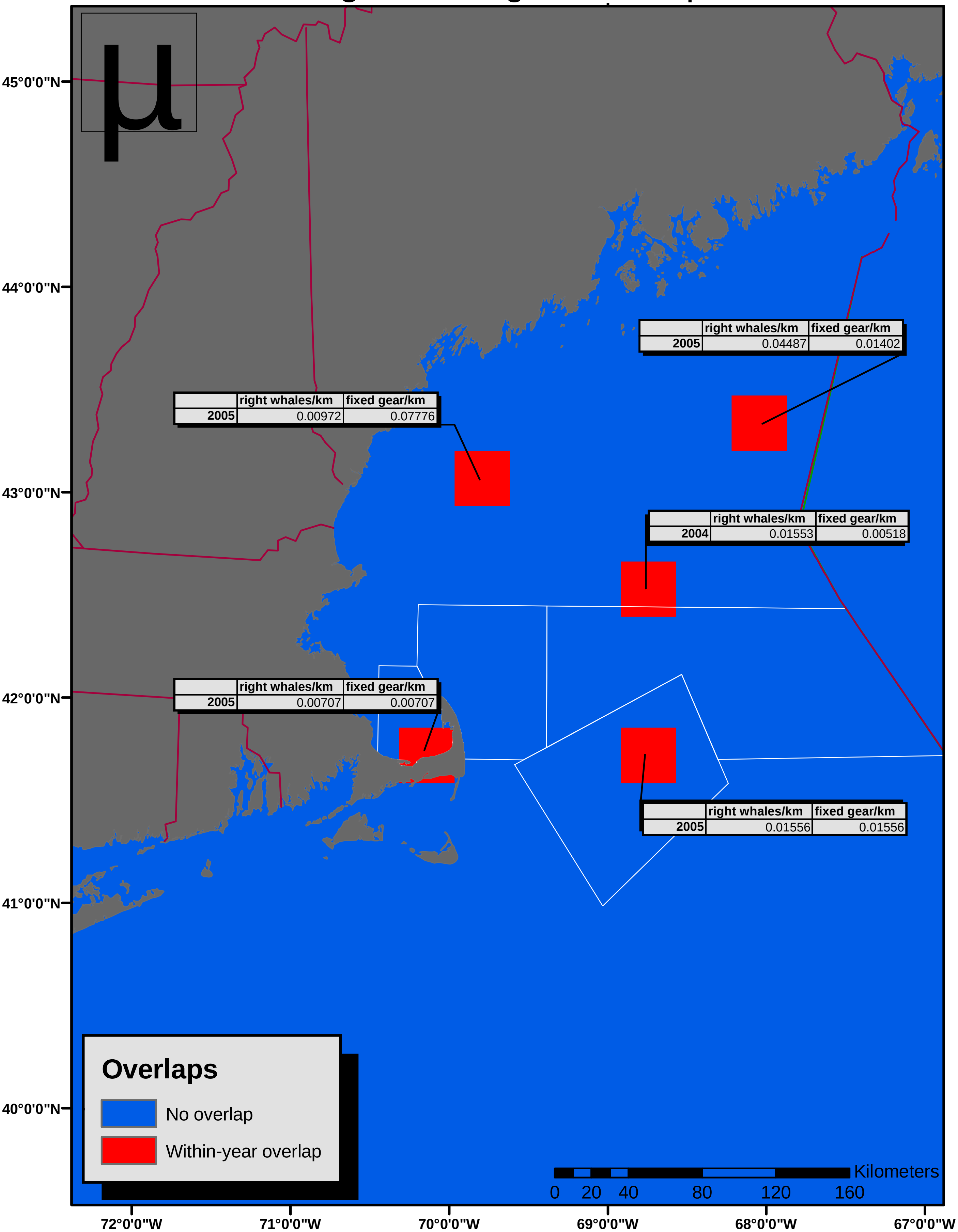
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 32: 30km grid cells, winter 2005 right whale/gear overlap



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 33: 30km grid cells, overall winter right whale/gear overlap



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 34: right whale and fixed gear averages per season

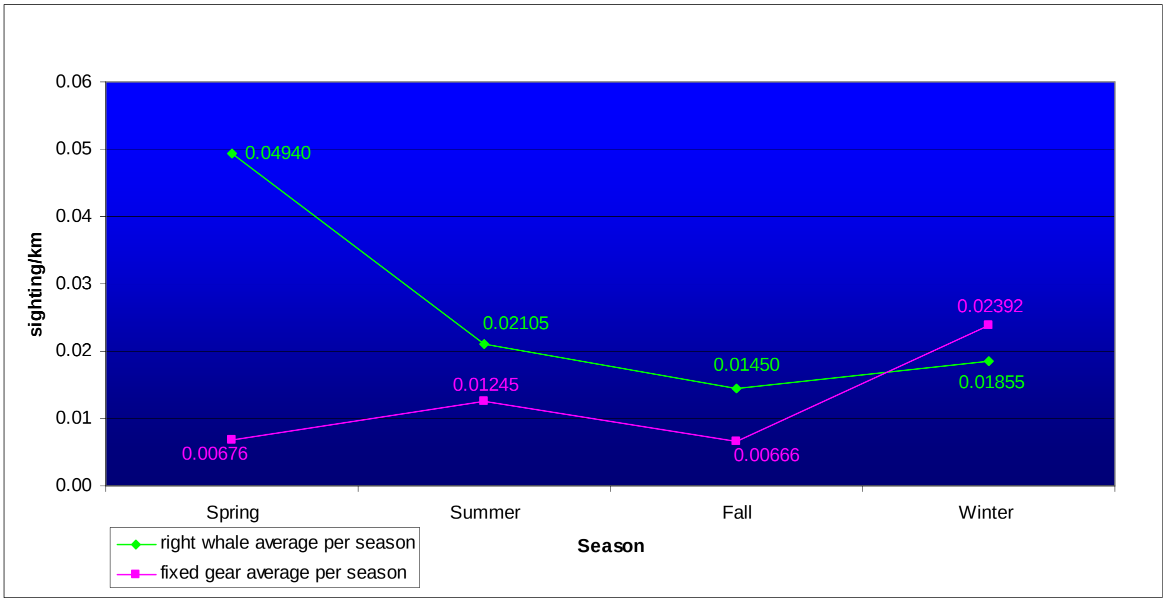
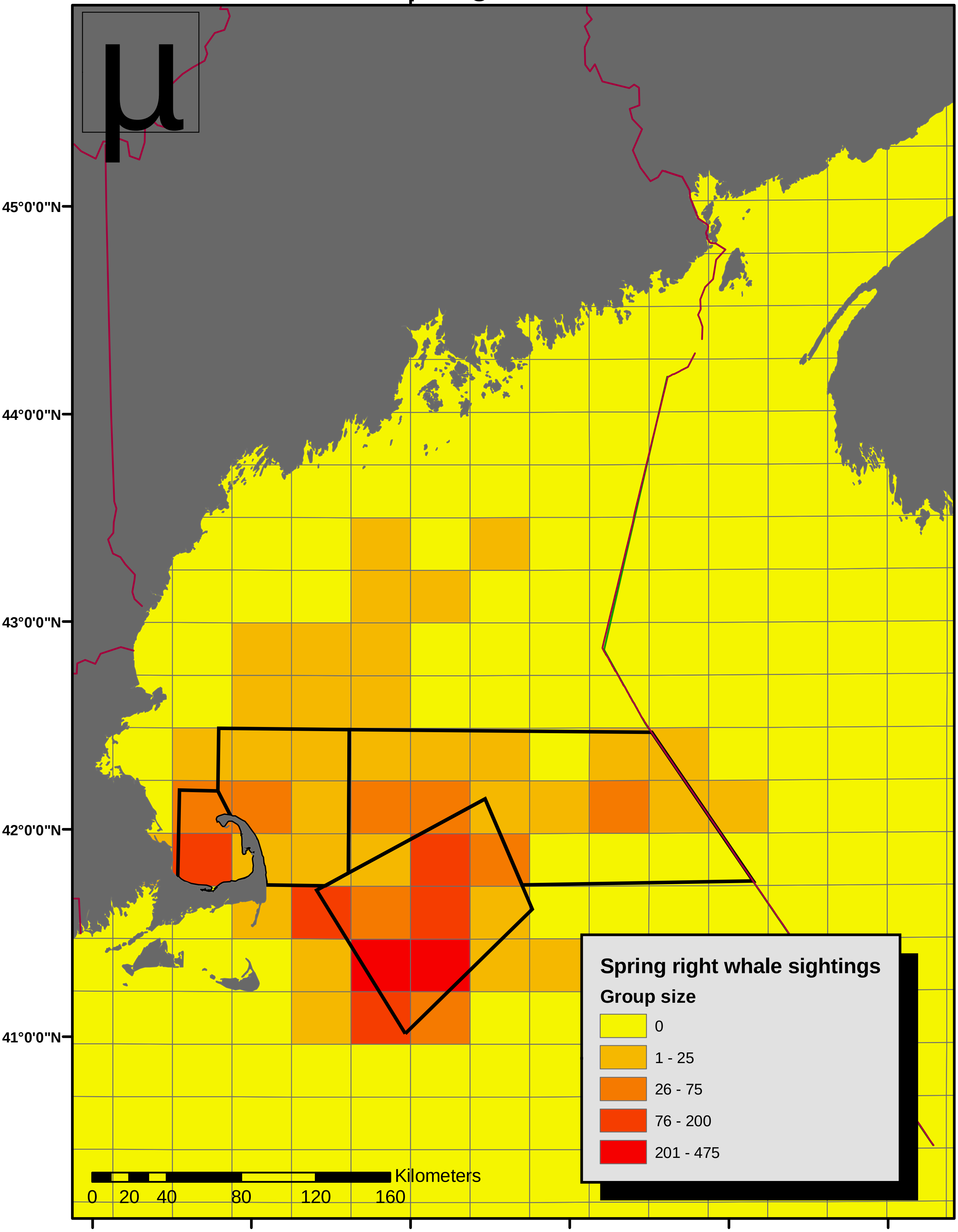
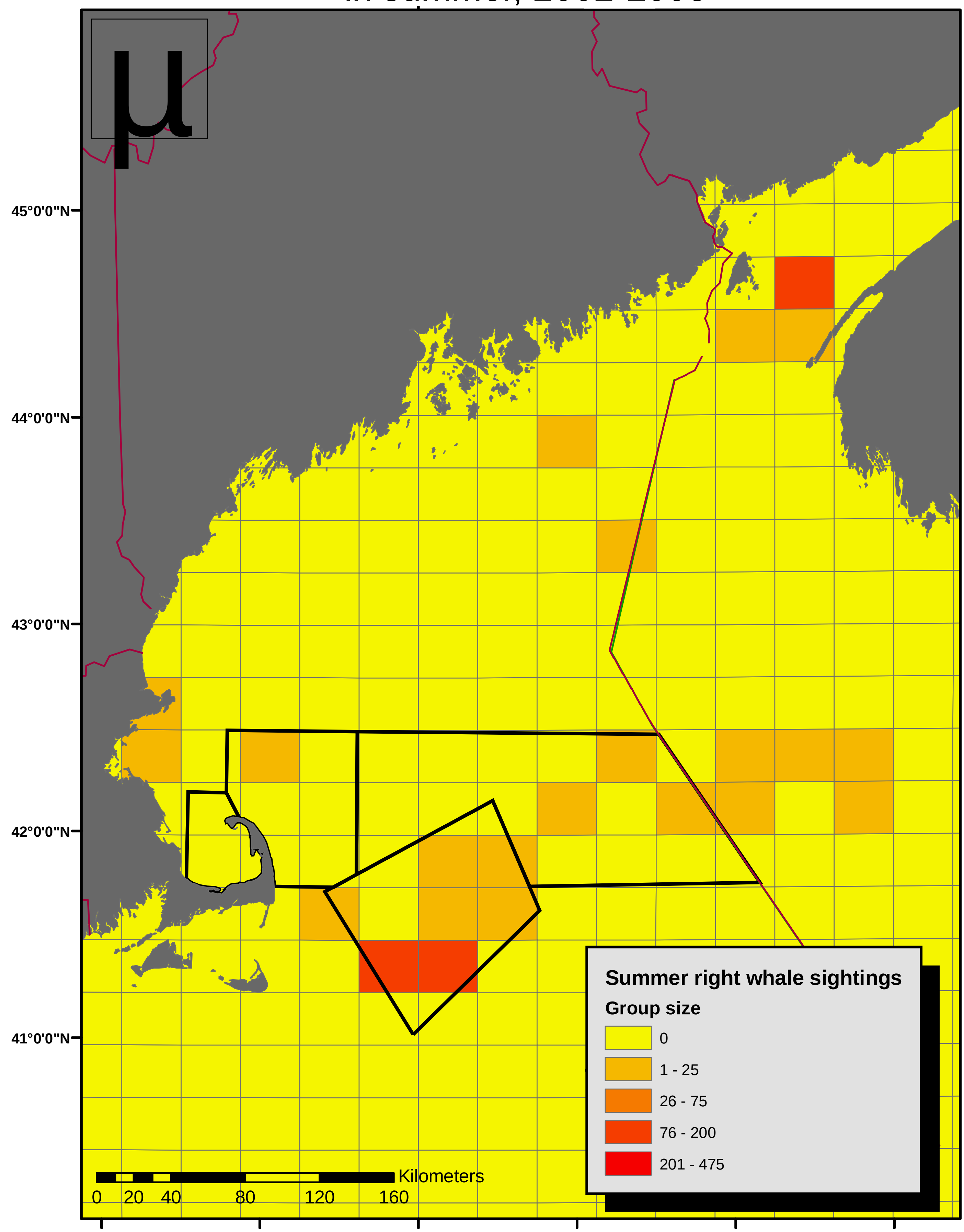


Fig. 35: right whale locations in spring, 2002-2005



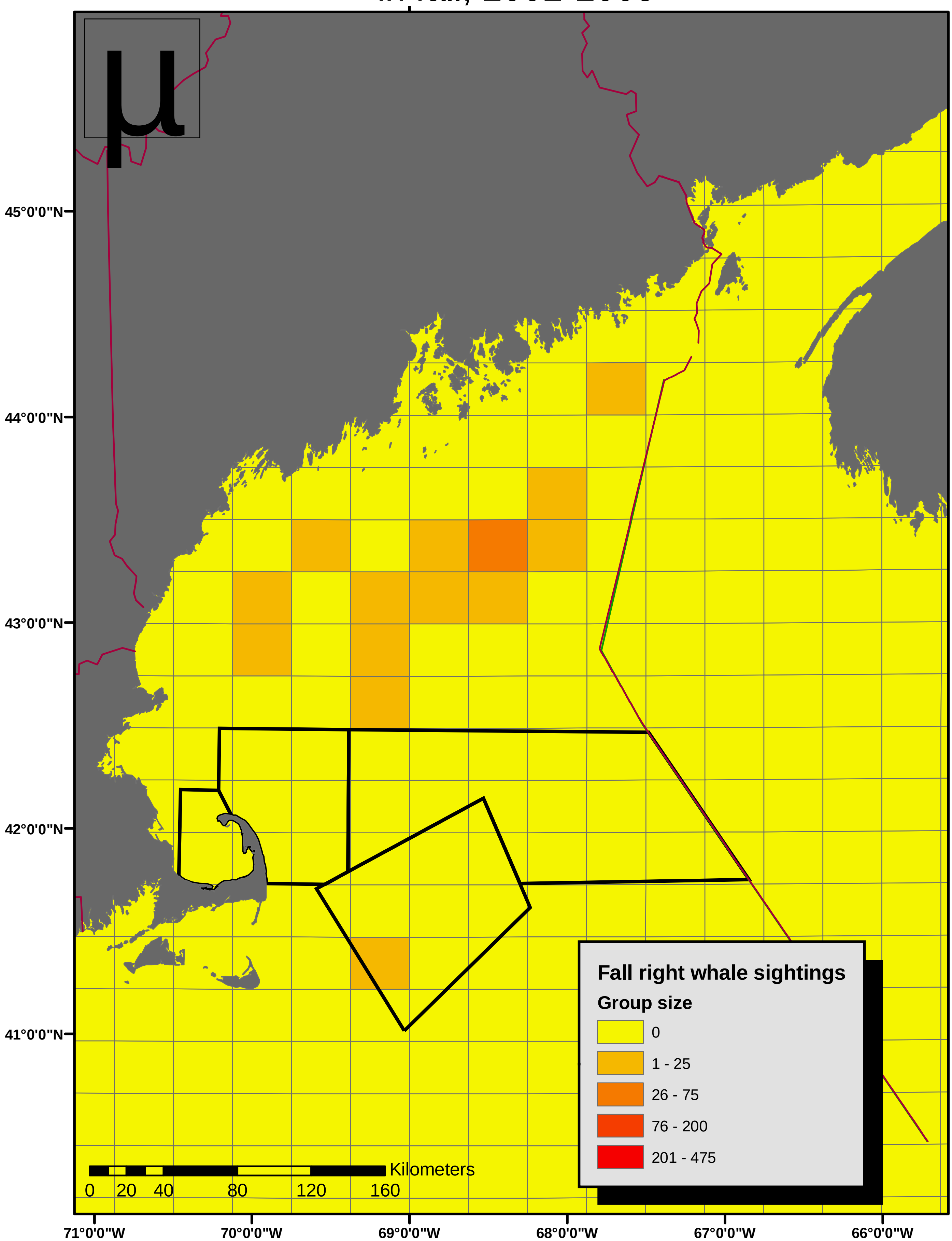
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 36: right whale locations in summer, 2002-2005



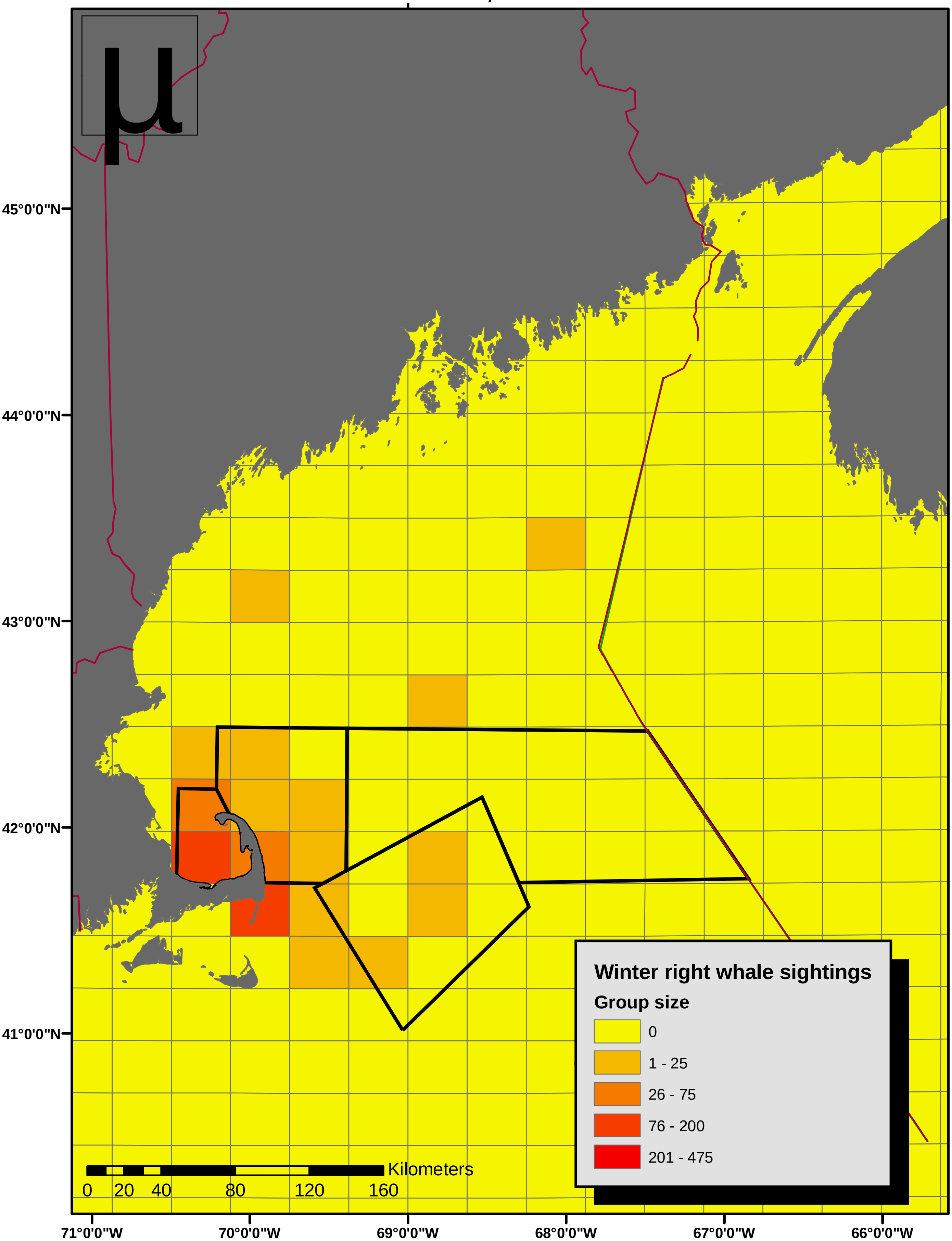
Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 37: right whale locations
in fall, 2002-2005



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 38: right whale locations in winter, 2002-2005



Map author: Brendan Hurley
Map created: 2/26/07
Projection: Universal Transverse Mercator, zone 19N

Fig. 39: 2001 state of Massachusetts lobster harvest by month
(reported with percentage of total catch) Dean et al. 2002

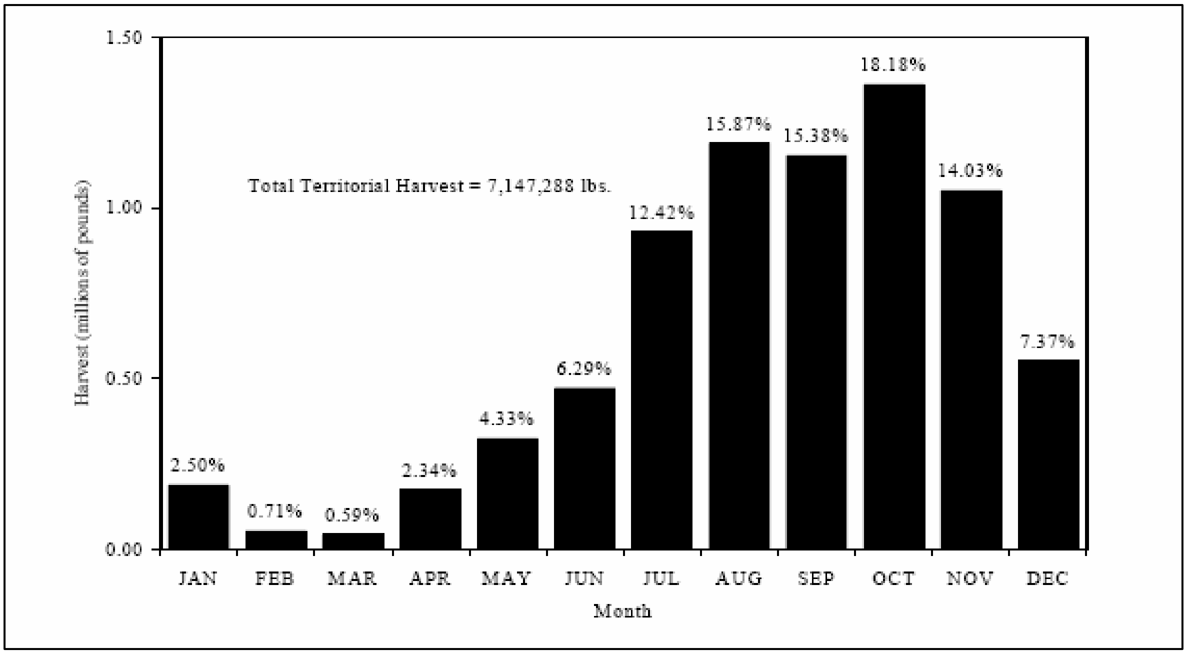


Fig. 40: 2002 state of Massachusetts lobster harvest by month
(reported with percentage of total catch) Dean et al. 2004

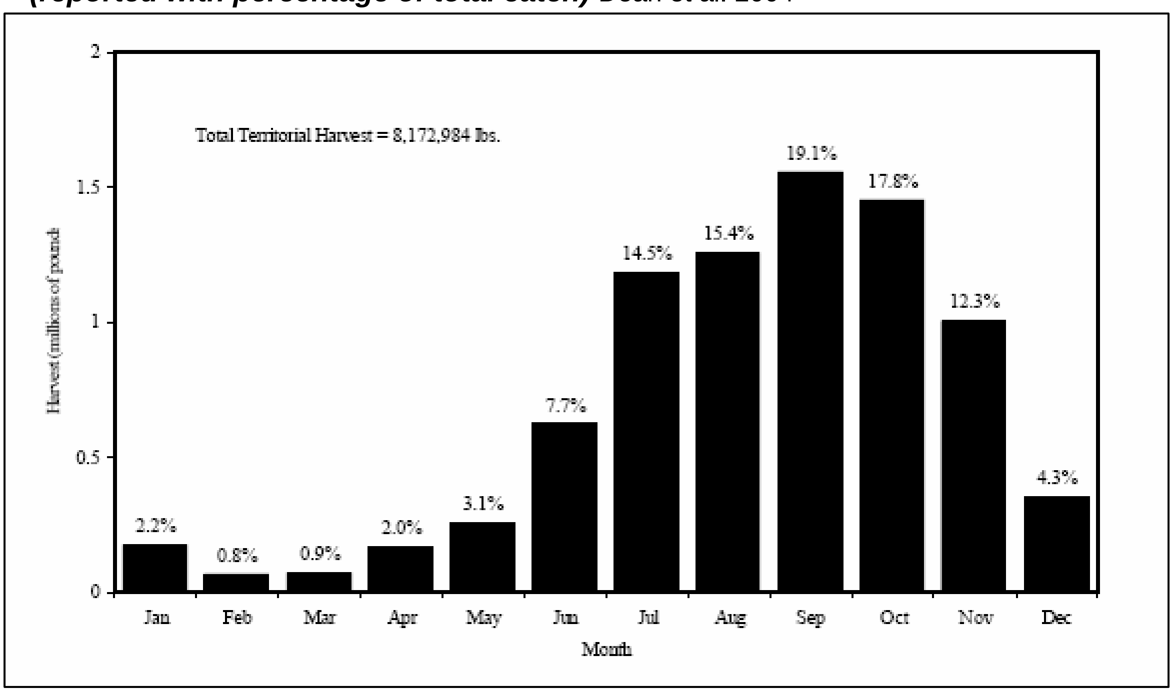


Fig. 41: 2003 state of Massachusetts lobster harvest by month
(Territorial refers to Massachusetts state waters; non-territorial refers to offshore federal waters) Dean et al. 2005

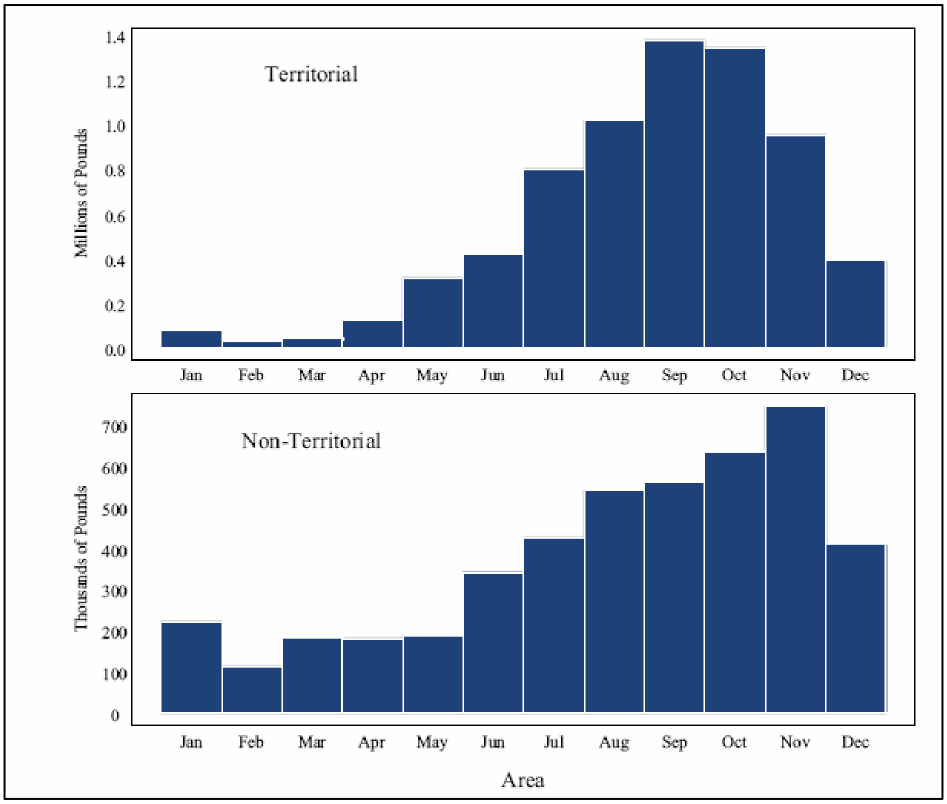


Fig. 42: 2004 state of Massachusetts lobster harvest by month
(Territorial refers to Massachusetts state waters; non-territorial refers to offshore federal waters) Dean et al. 2006

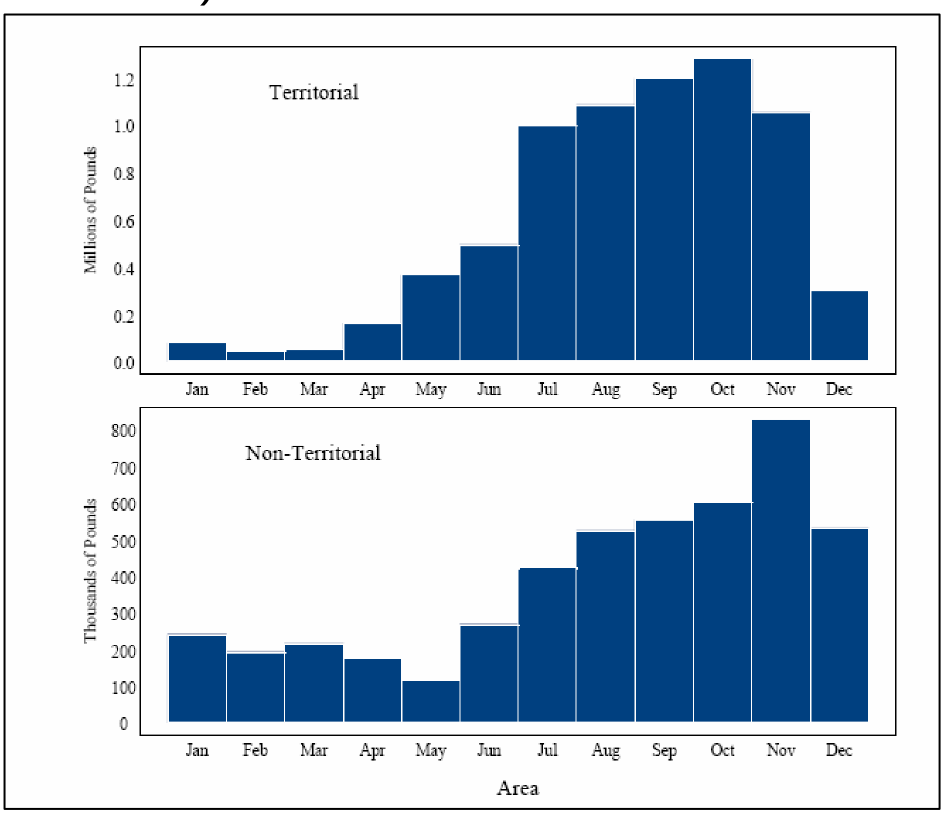


Fig. 43: 2001 state of Massachusetts lobster harvest by area

(Dean et al. 2002)

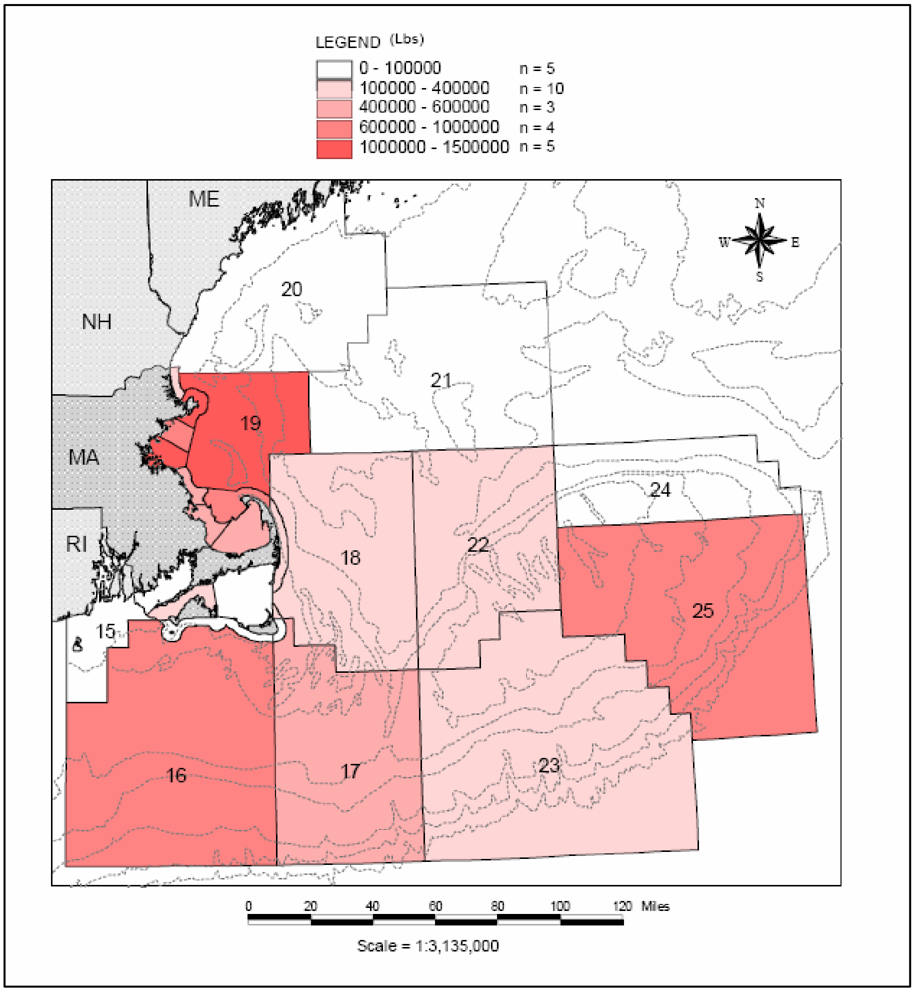


Fig. 44: 2002 state of Massachusetts lobster harvest by area

(Dean et al. 2004)

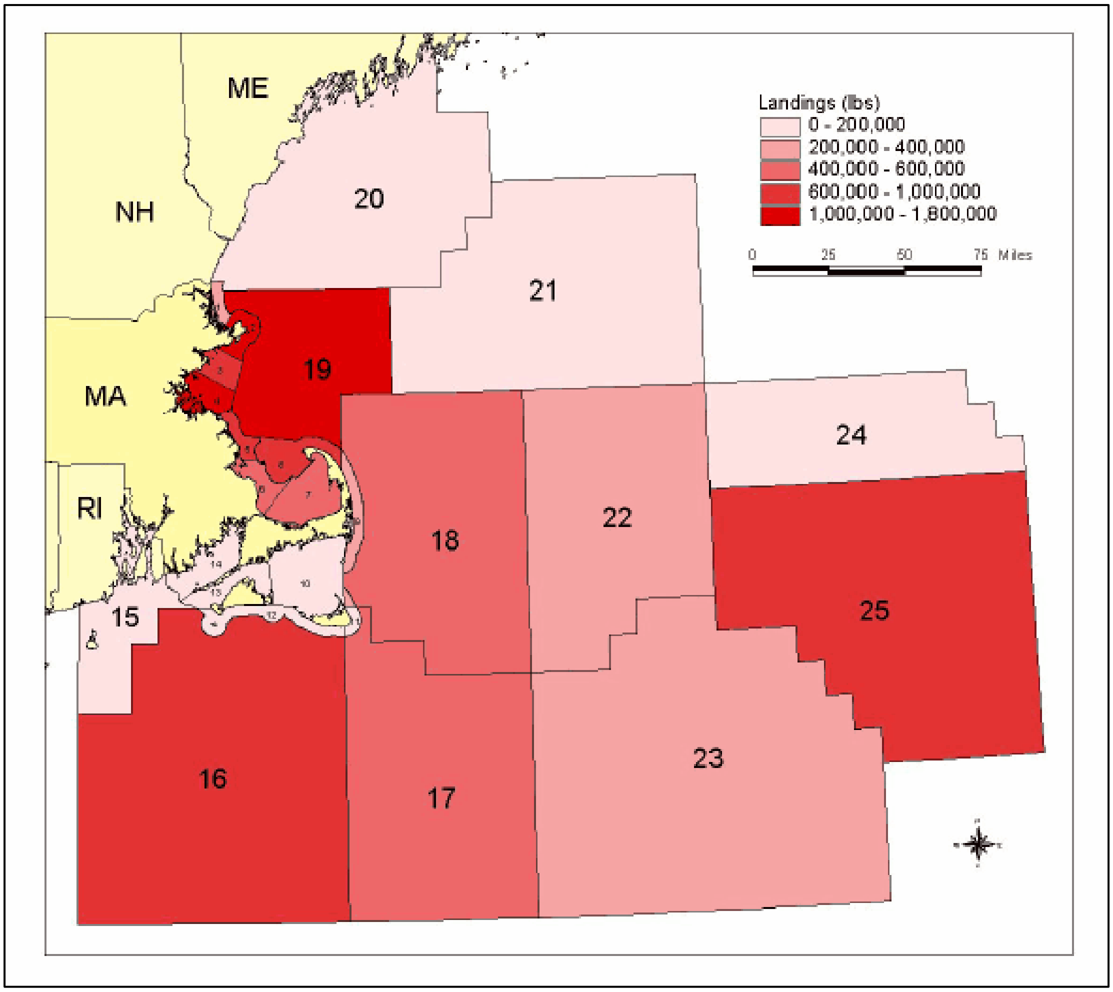


Fig. 45: 2003 state of Massachusetts lobster harvest by area

(Dean et al. 2005)

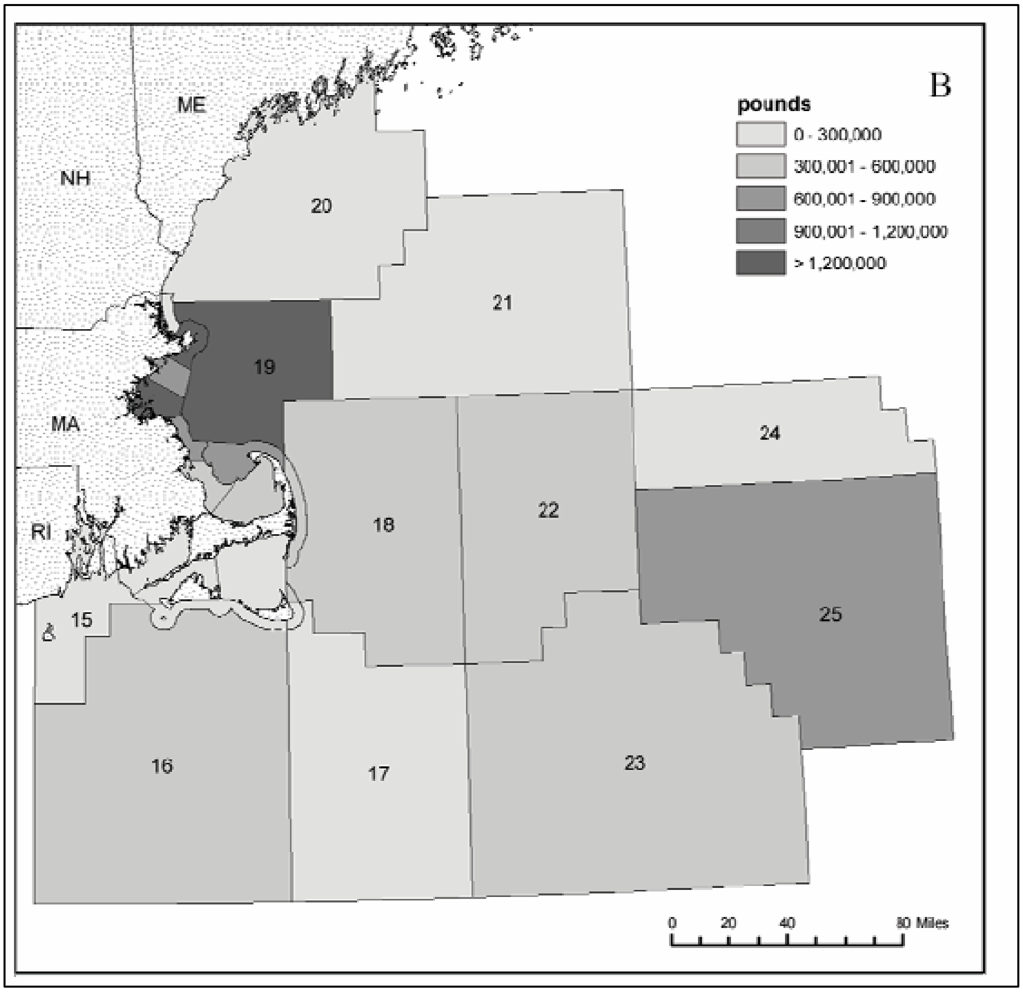


Fig. 46: 2004 state of Massachusetts lobster harvest by area

(Dean et al. 2006)

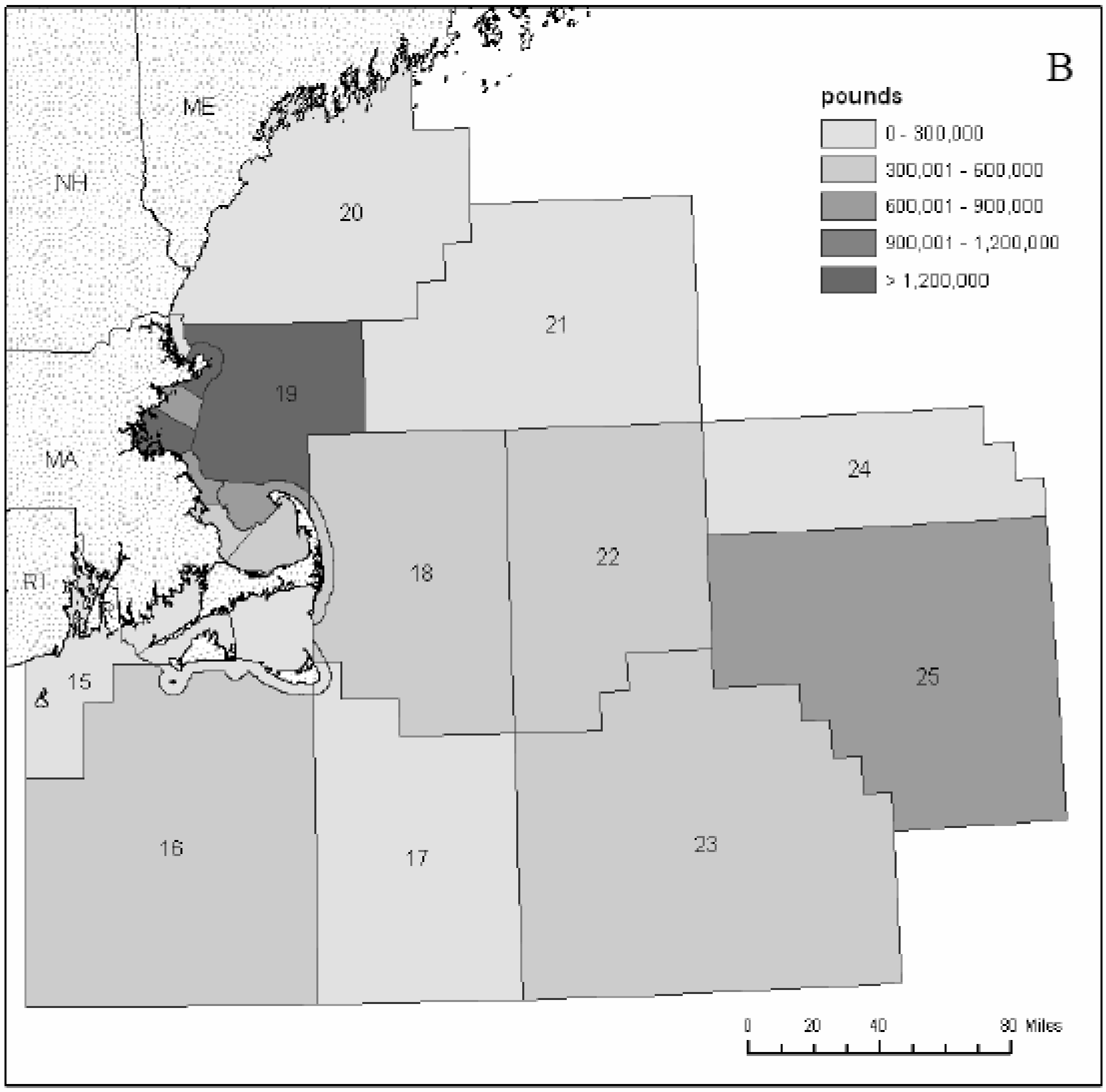


Fig. 47: Area where lobster statistical reporting area 18 overlaps the persistent right whale/fishing gear overlap.