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DISTRIBUTION OF MOLIDAE IN THE NORTHERN GULF OF MEXICO

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ABSTRACT We compiled all available sighting, stranding and bycatch data for the Family Molidae (molas) in the northern Gulf of Mexico (NGOM) to assess spatial and temporal distribution. Overall, 483 records were collected from shipboard and aerial surveys, fisheries bycatch, and strandings. Molas were recorded year-round, with a ubiquitous distribution in both nearshore and offshore waters. Ocean sunfish (*Mola mola*) were sighted with greatest frequency during the winter (December thru April) in sea surface temperature <24° C. Potential reasons for increased sightings during winter may be related to the lack of a well-defined thermocline in the NGOM; the species' "basking" behavior associated with thermoregulation; and oxygen replenishment after long, deep dives to oxygen-deficient depths.

RESUMEN Para determinar la distribución espacio temporal de la familia Molidae (molas) en la parte norte del Golfo de México (NGOM) se realizo una compilación de todos los datos de avistamientos (desde embarcaciones y censos aéreos), capturas pesqueras y varamientos disponibles. En total 483 registros fueron colectados. Los molas fueron registrados a lo largo de todo el año con una distribución universal en aguas tanto costeras como oceánicas. El pez sol (*Mola mola*) fue avistado con mayor frecuencia durante el invierno (de Diciembre a Abril) en donde la temperatura superficial del mar fue menor a 24° C. Una de las posibles razones del incremento de avistamientos durante el invierno puede estar relacionada a la bien definida termoclina en la NGOM; la especie muestra un comportamiento de reposo ("basking") asociado a la termorregulación y reabastecimiento de oxigeno después de un buceo prolongado en aguas profundas con deficiencia de oxigeno.

Introduction

Members of the Family Molidae (molas) are a poorly understood, highly derived group of fishes. This family is composed of four species—the slender mola (*Ranzania laevis*), sharptail mola (*Masturus lanceolata*), ocean sunfish (*Mola mola*), and southern ocean sunfish (*Mola ramsayi*). Recent genetic analysis confirms that there are two species within the genus *Mola*, with *Mola ramsayi* being limited to the southern hemisphere (Bass et al. 2005). The ocean sunfish is the most frequently encountered mola species, and it is considered sympatric with the sharptail mola (Santini and Tyler 2002).

Molas are found worldwide in tropical to temperate seas (e.g., Parenti 2003, Houghton et al. 2006). Despite their widespread distribution, little is known of the ecology, habitat preferences, physiology and metabolism of molas. In fact, most ecological data for these fishes are collected opportunistically as anecdotal accounts, strandings, and incidental catches. Recent reports indicate that molas are deep divers, active swimmers, and a common component throughout the water column in areas where they occur (Harbison and Janssen 1987, Seitz et al. 2002, Cartamil and Lowe 2004). Furthermore, incidental catches in fisheries demonstrate that molas are major components of gillnet and driftnet fisheries (e.g., Silvani et al. 1999, Cartamil and Lowe 2004) and are often also caught on longlines (e.g., Seitz et al. 2002, Desjardin 2005, this paper).

Since molas are not commercially important species, there are limited resources available to exclusively study these fishes and any available data or observations must be fully utilized to establish baseline information on the ecology and habitat association of these fishes where they occur. One example is an anecdotal report of a sharptail mola struck by the Johnson Sea-link submersible at a depth of 670 m off Chubbs Cays in The Bahamas (Harbison and Janssen 1987). Another example is results from opportunistic tagging of a sharptail mola with a pop-up satellite tag (PSAT) while conducting pelagic longlining in the northern Gulf of Mexico NGOM (Seitz et al. 2002). Their study reported that the sharptail mola spent 92.5% of its time at depths between 5 and 200 m, < 3% of the time at depths shallower than 5 m, and ~86% of the time in water with sea surface temperature (SST) greater than 20° C. Finally, Cartamil and Lowe (2004) tracked eight ocean sunfish using acoustic tags over a 24 to 72 hr period off southern California. Their data showed that ocean sunfish are active swimmers, able to travel distances of ~ 26 km/d, reaching speeds of 3.2 km/hr when active, and diving deeper than 50 m. These are good examples of the types of studies that are paramount to understanding more about molas, and specifically, the ocean sunfish.

Currently, under mandate from the Marine Mammal Protection Act (MMPA), the National Marine Fisheries Service (NMFS) is required to conduct assessment surveys designed to estimate the abundance of cetacean (whale and dolphin) stocks that reside in US waters. During these surveys, other "species of interest" (including molas) are commonly sighted and recorded. Our objective here was to document the distribution of molas in the NGOM. We used aerial and shipboard survey data, opportunistic sightings, incidental fisheries bycatch, stranding records, and published tagging data for molas to document the family's distribution in the NGOM.

METHODS AND MATERIALS

Study area

The study area was defined as waters of the NGOM between the US-Mexico border and Key West, Florida, from the shoreline extending south to the outer limits of the Economic Exclusive Zone (EEZ) into waters seaward of the 3,000 m isobath (ca. 699,070 km^2). Major features of the NGOM include the wide shelf (up to 200 km) off Florida, Texas, and Louisiana. The shelf is narrower off the Florida Panhandle near DeSoto Canyon, the Mississippi River Delta, and southern Texas. The continental slope is a steep escarpment from 1,000–2,000 m in the eastern NGOM. This area is also subject to the quasi-annual incursion of the Loop Current (Sturges and Evans 1983), which can extend north of Tampa Bay, Florida (~28°N). This incursion can create cyclonic and anti-cyclonic gyres that can extend onto the western Florida shelf (Paluszkiewicz et al. 1983), creating nutrient upwelling episodes along its edges.

Data types

All available sighting, stranding, and bycatch records for molas were compiled. Previously published records were reviewed and included here (e.g., Palmer 1936, Rivero 1936, Gunter 1941, Baughman 1950, Springer and Bullis 1956, Kemp 1957, Dawson 1965, Bright and Pequegnat 1974, Seitz et al. 2002).

NMFS-SEFSC longline fishery bycatch data

The NMFS deploys fishery observers to collect catch data from US commercial fishing and processing vessels. In 1992, the NMFS initiated scientific sampling of the US large pelagic fisheries swordfish/tuna longline fleet. Scientific observers are placed aboard vessels to report daily catch and effort information, as well as bycatch of non-target species (Beerkircher et al. 2002). Information for the Gulf of Mexico is collected by the Pelagic Observer Program located at the Southeast Fisheries Science Center (SEFSC) Miami Laboratory. We obtained Molidae information from 1992 through 2005.

TABLE 1

Summary of Molidae records, separated by record type, season and data source. The category 'other' refers to miscellaneous records including published and anecdotal accounts, a location point from tagging, and sightings not from marine mammal aerial and shipboard surveys. OS = ocean sunfish (*Mola mola*), SM = sharptail mola (*Masturus lanceolatus*), and UID mola = unidentified species of mola.

Source/Mola	F	Sp	Su	W	Total
Aerial					
OS	9	13	8	71	101
Shipboard					
OS	0	36	4	0	40
Bycatch					
OS	1	6	2	2	11
SM	6	16	10	13	45
UID mola	62	64	44	95	265
Stranding					
OS	0	0	0	2	2
SM	0	0	0	1	1
Other					
OS	0	3	5	4	12
SM	3	0	1	2	6
Totals	81	138	74	189	483

Aerial and shipboard survey data

Data collected during NMFS-SEFSC shipboard surveys were used to provide additional information on the distribution of molas. These surveys were conducted during the summers of 2001 and 2003, while the 1996, 1997, 1999, 2000, and 2004 surveys occurred during the spring (Table 1; Figure 1A). The 2001 survey covered shelf waters between the 10 and 500 m isobaths, while the 2003 and 2004 surveys focused on oceanic waters between the 200 m isobath and the EEZ. Detailed shipboard survey protocols can be found in Fulling et al. (2003), Mullin and Fulling (2004), and Mullin et al. (2004).

Three primary aerial surveys using line-transect methodologies (Buckland et al. 2001) were conducted by the NMFS-SEFSC; these were GulfCet I, GulfCet II, and the Gulf of Mexico (GOMEX) surveys. In 1992, the NMFS-SEFSC, in cooperation with the Minerals Management Service, initiated research to assess cetacean abundance/distribution in the NGOM; this program was known as the GulfCet Program. The GulfCet I aerial surveys were conducted quarterly during 1992–1994; the study area was bounded by the longitude of the Florida-Alabama border and the Texas-Mexico border, taking place between the

100 and 2,000 m isobaths (Hansen et al. 1996; Figure 1B). GulfCet II surveys were biannual surveys during 1996–1998 covering the shelf and offshore waters (out to the 2,000 m isobath) off Alabama and Florida (Mullin and Hoggard 2000; Figure 1B). The GOMEX aerial surveys conducted in 1992–1994 were fall surveys designed to provide information on bottlenose dolphin (*Tursiops truncatus*) abundance/distribution (Blaylock and Hoggard 1994). These surveys covered bays, sounds, estuaries and shelf waters out to the 200 m isobath. The GOMEX surveys only covered 1/3 of the NGOM each year; and therefore, did not cover the entire NGOM in one survey (Figure 1C). Aerial surveys during 1997–1998 were supplemented with an infrared temperature probe mounted on the aircraft, thereby allowing instantaneous SST for each sighting.

Results

We collected 483 mola occurrence records for the NGOM (Table 1). These did not include 2 known underwater sightings off the Dry Tortugas—one made by the Deep Worker submersible at 500 m by Sylvia Earle or an ROV sighting made at 520 m (Oceansunfish.org 2006), since exact coordinates or time of year could not be obtained. Molas (sharptail mola and ocean sunfish) were sighted in both nearshore, shallow waters and deep, offshore waters, with no obvious concentrations in any particular locations (Figure 2). Molas were sighted year-round (Figures 3A–D). No records of slender mola occurrence were collected in the NGOM. The greatest number of records were pelagic longline bycatches ($n = 265$) and were of unidentified mola species. Molas were sighted and caught with greatest frequency during the winter and spring ($n = 189$ and 138, respectively; Figure 3A, B). There were 166 ocean sunfish records, 101 of these were sightings made during aerial surveys. Winter aerial surveys accounted for 70% of the total sightings of the ocean sunfish ($n = 71$) with the greatest concentration of ocean sunfish occurring off the Florida Panhandle near DeSoto Canyon (Figure 4). Sixty-one of the 101 ocean sunfish sightings were collected in conjunction with instantaneous SST. These values ranged from 13.8–29.3° C ($\bar{x}$ = 19.9° C, $s_{\bar{x}}$ = 0.45) and 96.8% (n = 59/61) of those sightings occurred in temperatures < 25° C ($\bar{x}$ = 19.5° C, $s_{\bar{x}}$ = 0.40; Figure 5).

Discussion

It is evident from our findings that sharptail mola and ocean sunfish are widely distributed in NGOM and are found in shallow waters over the continental shelf, as well as deeper waters over the continental slope and abyssal plain. Temporal and spatial aspects related to GOMEX aerial survey effort in waters over the West Florida Shelf might explain the lack of sightings in this area. There is one area with a complete lack of aerial survey effort on the West Florida Shelf (Figures 1C). The remainder of the West Florida Shelf was surveyed during the fall, when we did not observe ocean sunfish basking. West of the Mississippi River, the lack of records is again likely due to the timing of the GOMEX aerial surveys—fall (Figure 1C). It should be noted that the DeSoto Canyon region is one of the few areas in the NGOM that received year-round aerial survey effort (specifically, GOMEX and GulfCet II).

Bycatch records and shipboard survey data proved invaluable for documenting the occurrence of these fishes, since these data addressed deeper waters (out to and seaward of the EEZ) that aerial surveys could not cover due to fuel/time constraints. Additionally, while not extensive with regards to coverage, fisheries bycatch data provided solid information on the distribution of molas throughout the year. These data were independent of weather conditions that consistently affect sightability of the species with systematic surveys. Without these bycatch records, the interpretation of aerial survey data would have likely restricted the distribution of ocean sunfish in the NGOM to the DeSoto Canyon area during the winter when SST was lowest, as this is the region and season with the greatest number of aerial survey ocean sunfish sightings.

Several studies have demonstrated a relationship between cool water and mola sightings. For example, Lee (1986) sighted molas with greatest frequency during cool water months (March–May, n = 5/20 sightings) in shallow waters off of North Carolina. Sims and Southall (2002) reported that nearly all of their ocean sunfish sightings occurred between 13° and 17° C in the English Channel, UK. Cartamil and Lowe (2004) found that acoustically tagged ocean sunfish encountered water temperatures ranging from 6.8 to 21° C off Southern California. Our study supports these findings, given that the mean SST for ocean sunfish sightings from our aerial surveys was ~19.9° C. However, both of the studies mentioned occurred in areas where the water temperature is consistently cooler year-round than the waters in NGOM and during seasons when our sighting frequencies were the lowest (summer). Within the NGOM, Seitz et al. (2002) reported that a PSAT-tagged sharptail mola spent ~86% of the time in waters with temperatures > 20° C, was located rarely above 5 m depth, and made dives to ~700 m experiencing water temperatures as low as 7° C. The animal tagged by Seitz et al. (2002), however, was caught on a longline with a hook set at 85 m in April and SST was 23.9° C. While water temperature preferences of the ocean sunfish are basin-specific, it is

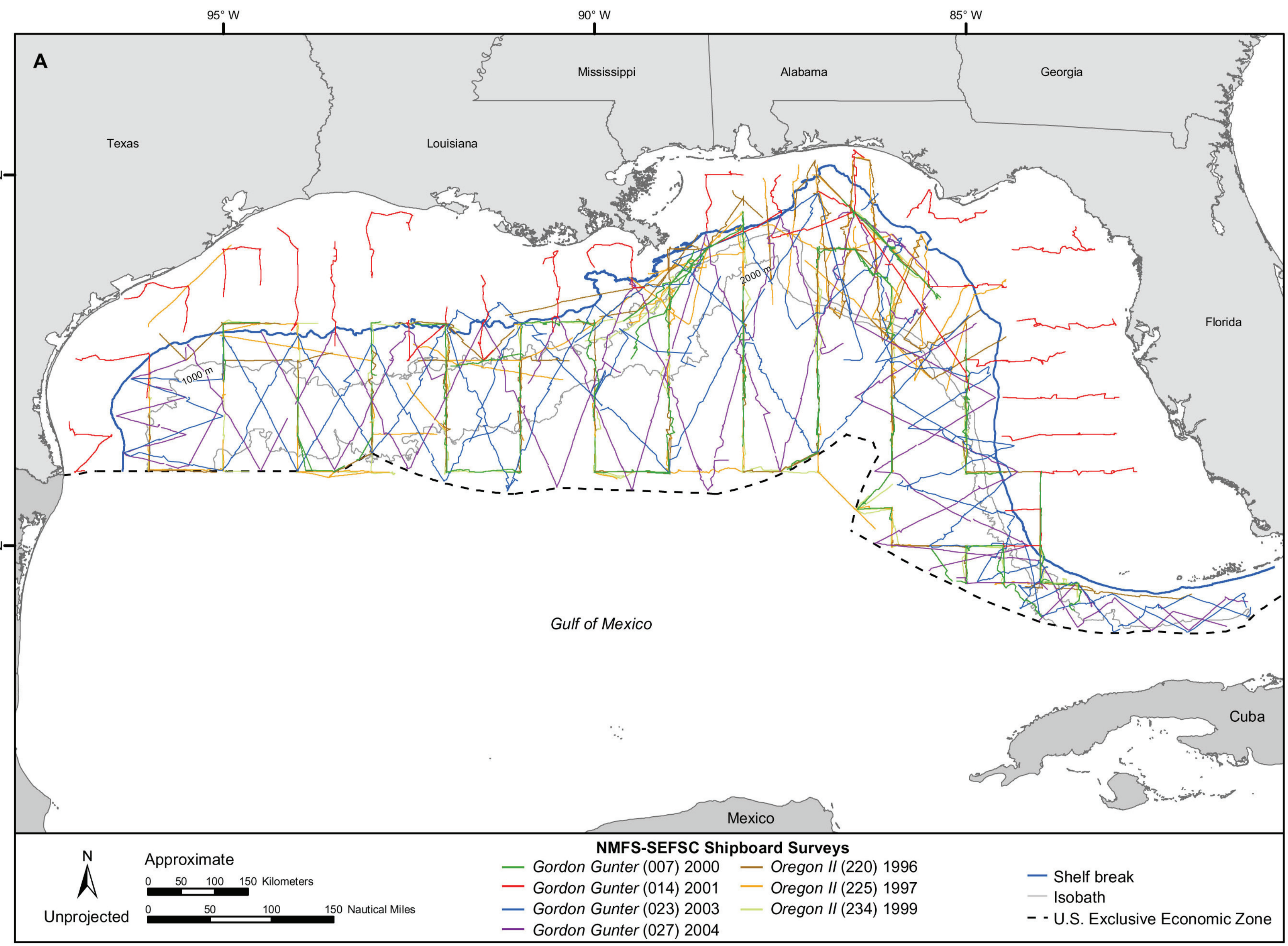
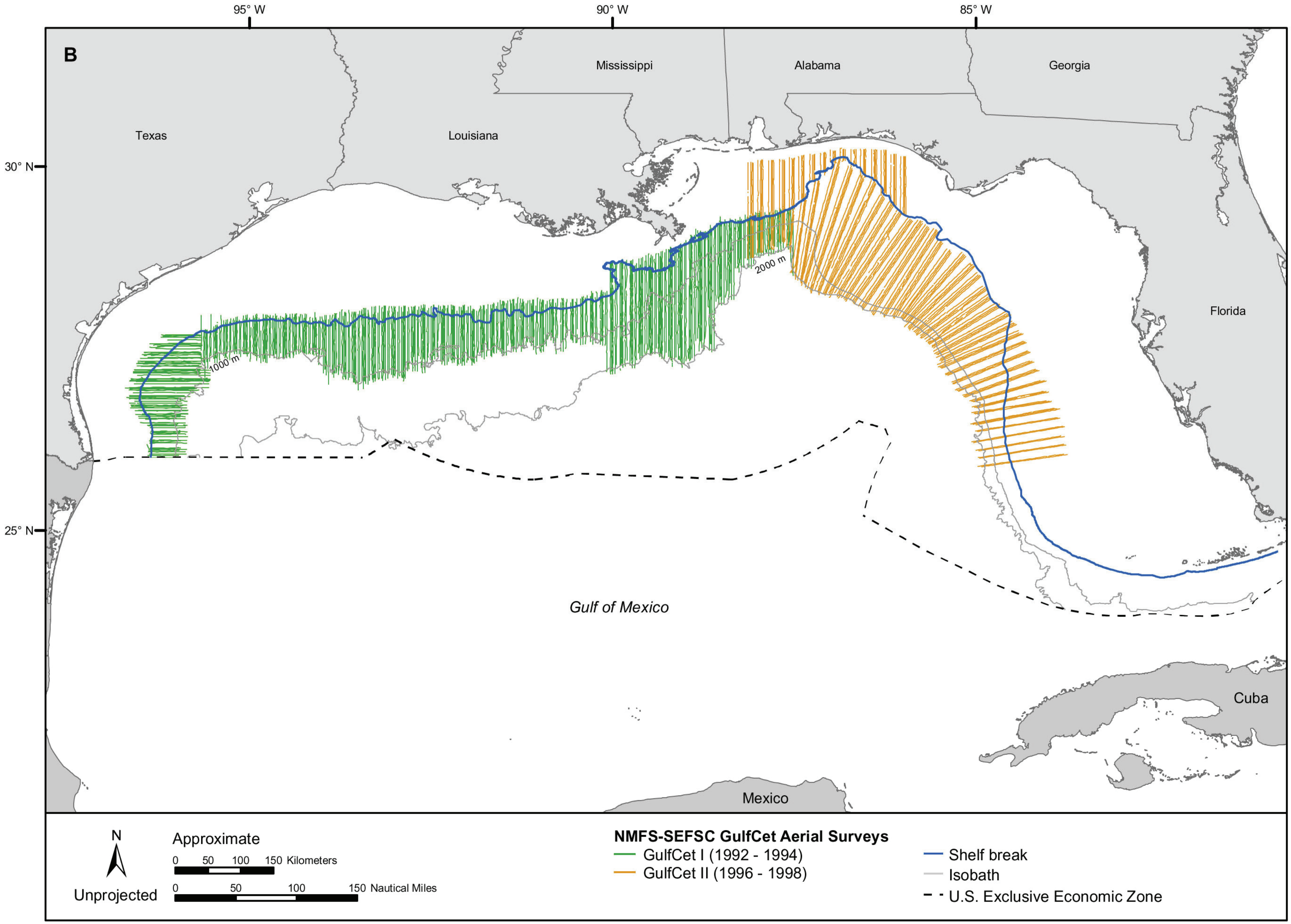


Figure 1. Survey effort from shipboard (A), and aerial surveys [GulfCet I and II (B); and GOMEX (C)] in the northern Gulf of Mexico. Shelf break, isobaths (1000 m increments), and Economic Exclusive Zone are depicted.


B
95° W
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Texas
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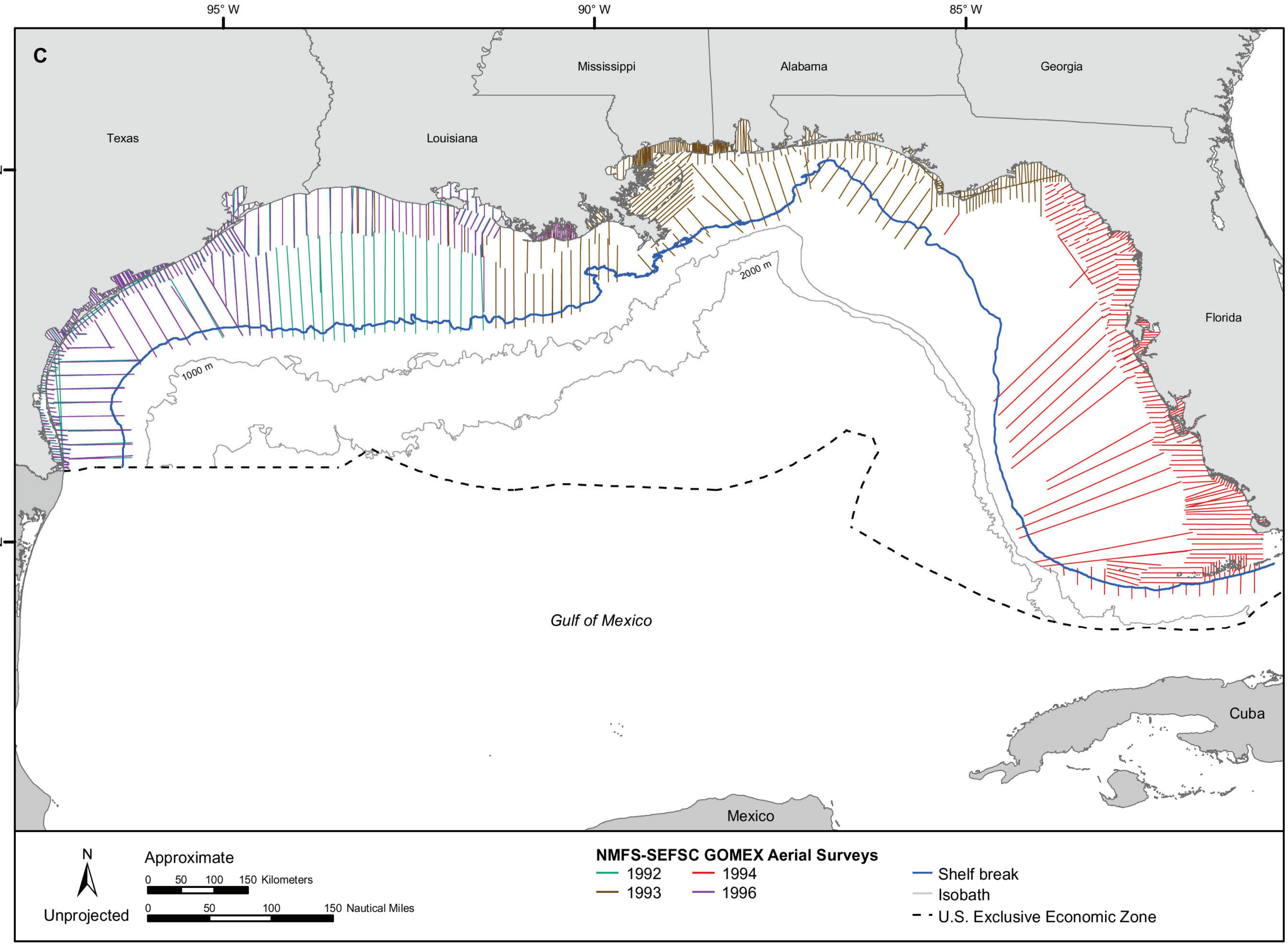
NMFS-SEFSC GulfCet Aerial Surveys
GulfCet I (1992 - 1994)
GulfCet II (1996 - 1998)
Shelf break
Isobath
U.S. Exclusive Economic Zone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NMFS-SEFSC GOMEX Aerial Surveys
1992
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Shelf break
Isobath
U.S. Exclusive Economic Zone

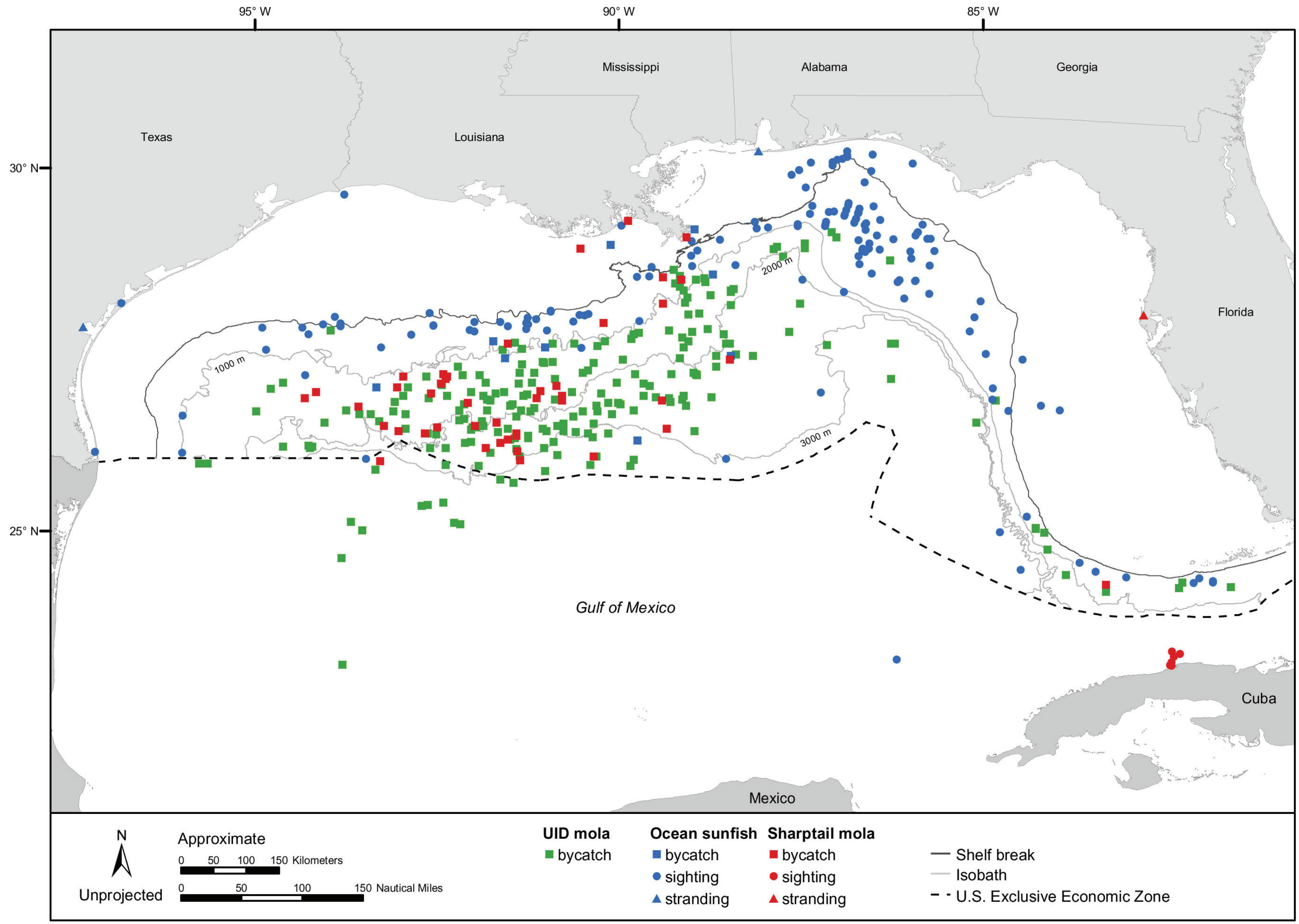


Figure 2. **Distribution of Molidae from shipboard and aerial surveys, longline fisheries bycatch, strandings, published records, and anecdotal accounts. Shelf break, isobaths (1000 m increments), and Economic Exclusive Zone are depicted.**

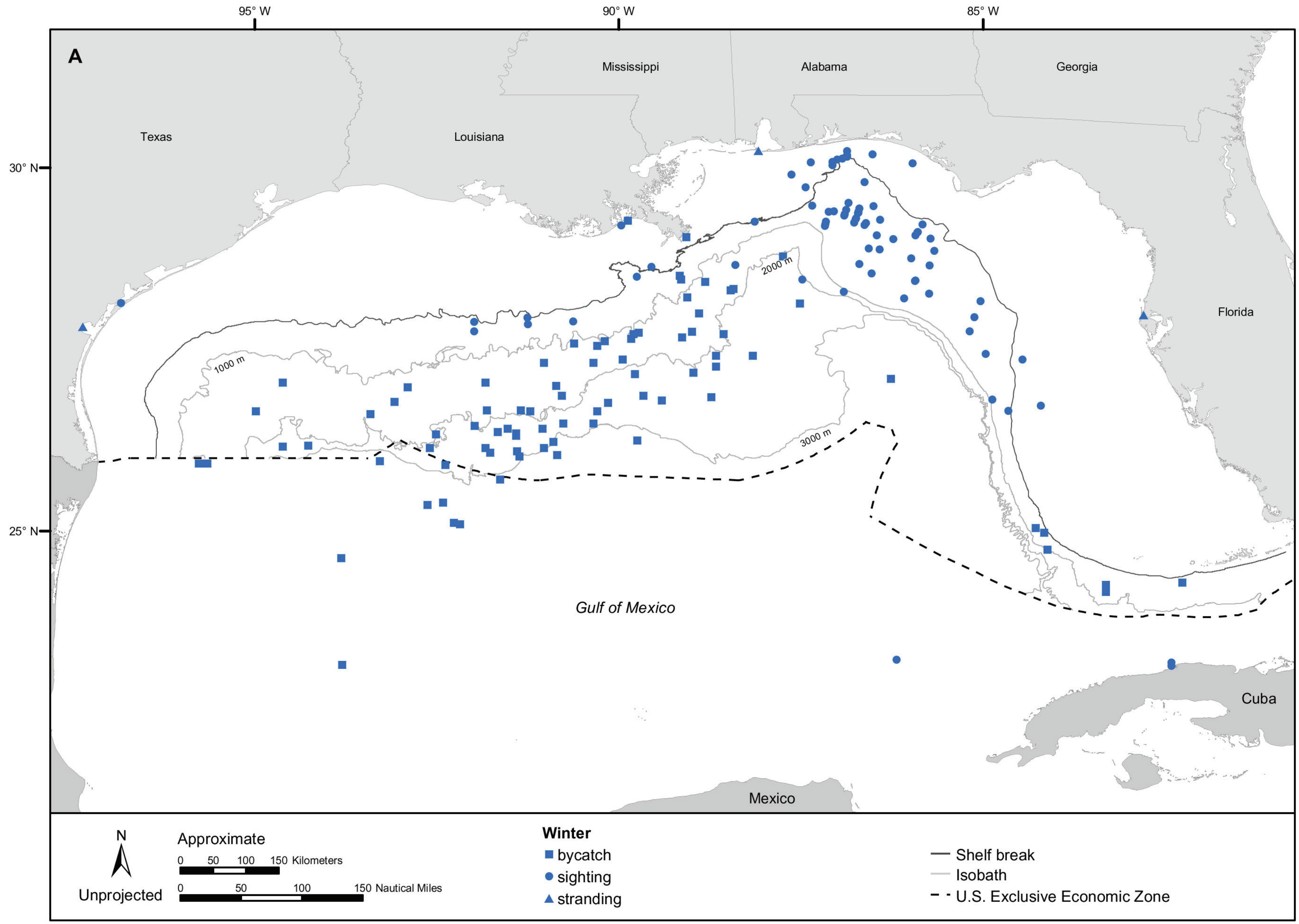
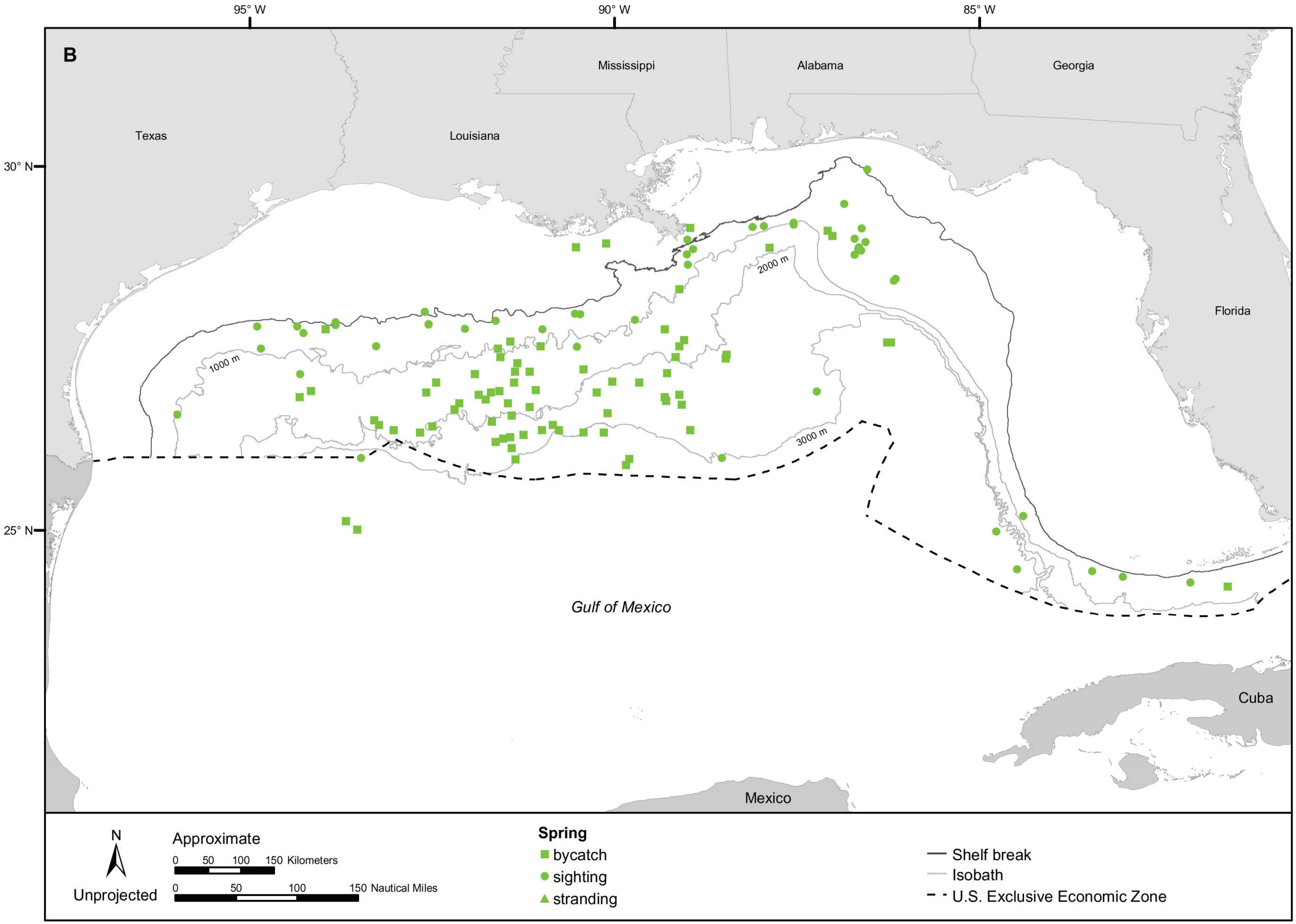


Figure 3. Seasonal break downs of Molidae from shipboard and aerial surveys, fisheries bycatch, strandings, published records, and anecdotal accounts. Winter (A), Spring (B), Summer (C), and Fall (D). Shelf break, isobaths (1000 m increments), and Economic Exclusive Zone are depicted.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Cuba
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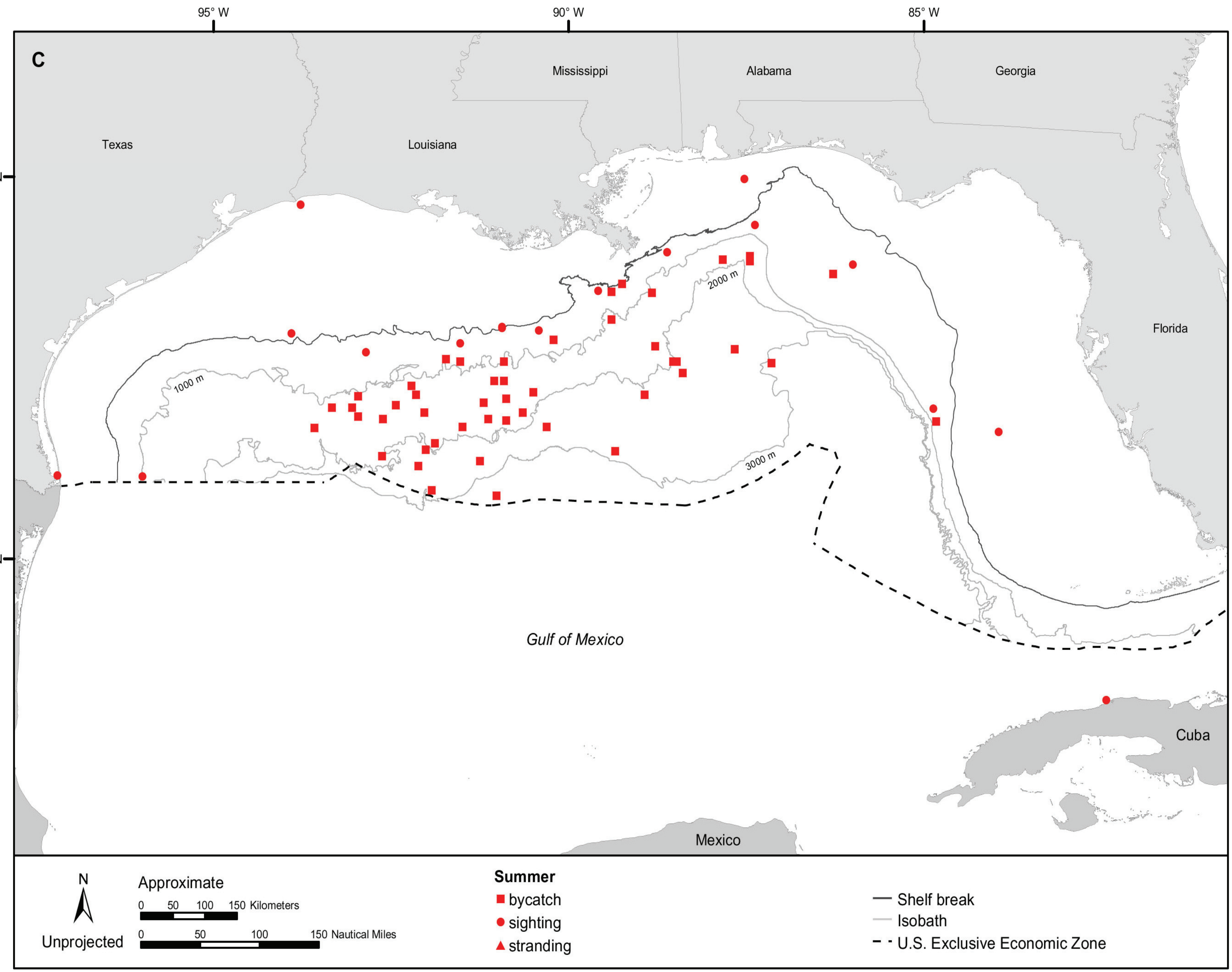
0 50 100 150 Nautical Miles
Spring
bycatch
sighting
stranding
Shelf break
Isobath
U.S. Exclusive Economic Zone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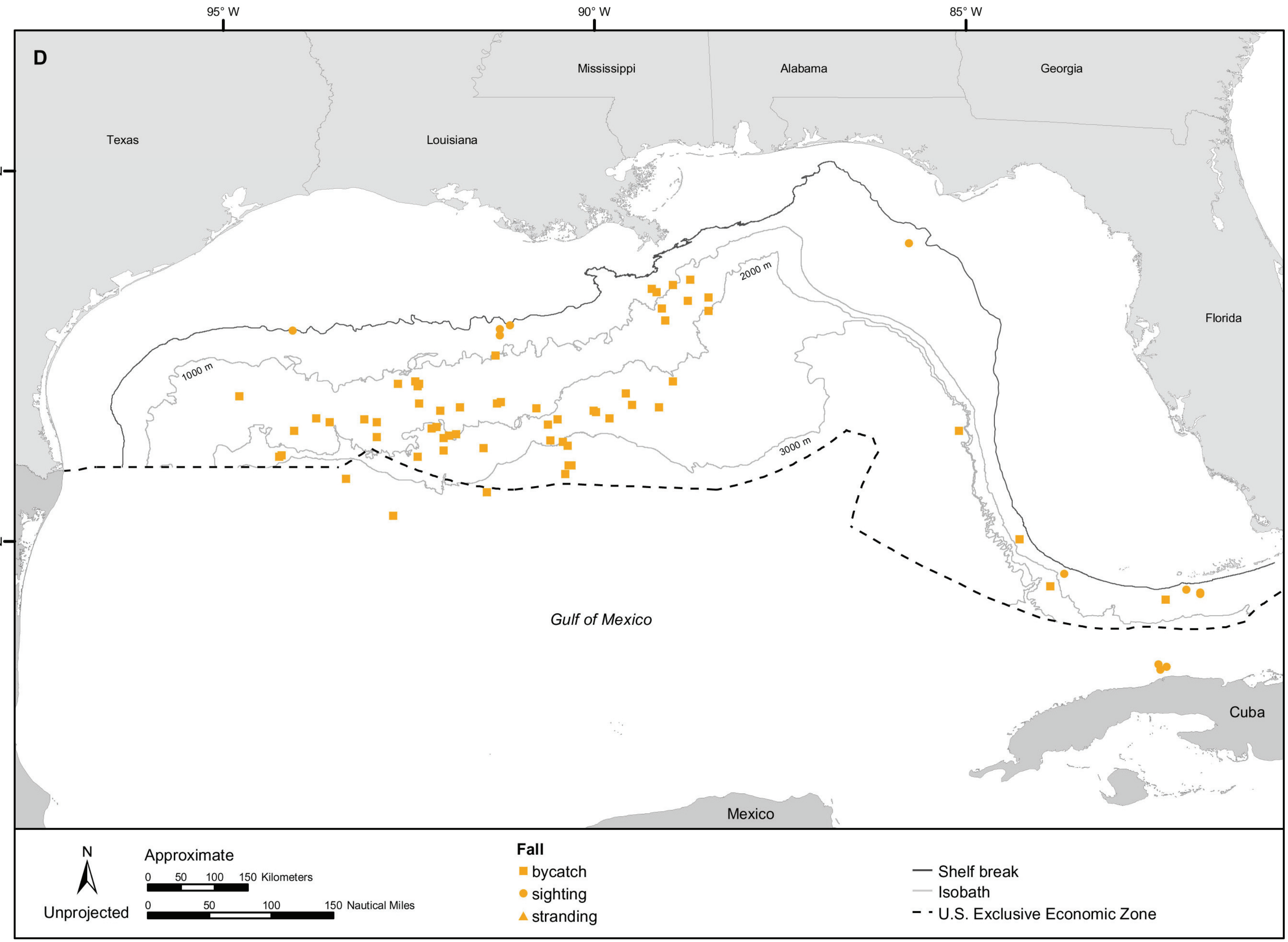
U.S. Exclusive Economic Zone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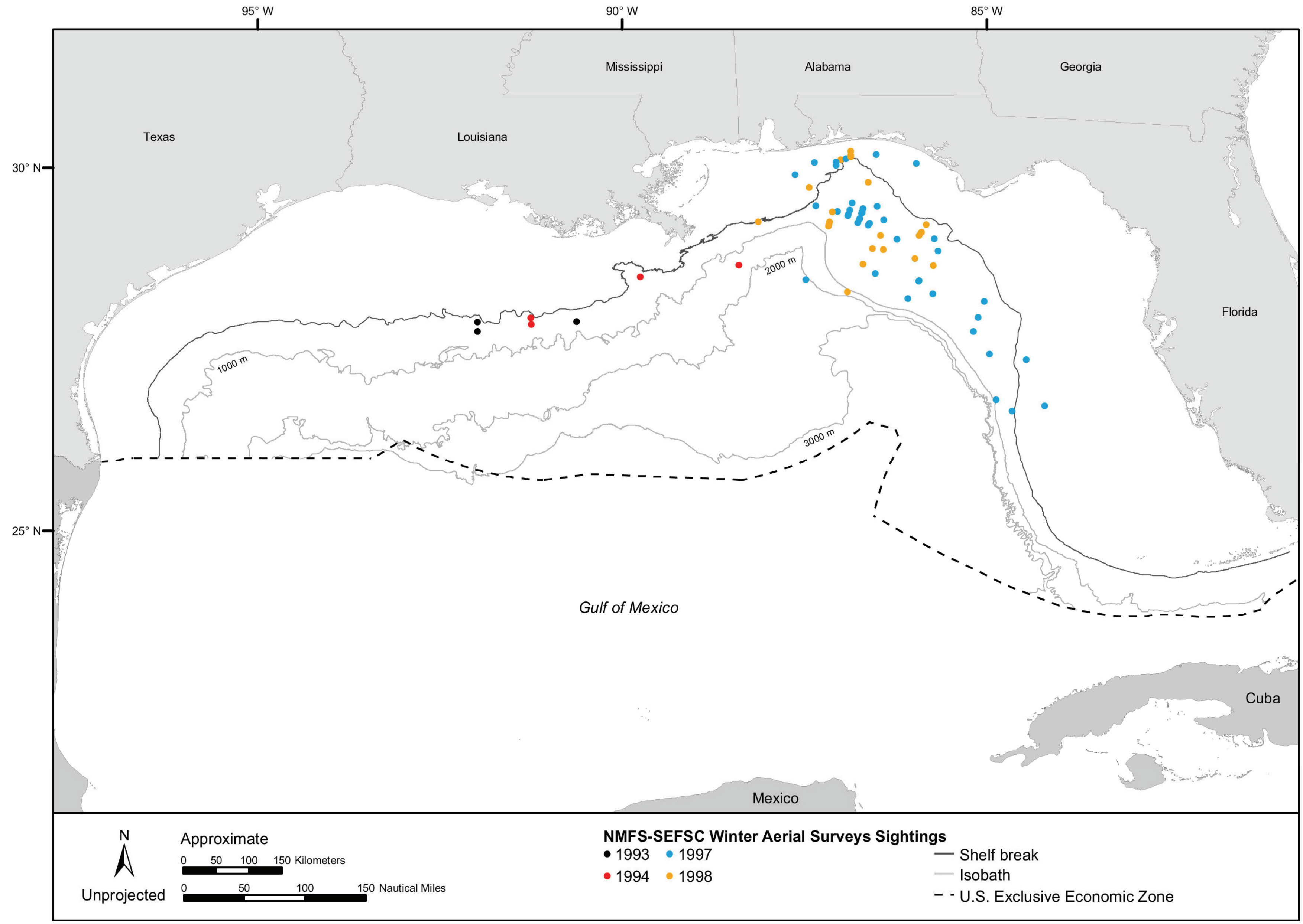

Figure 4. All ocean sunfish (*Mola mola*) sightings from winter aerial surveys. Shelf break, isobaths (1000 m increments), and Economic Exclusive Zone are depicted.

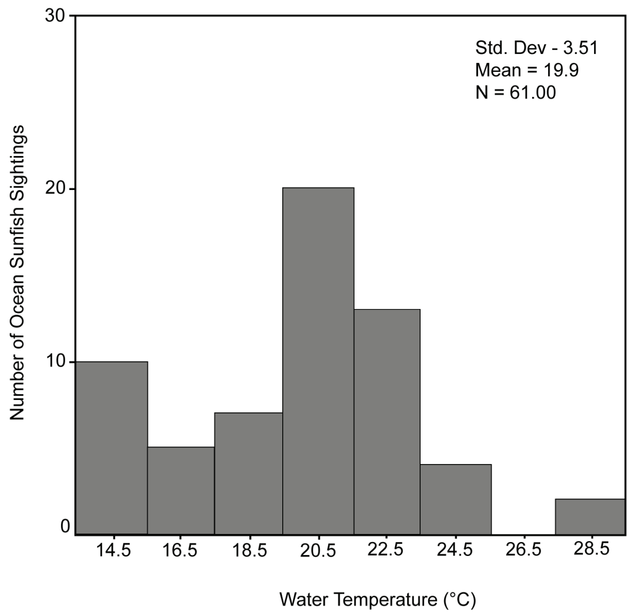

Figure 5. Ocean sunfish (*Mola mola*) sightings relative to sea surface temperature (° C) from 1997 and 1998 NMFS-SEFSC aerial surveys.

evident that water temperature in combination with thermocline depth may be important drivers in the distribution of ocean sunfish.

The majority of records (other than bycatch and strandings) we collected were of molas "basking" at the surface. This behavior is not well understood and has been suggested by some to only be exhibited by those molas which are sick and near death (Fraser-Brunner 1951, Schwartz and Lindquist 1987). This thought no longer appears valid given the accounts of mola sightings, tagging studies and the ability of those tagged animals to consistently be tracked for long periods of time after capture (T. Thys, per. comm., Sea Studios Foundation, Monterey, CA). Molas are consistently shown to frequent cold, deep waters (Harbison and Janssen 1987, Seitz et al. 2002, Sims and Southall 2002, Cartamil and Lowe 2004) on what are likely feeding dives, based on underwater sightings from semi-submersibles where high concentrations of their gelatinous prey also have been simultaneously observed (Harbison and Janssen 1987). Cartamil and Lowe (2004) also found that ocean sunfish spend a significant amount of time within the warmer near surface waters following these deep dives to cooler waters. Ascents to the warmer surface waters to increase body core temperature may be a mechanism for increasing metabolism (Cartamil and Lowe 2004). Within the NGOM, basking behavior may not take place year-round, since water temperatures increase during warmer months of the year and warmer waters are encountered deeper in the water column. Therefore, thermocline depth during other seasons may be an important factor in low sighting rates in various regions including the NGOM.

Depth of the thermocline is area specific and variable depending on dominant currents. The thermocline is well developed and rarely absent off the California coast regardless of season. However, in the NGOM the thermocline is absent or very deep in the cooler months (> 100 m, November–April), while averaging ~ 40 m in the spring and summer (Weatherly 2004). The lack of a well-defined thermocline during winter months would require ocean sunfish to move into shallower waters to gain any thermal benefit. Variation in thermocline depth may explain the difference in the amount of time molas spend in the warmer mixed layer between the waters off California (Cartamil and Lowe 2004) and the NGOM (Seitz et al. 2002). Support for this concept comes from a recently PSAT-tagged ocean sunfish that swam from Massachusetts to the NGOM, north of the Yucatan Peninsula and equally distant from both Mexico and Cuba (I.F. Potter, per. comm., University of New Hampshire, Durham, NH). Dive records collected from that PSAT indicated the animal remained deeper in the water column the further south it traveled.

Additionally, deep dives by ocean sunfish for feeding subject these fish to water depths with low dissolved oxygen (DO) levels which may be considered stressful. As with swordfish (*Xiphias gladius*) (Carey and Robison 1981), ocean sunfish may be required to ascend to water depths high in DO to physiologically recover. This concept is supported by Cartamil and Lowe (2004) who showed that tagged fish spent a significant amount of time in the warm mixed layer after making long, deep dives off southern California. There are likely several benefits to basking behavior such as a combination of increasing body temperature and physiological recovery. Further behavioral and physiological studies are warranted.

One potential problem with these survey data is misidentification of the two mola species occurring in the NGOM (sharptail mola versus ocean sunfish). Since these data were not collected with molas as a focus, this concern cannot be addressed at this time. However, more recent surveys are now addressing this issue, with training of observers for species identification. The other concern is that the ocean sunfish could be mistaken for another fish, the opah or moonfish (*Lampris regius*). This possibility seems unlikely given the fact that the opah has a well-defined caudal peduncle and fin. It is therefore unlikely, that this species was confused with molas.

Ocean sunfish do not have to come to the surface to breath, thus, animals below the surface were missed. Some sightings may have been detected, but were not recorded since observers were instructed to ignore other species (including ocean sunfish) if they were interfering with detecting and recording the target species (i.e., marine mammals and sea turtles).

Concentrations of ocean sunfish near DeSoto Canyon from aerial surveys are interesting and may be unique given the location of these sightings. This region of the NGOM is influenced by incursions from the Loop Current and the Mississippi River plume. Both of these oceanic features are known to greatly enhance primary productivity (Lee et al. 1992, Lohrenz et al. 1999, Wiseman and Sturges 1999), thereby creating highly productive regions for higher trophic levels (Biggs and Ressler 2001). Further work in this region is needed and may provide further information on the habitat requirements of the two mola species known to occur in the NGOM.

In summary, for the NGOM, winter aerial surveys are most productive for generating sightings of molas. In fact, recent surveys for cetaceans off the US Atlantic coast (between Cape Hatteras, North Carolina and Savannah, Georgia) demonstrated that ocean sunfish were spotted with higher frequency in the winter instead of the summer months (G. Fulling and W. Hoggard, per. observ.). More specifically, aerial surveys are more beneficial for sighting molas than shipboard surveys since the altitude and speed of the platform allows for greater frequency and probability of detection. However, the high costs associated with aerial surveys likely preclude these platforms as regular survey mechanisms for dedicated mola studies, particularly since molas are not of commercial interest and as a result there are no management implications for them. It is therefore imperative to collect these data in conjunction with other dedicated surveys on a "non-interference" basis.

Further attempts to collect data will build on the information presented here and will enhance our understanding of these unique fish. Future work must incorporate PSATs which have been and will continue to be very useful in providing valuable information to address many unknown aspects of molas. These types of studies are currently ongoing in the North Pacific, conducted by the Monterey Bay Aquarium (T. Thys, per. comm., Sea Studios Foundation, Monterey, CA). More detailed analyses of fisheries bycatch (both longline and trawl) data will also be critical in our understanding of distributional and behavioral ecology of both mola species common to the NGOM. Though our study was restricted to readily available data from other sources, we have demonstrated that there is a need to incorporate all sources of information to elicit more knowledge on the ecology of a relatively unknown species.

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