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Gulf of Mexico Historic (1955–1987) Surface Drifter Data Analysis

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ABSTRACT

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Analysis of historic (1955–1987) surface drifters (mostly cards and bottles) released in the Gulf of Mexico reflect two meteorological seasons of the Gulf, winter and nonwinter. Five clusters of high drifter recoveries evident in both seasons were identified: 1) south Texas; 2) Louisiana-Texas border; 3) Mississippi River Delta to Cape San Blas, Florida; 4) Tampa, west Florida; and 5) southern to eastern Florida. A chi-squared test revealed that the distributions of drifter landings and human population, represented by human marine activities, are different at the 95% confidence level. Currents and winds are the dominant factors controlling the geographical distribution of drifter landings, while population density in coastal areas plays a minor role. The drifters' geographical distribution and the distributions of marine mammal and turtle strandings have correlations (statistically not significant) of 0.25 and 0.31, respectively. Recovered drifters in selected segments in the eastern Gulf received drifters released primarily in the eastern Gulf, whereas western areas received drifters from everywhere. This distribution is probably the result of the westward surface drift driven by prevailing westward winds in the Gulf. Landing probabilities from drifters when compared with results from the Oil Spill Risk Analysis (OSRA) model were within an order of magnitude and their spatial distributions have correlation coefficients of 0.44 to 0.49 (significant at 80% level) for the total, winter, and nonwinter seasons.

ADDITIONAL INDEX WORDS: *Drift bottles, geographic distribution, clusters, seasonal variations, stranded animals, landing probabilities, Gulf coast, oil spills, correlation analysis.*

INTRODUCTION

The Gulf of Mexico is an elliptical basin with a surface area of 1.6×10^6 km^2 and about 5,000 km of shoreline, Figure 1. The Gulf's main source of water, the Loop Current (transport $\sim 30 \times 10^6$ m^{3}s^{-1}), enters through the Yucatan Channel from the Caribbean Sea and exits through the Straits of Florida to the Atlantic Ocean. Early attempts to ascertain the Gulf's surface circulation extensively employed surface drifters, *e.g.,* CHEW *et al.* (1962); GAUL and BOYKIN (1964; 1965); GAUL *et al.* (1965); SALSMAN and TOLBERT (1963); WATSON and BEHRENS (1970); SWEET (1971; 1974); TEMPLE and MARTIN (1979). Other surface drifter studies focused on red tides or fishery issues (HELA *et al.,* 1955; WILLIAMS *et al.,* 1977). Still, another application of drifters is for estimating the wind drift factor (TOMZACK, 1964). Satellite-tracked drifters have been employed to study the dynamics and circulation of Loop Current eddies in the Gulf of Mexico (*e.g.,* KIRWAN *et al.,* 1984; 1988; HAMILTON, 1992), and the ocean's upper-meter currents (*e.g.,* JOHNSON *et al.,* 1996).

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A substantial base of historic surface drifter data exists in the form of maps or tables, providing dates, locations, and numbers of released and recovered drifters. This extensive database has received little attention from oceanographers because of interpretation difficulties. Application of these data for assessing surface pollutant landings and marine debris needs to be considered. A historic database of surface drifters has never been constructed. Such a database would allow analyses of these data using computer graphical, statistical, and geographical information systems. This work presents a database of historic drifter data and analyses using computer techniques and recent knowledge of the Gulf's oceanography. The geographical distribution of drifter landings is compared with the distributions of marine mammal and turtle strandings in the Gulf of Mexico. Finally, landing probabilities estimated from surface drifters are compared with results from the Minerals Management Service's Oil Spill Risk Analysis (OSRA) numerical model.

METHODS

Historic surface drifter data were obtained from fifteen publications spanning 32 years (1955–1987); however, de-

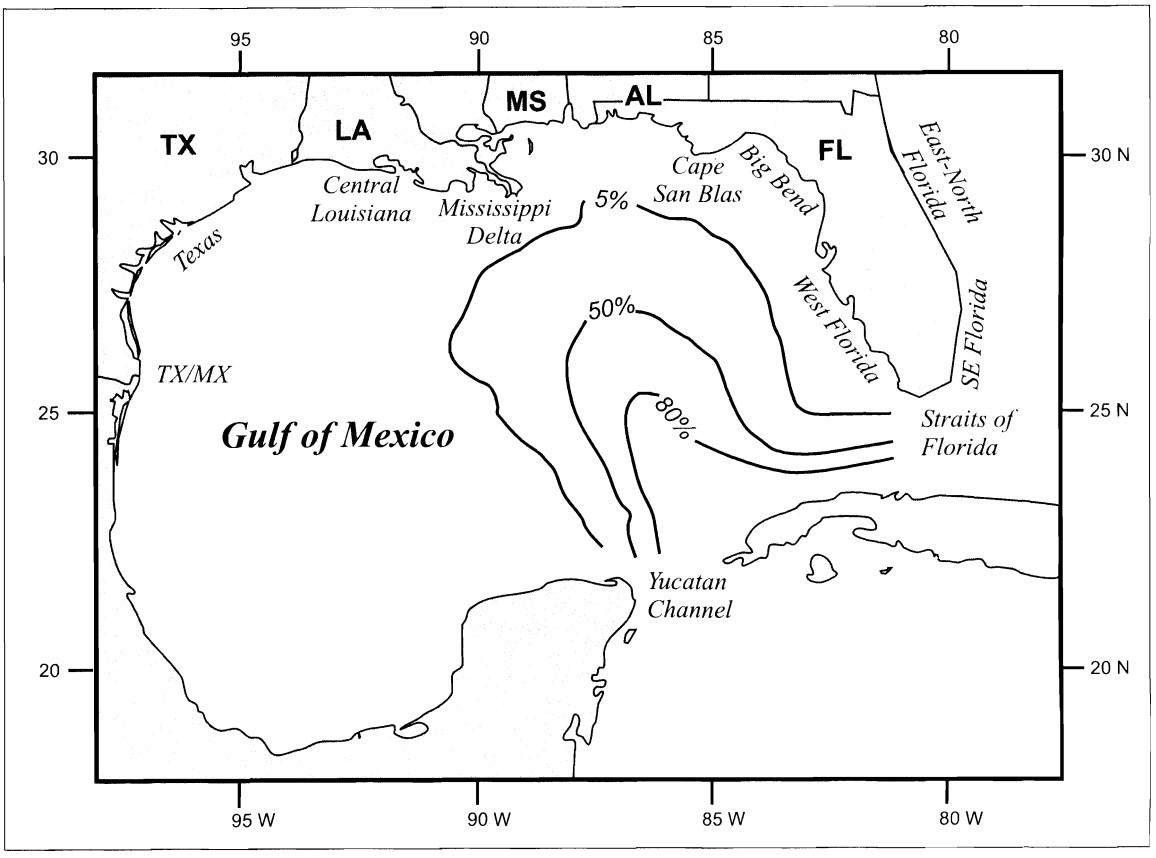

Figure 1. Gulf of Mexico and selected geographical sites. Contours indicate percentage of time Loop Current waters is found there.

spite many efforts this is not an exhaustive synthesis. Some data were not included either because we lacked access or were unaware of their existence during our data compilation. Typical data sources included are for example DRENNAN (1963; 1968); METCALF *et al.* (1977); PASKAUSKY and NOWLIN (1978); SCHROEDER *et al.* (1987) and eleven others. The digital data file was created using three data sources: 1) tabular information (latitude and longitude) of release and recovery sites; 2) overlaying a grid of 1° latitude × 1° longitude on maps of release and recovery sites; 3) digital data were appended to our file.

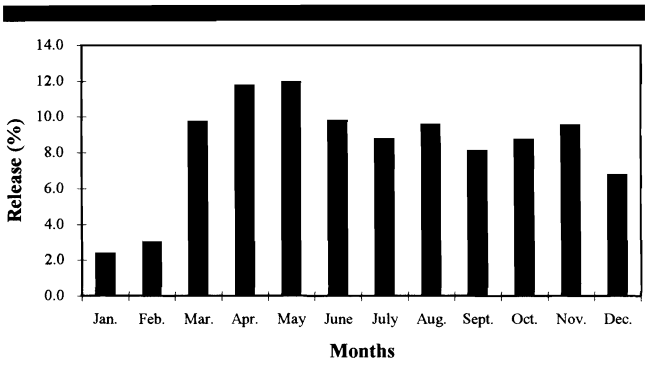

Figure 2. Monthly drifter releases in the Gulf of Mexico during the period 1955–1987.

Database attributes are release and recovery latitudes and longitudes, dates of release, and number of recovered drifters. Recovery dates were not employed because of inconsistent reporting and uncertainties, *i.e.,* beached drifters may lie unnoticed for long periods. Differences of timing (*i.e.,* data from different years) and drifter types (*i.e.,* glass bottles, cards, plastic drifters) were not considered. Data from different years can be interpreted as a long experiment designed to study interannual variability.

The drifter data were compared with two independent datasets: strandings of marine mammals and marine turtles. Marine mammal stranding data (1898–1991) were obtained from the Smithsonian Institution (J.G. MEADE Smithsonian Institution, *written communication* 1997). Marine turtle strandings for the Gulf and eastern Florida (1989–1993) were digitized from published reports (TEAS and MARTINEZ 1989; 1992; TEAS, 1992a; 1992b; 1993; 1994). Because turtle strandings were reported by statistical zones, they sometimes did not exactly match our coastal grid, but this did not affect trend identification.

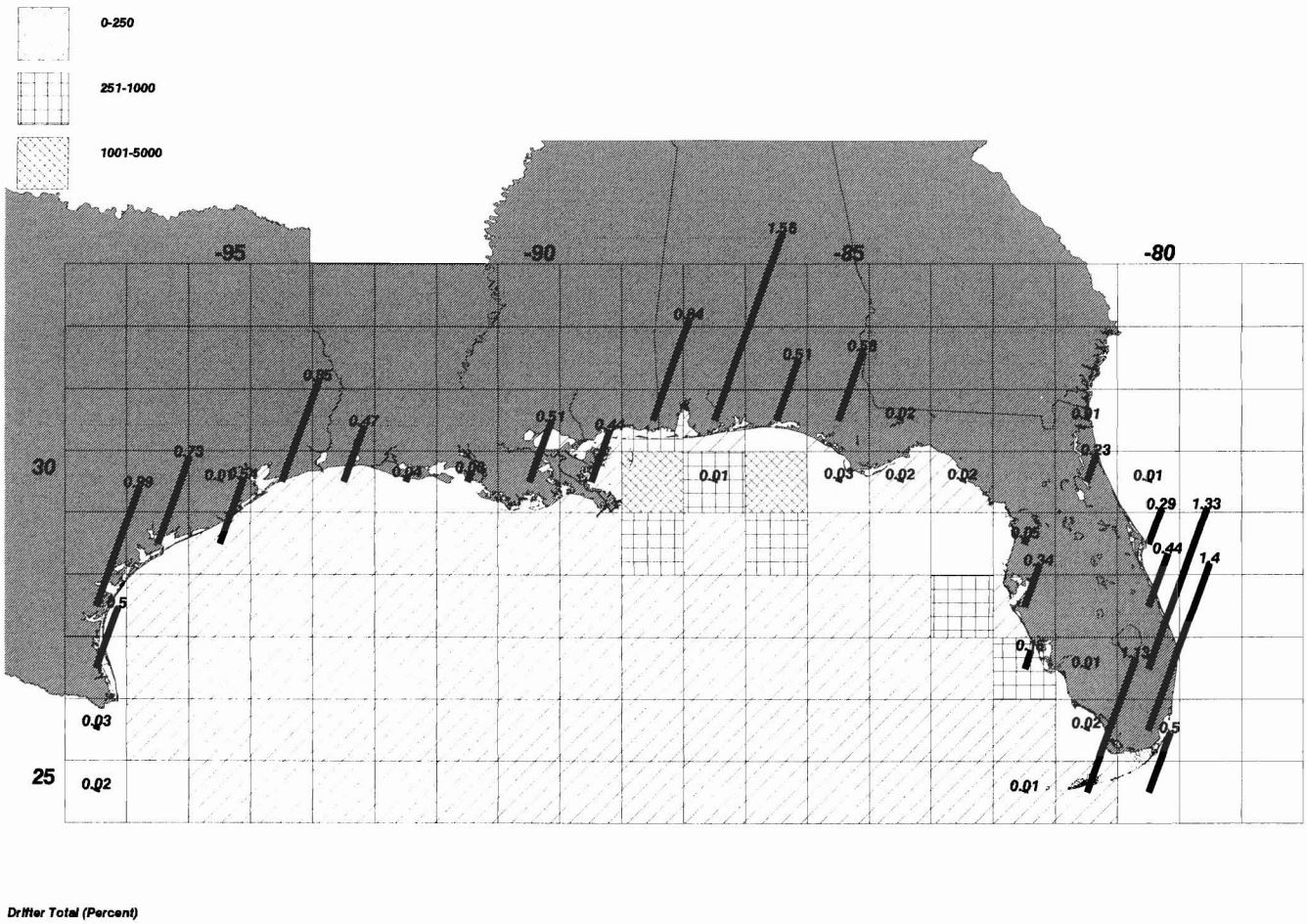

Figure 3. Geographical distribution of drifter release in the Gulf of Mexico. The bars represent total recoveries in percentages.

To learn the origin of drifters beached on selected coastal segments the data were analyzed using a Geographical Information System (GIS). The coastline was divided into 2° (latitude or longitude) bins and the number of drifters originating in each offshore cell were recorded. The bin size was selected to increase the sample size (degrees of freedoms) and reduced the variance or uncertainty of the results.

Human population bias on the distribution of recovered drifters was examined using a multinomial experimental design (MENDENHALL, 1979). Two types of data were employed for assessing this bias: 1) human population and 2) human marine activities. Population data were obtained from the U.S. CENSUSES of 1960, 1970, 1980, and 1990 (U.S. DEPT. OF COMMERCE, 1990). Human activity data along the coast (fishing, swimming, and boating) were from the Gulf of Mexico Coastal and Ocean Zone Strategic Assessment: Data Atlas (Figure 4.30; U.S. DEPT. OF COMMERCE, 1985). These data represent relative intensity of human marine activities along the Gulf Coast for 1980 and exclude human freshwater activities. The quality and limitations of these data are discussed in U.S. DEPT. OF COMMERCE (1985).

The probability of finding a drifter in a $1° \times 1°$ coastal cell was estimated by dividing activities in a cell by their total. The recovery probability multiplied by total drifters recovered yielded expected number of drifters in a coastal cell. Expected recoveries and observed drifter returns were compared using a chi-square (χ^2) test (MENDENHALL, 1979; TAYLOR, 1997). The test's null hypothesis (H_0) is that geographic distribution of drifter returns and population should be similar over a long time if the drifters are uniformly distributed. The alternative hypothesis (H_1) is that the drifters' geographic distribution is nonuniform, and both distributions (returns and activities) differ.

Data of released and recovered drifters were used to calculate a landfall probability for $1° \times 1°$ coastal cells as a ratio of recovered to total drifters released. These probabilities were compared with landfall probabilities estimated from the OSRA model (PRICE *et al.*, 1996). The model tracks the surface centroid of an hypothetical oil spill. Weathering and spreading are not accounted for by OSRA. Spill movement is driven by monthly mean surface currents produced by an enhanced version of the Mellor-Blumberg model (HERRING *et*

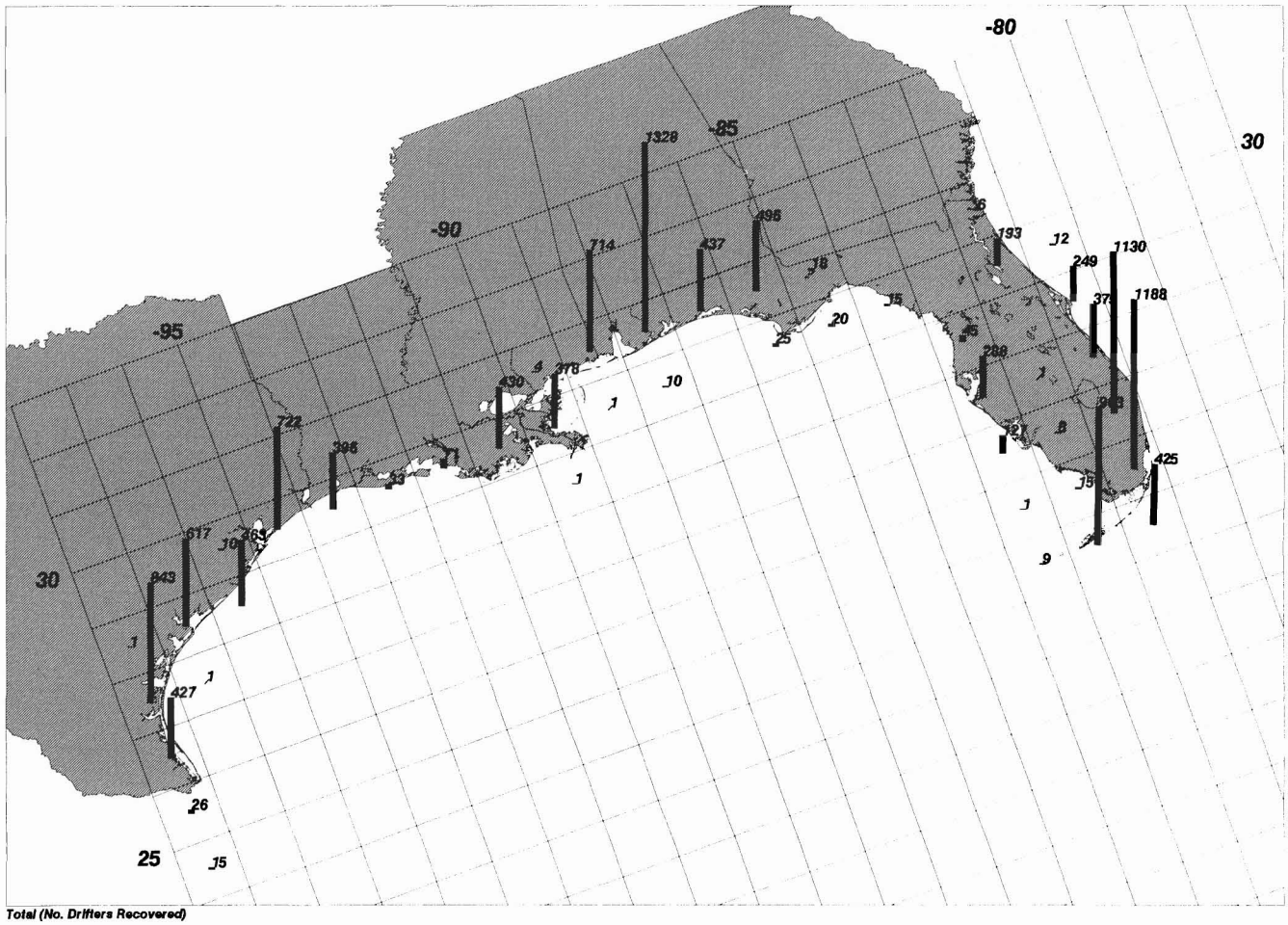

Figure 4. Geographical distribution of all drifters recovered in the Gulf of Mexico.

al., 1999) and surface current derived from satellite tracked drifters from an MMS sponsored study. Geostrophic surface winds corrected for frictional effects (RHODES *et al.*, 1989) provided wind forcing for oil spill advection. This model estimates contact probability using hypothetical oil spills launched from offshore cells with historic drifter releases. In all, 900,000 virtual spills were released from 450 locations at 2,000 spills per site over four seasons, but we only consider winter and summer seasons. The spills were tracked for 30 days or until they hit land or left the model domain. The model domain is bounded by 23°N and 30.5°N, and between 78°W and 97.5°W.

RESULTS

Geographical and Seasonal Analyses

More than 85,000 drifters were released mainly in the Gulf from 1955 to 1987; however, some releases occurred in the Caribbean Sea. In total, 13,000 drifters were recovered in the Gulf and, of these, 12,542 landed from Texas to eastern Florida. This work examines the 12,542 drifters recovered along the American coast.

Monthly total drifter drops range from 1,700 drifters in January to more than 10,600 in July. Releases were low from January to May, but increased to more than 6,500 in the remaining months. Figure 2 shows that monthly releases, in percentage, increased from 2 to 8% from January to May and fluctuate between 9 and 13% thereafter. This figure shows two temporal clusters of drifter releases. The Gulf of Mexico experiences two meteorological seasons: winter (December–March) and summer (May–October), with two transitional months (April and November) (FLORIDA A&M UNIVERSITY, 1988). Oceanographically, some Gulf areas also experience two seasons. For example, the Louisiana-Texas shelf has westward currents in nonsummer (October–April) but these reverse in summer (May–September) (TEMPLE and MARTIN, 1979; COCHRANE and KELLY, 1986; NOWLIN *et al.*, 1998).

The geographical distribution of drifter releases, Figure 3 is fairly uniform across the Gulf of Mexico, with most areas having 250 releases or less, including the Yucatan Channel

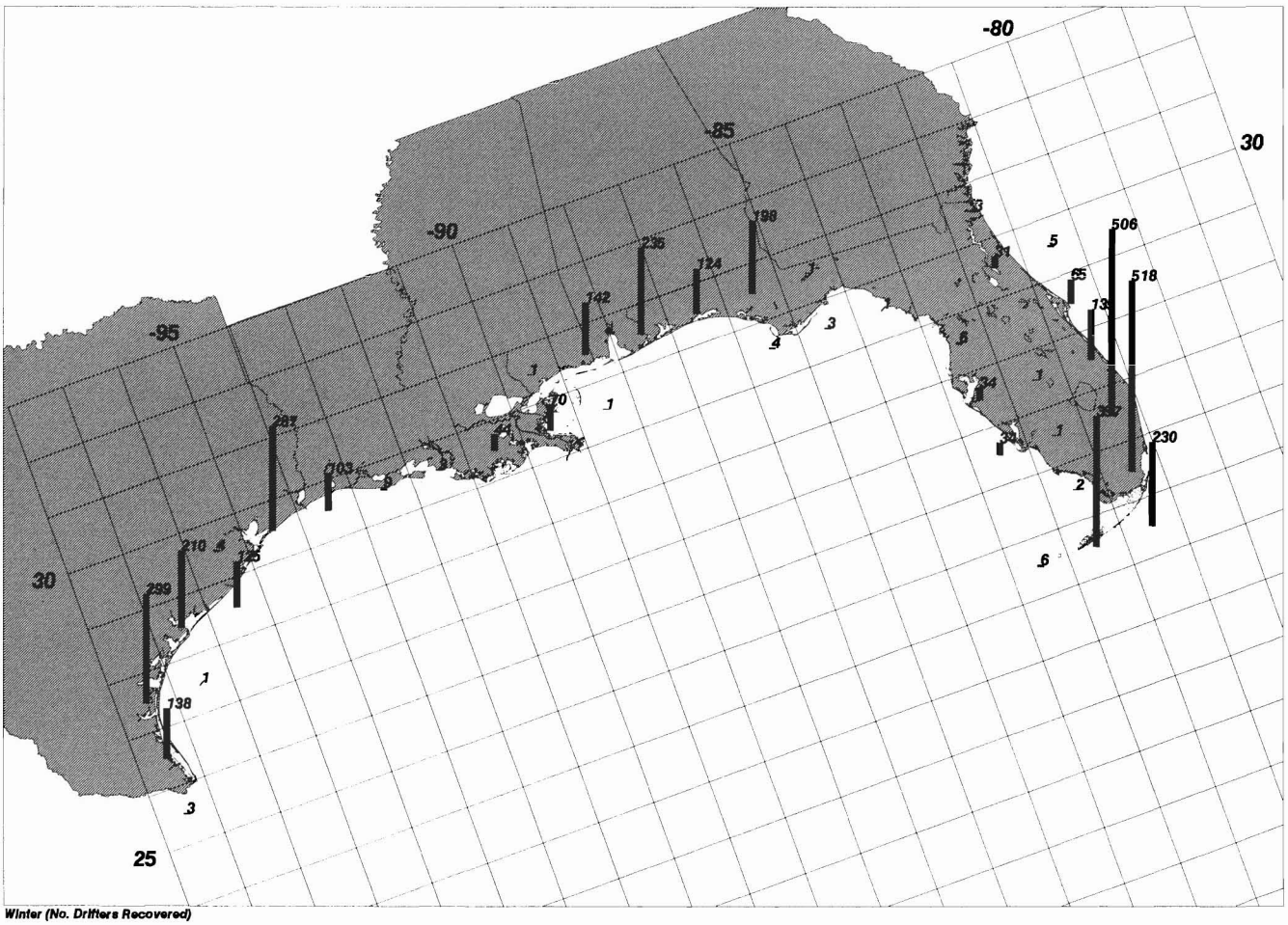

Figure 5. Geographical distribution of recovered drifters released in winter (December–March) in the Gulf of Mexico.

and Caribbean Sea. An exception is off Alabama-Florida where a cluster of large number of releases, 251–5000, occur due to several studies (GAUL and BOYKIN, 1964; 1965; GAUL *et al.,* 1965; TOLBERT and SALSMAN, 1964). Another exception is off Tampa, Florida with 251 to 1,000 releases by WILLIAMS *et al.* (1977) and HELA *et al.* (1955). Gulf 1° × 1° offshore cells with no releases are not uncommon or random, but reflect the objectives of the original studies.

The geographical distribution of recovered drifters, Figure 4, shows five clusters of high landing areas: 1) southern Texas; 2) the Louisiana-Texas border; 3) Mississippi Delta, Louisiana to Cape San Blas, Florida; 4) near Tampa, western Florida; and 5) off southern and eastern Florida. At the 1° × 1° cell scale, the place of maximum returns occurred between the Mississippi Delta and Cape San Blas Gulf (≈10%), with southern Florida (≈9.5%) and southern Texas (≈7%) ranked second and third, respectively. Areas in the Big Bend, southwest Florida, and central Louisiana had the lowest values.

The clustering of drifter releases, the Gulf's meteorology, and the regional oceanography suggest examining seasonal changes in these data. We defined two seasons, winter (December–March) and nonwinter (April–November), after the meteorological regime. Figures 5 and 6 show the winter and nonwinter geographical distributions of recovered drifters, respectively. About 78% (8,602) of all releases occurred in nonwinter, the remaining 22% (3,940) in winter. The five clusters remain evident in both periods, and the correlation between winter and nonwinter recoveries is 0.82, indicating similar distributions. Higher nonwinter recoveries are expected because of the higher number of drifters released during these months. Another seasonal difference is an increase (60- to 89-percent increase) of recoveries between the Mississippi Delta and Cape San Blas from winter to nonwinter. Nonwinter landings along the eastern Florida coast have maximum values of ≈8%, but winter recoveries almost doubled, ≈14%. Along the northeastern Gulf, nonwinter landings are higher than winter (13% vs. 6%). Recoveries along the Louisiana coast are almost uniform spatially, but vary from ≈5% in nonwinter to 2% in winter. Along Texas, the winter and nonwinter landings are nearly equal (≤6% vs. ≤7%).

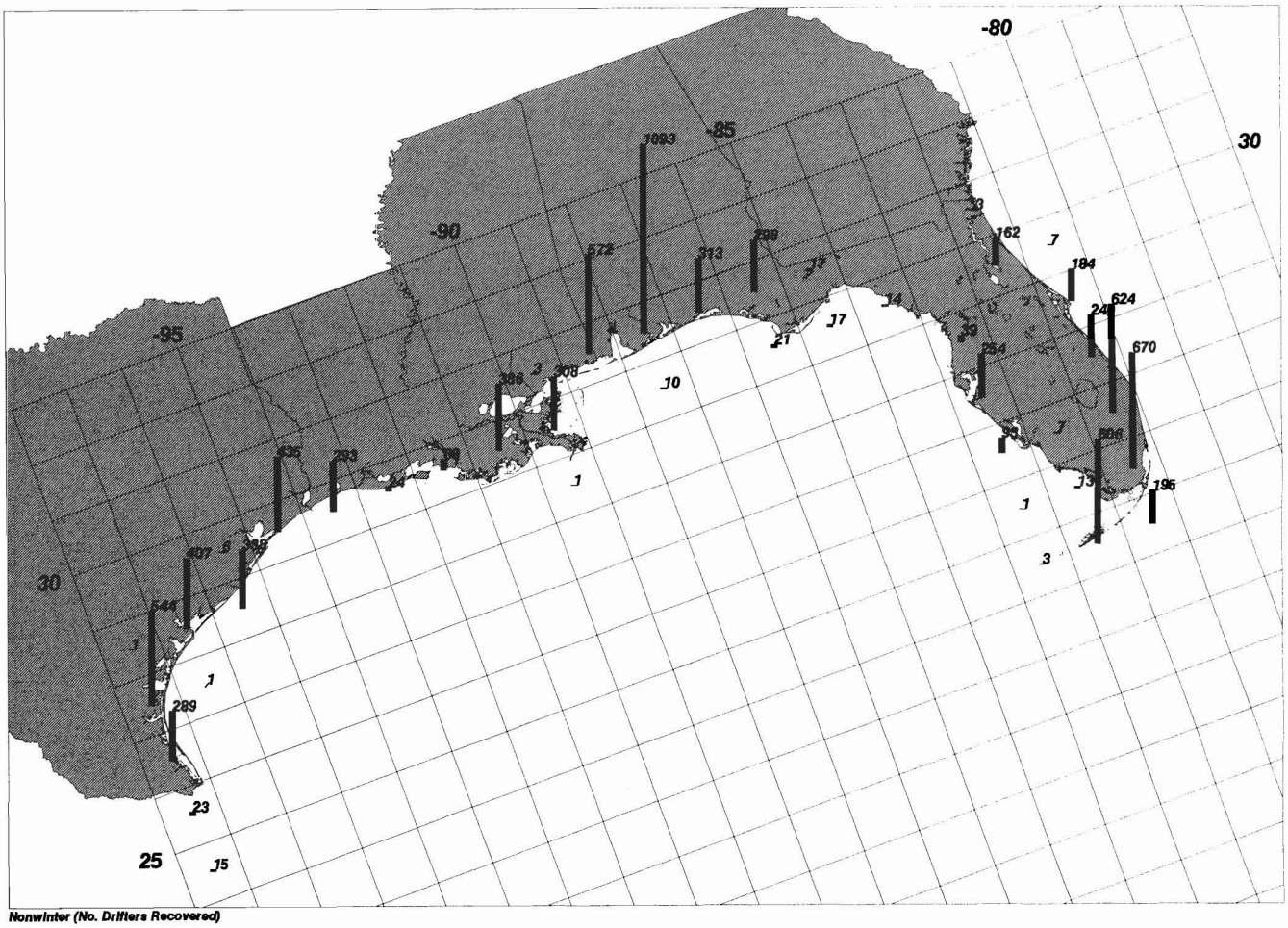

Figure 6. Geographical distribution of recovered drifters released in nonwinter (April–November) in the Gulf of Mexico.

Stranded Animals

Figure 7 shows the landings of drifters, marine mammals (whales, dolphins, and manatees), and marine turtles per kilometer along the coast from Texas to Florida. The data was normalized to remove possible bias introduced by comparing recoveries from segments of varying length. Notice that the five clusters identified in Figures 4, 5, and 6 are well defined in these datasets. Note too the lack of landings along the Big Bend area. The marine mammals data do not extend to eastern Florida as do the turtle data. These considerations, along with the fact that drifters tend offshore when caught in the Florida Current, help explain, some differences observed in the eastern Florida seaboard. The correlation coefficient between drifter landings and marine mammals is 0.25 and between drifters and turtles 0.31. Data past 3,500 km in Figure 7 were not used in calculating the correlation coefficients due to lack of stranding data for marine mammals. These correlations coefficients are not significant at the 95% confidence level. The agreement between these three geographic distributions is striking when differences in timing (data from different years), gathering of animals in preferred areas, and that animals travel along established routes are considered. We believe that the observed trends are robust and are consistent with the drifter clusters.

Influence Areas

Using the GIS we examined the five clusters of drifter landings. Figure 8(a, b) shows that drifters beached in Texas originated over the entire Gulf, but most notably from near the Mississippi Delta and western Gulf. Also, there are contributions from the southern Gulf near Mexico. Figure 8(c, d) shows that beached drifters from the Mississippi Delta to Cape San Blas area had contributions introduced mainly in the eastern Gulf, mostly introduced along the nearby shelf with a small number originating in the western Gulf, see Figure 3. Figure 8(e, f, g) shows that the origins of the beached drifters in western, southern, and eastern Florida were the Caribbean Sea, Yucatan Channel, and eastern Gulf. Small contributions from the western Gulf are evident. However, the areas in eastern and southern Florida received most drift-

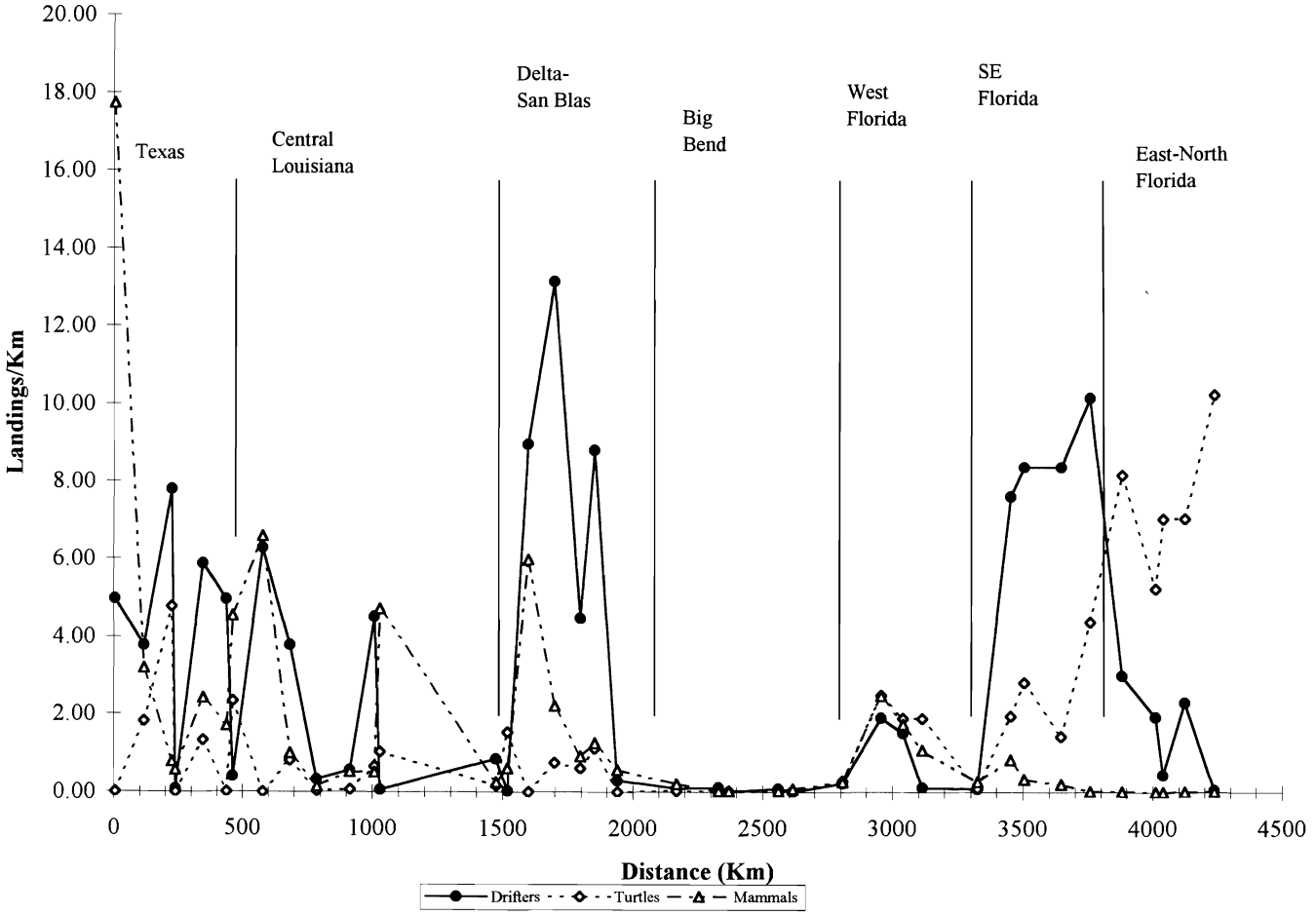

Figure 7. Landings of drifters, marine mammals, and marine turtles per kilometer of coast from Texas to Florida.

ers introduced near the Mississippi Delta, whereas western Florida received most drifters originating immediately offshore. These uneven origins, we believe, represent the integrated effects of winds, westward surface currents (U.S. NAVY, 1986), coastal geography, and a divergence zone south of the Mississippi Delta (CHEW *et al.*, 1962). This aspect is discussed in more details in the next section.

Human Influence

Human influence on the distribution of drifter returns is often perceived as a major bias. This perception stems from the passive nature of drifters. Since the drifter data cover 3 decades (1955–1987), we examined the coastal population from 1960 to 1990 in the Gulf and eastern Florida to detect possible effects. Population changes in coastal areas of the Gulf, not presented, show the following: from 1960 to 1970 coastal area from the Big Bend and westward either experienced loses or increases of ≤20% in most areas, the Florida coast south of the Big Bend increased from 20 to 190%. From 1970 to 1980 most of the Gulf's coastal areas experienced population increases, and the Florida coast the highest (40–190% change). From 1980 to 1990 most areas west of Mobile show population declines, but the Florida Panhandle to the Big Bend increased by 20–40% mostly. South of Big Bend, population increases were 20–190%, with 40% increase most common. Superficially, these observations would suggest a high correlation between drifter returns and coastal population (*cf.,* PARKER *et al.,* 1979).

An appropriate comparison is between drifter landings and people at the beach/coast, *i.e.* human marine activities. Figure 9 shows human marine activities along the Gulf for 1980 (U.S. DEPT. OF COMMERCE, 1985). Given that the coastal population along the Gulf coast peaked in 1980, except for Florida which shows continuous growth, we assume that 1980 human activity data should adequately represent human coastal activities between the 1960's and 1980's except in Florida. We further assumed that the proportion between total population and people at the beach remained unchanged again except in Florida. Recall that most (>90%) of our data was collected before 1980, thus using 1980's human activity data should not introduced large errors. The reduced χ^2-test with 0.05% probability of being equal shows a significant dif-

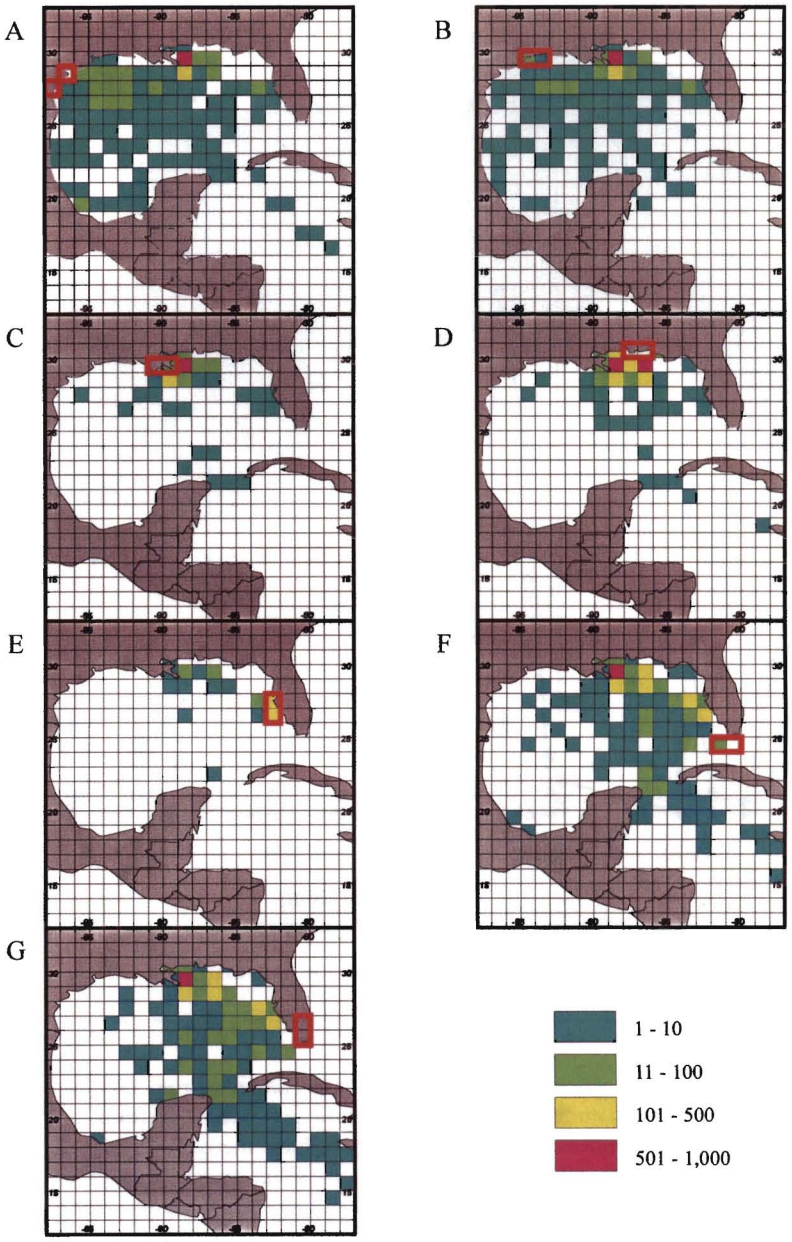

Figure 8. Drifter release areas contributing to the recovery numbers in (a) Texas; (b) Louisiana- Texas border; (c) Mississippi Delta; (d) the northeastern Gulf; (e) western Florida; (f) southern Florida; and (g) eastern Florida. This figure represents all drifters released.

ference between observed and expected returns, leading us to reject the null hypothesis. Therefore, we accept the alternative hypothesis: the observed distribution of beached drifters cannot be explained solely by human marine activities. This result implies that other factors such as currents and winds distribute the drifters across the Gulf. It is important to note that despite the population increases along west Florida, this area had the least returns of drifters, except around Tampa; and even in this case the returns seem correlated with a large number of releases off this area, Figure 3.

Landing Probabilities

Drifter-derived landfall probabilities for all seasons are shown in Figure 10. The most striking feature is the small probability values (≤3.0%). Notice five clusters of high probability: between 95° and 97°W in Texas; the Louisiana-Texas border; the northeastern Gulf between 85° and 90°W; near Tampa; and eastern Florida along 80°W. Figure 11 shows the Oil Spill Risk Assessment (OSRA) landfall probabilities for all seasons. Again, all values are small, ≤3.0%. Spatially, five

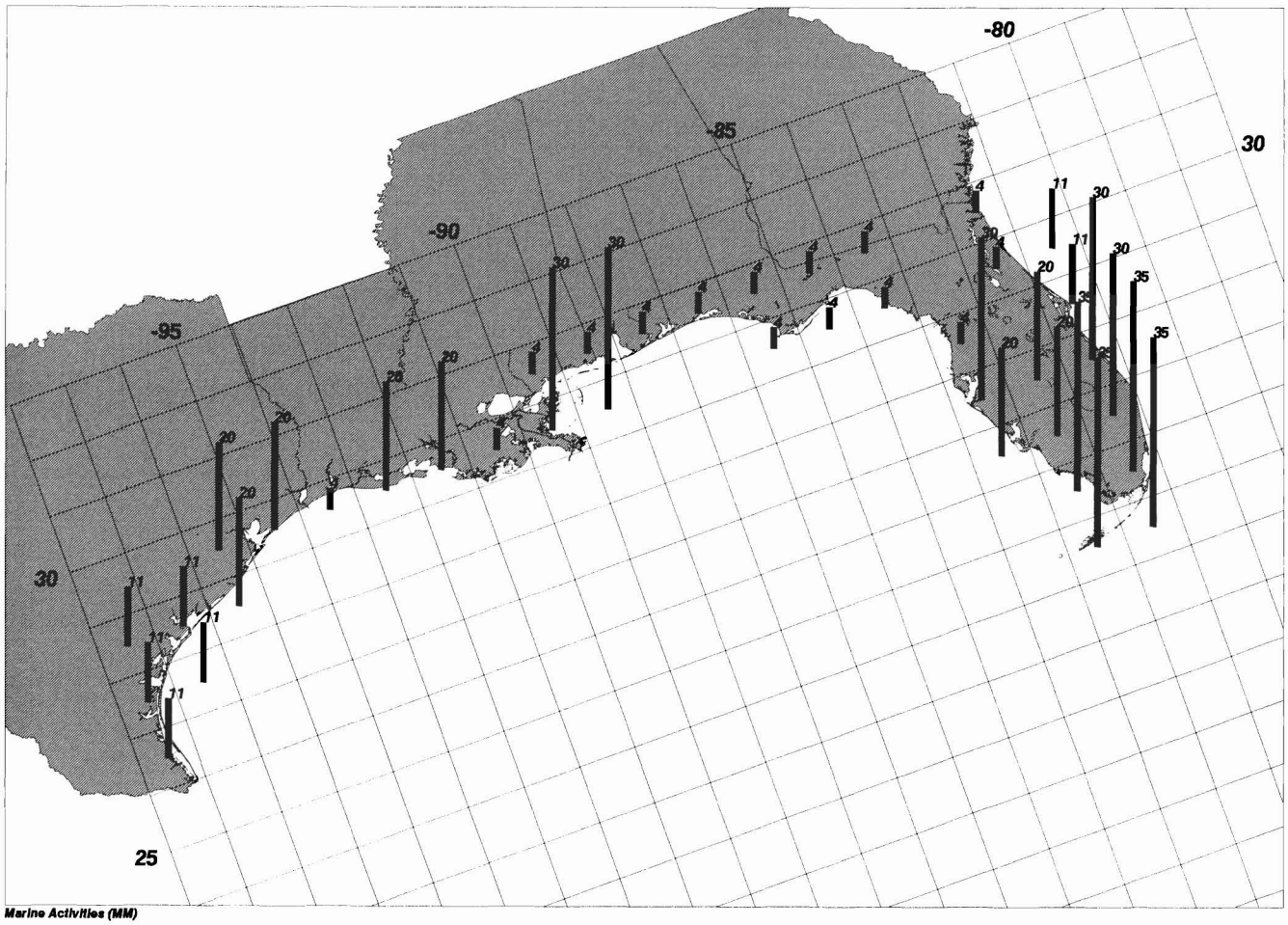

Figure 9. Distribution of marine activities in millions (MM) during 1980 along coastal areas of the Gulf of Mexico.

clusters of high probability values are evident here. The five clusters are southern Texas; Louisiana-Texas border; the Mississippi Delta to Cape San Blas; and southern Florida. Notice that eastern Florida generally has low values, <0.5%. The correlation between the drifters and OSRA landfall probabilities is 0.46. Figures 12 and 13 present the drifter and OSRA landfall probabilities for winter. Again, values are ≤3.0% in both cases and the correlation between drifter and OSRA is 0.44. The nonwinter spatial distribution (not shown) is similar to that of winter and has comparable correlation (0.49) between drifter and OSRA landfall probability estimates. These correlation coefficients are significant at the 80% confidence level, but not at the 95% confidence level. A notable difference is the increased landfall probability along the eastern Florida coast in winter, Figure 12. This probability increase may be explained by southward winds during cold fronts transporting drifters into the Loop Current. Once in the Loop Current, drifters drift outside the Gulf and off Florida, where prevailing westward winds may push them ashore.

The spatial distribution of drifter landfall probabilities exhibits correlations of 0.44 to 0.49 with the OSRA probability distribution. Differences can be attributed to the fact that drifter data are more representative of the Gulf's climatology, while OSRA results represent just one climate realization. Differences between the OSRA and drifter results can also arise because of differences of drifter types. The OSRA spills are represented by a surface point, which is driven by winds and monthly means surface currents. The drifters' vertical extension causes a response winds, surface currents, and waves which introduced large variability. These differences accentuate as drifters approach the coastline.

DISCUSSION

Extraction of current or drift values from surface drifter studies requires making assumptions about trajectories and travel times that, coupled with sample size and return sample, cast doubts on the representativeness and robustness of these estimates. However, combining several studies, *i.e.,* increasing sample size, and focusing on the spatial distribution of drifters should mitigate these concerns for estimating land-

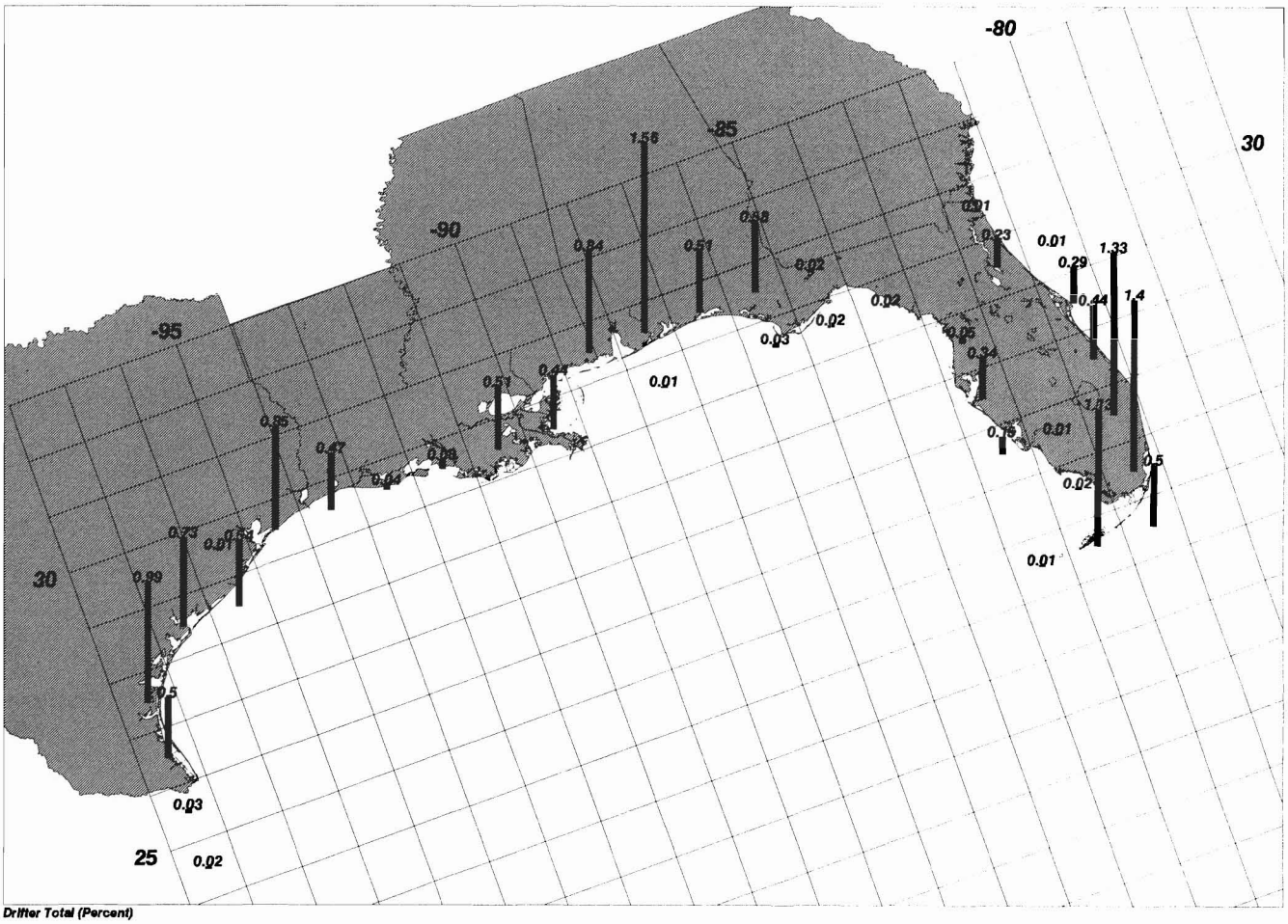

Figure 10. Landfall probabilities estimated using all recovered drifters.

ing and associated contact probabilities. This study combines data from 15 drifter studies in the Gulf of Mexico to construct a database. The time release distribution of recovered drifters reflects the two relevant seasons for the Gulf of Mexico: winter and nonwinter, and agrees with the meteorological biseasonal regime of the Gulf-winter and summer (FLORIDA A&M UNIVERSITY, 1988). Our analysis revealed five coastal areas acting as attractors of surface drifters in the Gulf of Mexico. The five areas evident in both seasons are: southern Texas; the northwestern Gulf (Louisiana-Texas border); the northeastern Gulf of Mexico (Mississippi River Delta to Cape San Blas); near Tampa, Florida; and southern and eastern Florida. Previous studies identified several of these attractors (PARKER *et al.,* 1979; WILLIAMS *et al.,* 1977). Marine mammals and turtle strandings, Figure 7, also display the same clusters.

The observed distribution of beached drifters may be qualitatively explained using the Gulf's wind and ocean current fields. Nonwinter prevailing winds are westward over most of the Gulf, but become northward near Texas. In the northeastern Gulf a northward component is present most of nonwinter. Winter winds become southward especially near Texas, but are more westward in southern Florida (RHODES *et al.,* 1989). The westward wind direction most of the year explains the high number of drifters in eastern/southeastern Florida and Texas, and lower landings in western Florida. The first two regions are windward while the latter region is leeward.

The high number of drifter landings between the Mississippi Delta and Cape San Blas is partially explained by the northward winds. These wind fields, coupled with generally alongshore currents (DINNEL, 1988; KELLY, 1991) and higher releases in nonwinter, explain the higher, nonwinter recoveries. In winter, the southward winds push drifters offshore in the northern Gulf, thus explaining the observed reduction of landings during this season. These southward winds also increase the chances of drifter entrainment in the Loop Current and leaving the Gulf, *e.g.,* SCHROEDER *et al.* (1987). The westward winds push these drifters onshore, resulting in higher landings in eastern Florida this season. This seasonal change is reflected in the landfall probabilities that are higher in winter for southeastern Florida. A card-drifter study off

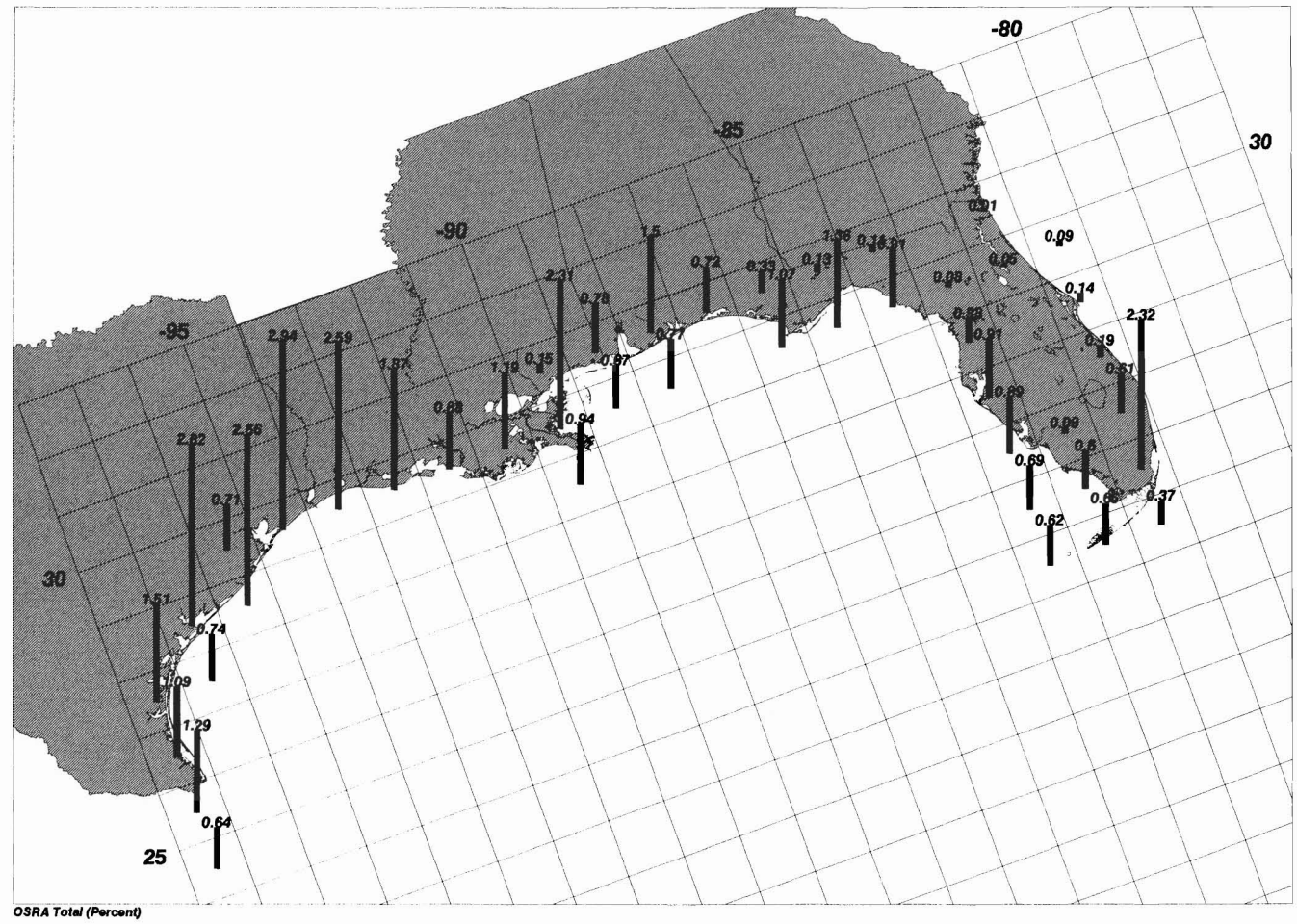

Figure 11. Landfall probabilities estimated from the OSRA for all seasons.

eastern Florida showed that drifters released in the Florida Current move onshore under westward winds (MAUL and BRAVO, 1989). A survey of tarballs in Florida (ROMERO *et al.*, 1981) observed a similar distribution along southern and eastern Florida. ROMERO *et al.* (1981) attributed tarball landings to prevailing winds and currents near Florida. Recent releases of drogued drifters (323 over a year) in the northeastern Gulf reveal few landings on the western Florida coast and not even penetration of drifters onto the shelf south of Tampa, Florida (Figure 14). This observation supports the low landings and contact probabilities in western Florida. YANG *et al.* (1999) obtained similar results using simulated drifters in a numerical model of the west Florida shelf. Marine debris accumulation along Texas (AMOS, 1993) matches the drifter accumulation, and is explained by prevailing westward winds and westward surface currents (U.S. NAVY, 1986) pushing materials onto the windward beach.

The influence of surface currents on drifter distribution is best illustrated by examples of satellite-tracked drogued drifters in the Gulf. Though, MAUL and BRAVO (1989) found little correlation between drogue and surface drifter results, the surface currents from ship-drift suggest that the Gulf may be bisected by a line along 86° or 87°W to the Mississippi Delta. CHEW *et al.* (1962) also postulated the existence of a divergence zone south of the Mississippi Delta that might distribute drifters east-west. SAIC (1986; 1987; 1988) presents drogue drifters tracks released along the imaginary line moving eastward, entering the Straits of Florida and leaving the Gulf. Figure 4.2-1 on SAIC (1987) and Figure 4.3-4 on SAIC (1988) show tracks of drifters released west of the line that are trapped by eddies and drift westward. Drifter data from MURPHY *et al.* (1975) support this idea. However, drifters from all over the Gulf tend to land in all clusters (Figure 8). Along Texas and Louisiana, the coastal current runs westward for most of the year, except May–July, which transports drifters to Texas (TEMPLE and MARTIN, 1979; COCHRANE and KELLY, 1986; NOWLIN *et al.*, 1998). During summer, the flow reverses and keep drifters along offshore Louisiana. Between the Mississippi Delta and Cape San Blas, currents also are mostly alongshore and tend to distribute drifters east to west (DINNEL, 1988; KELLY, 1991).

Drifter trajectories from the northeastern Gulf, Figure 14,

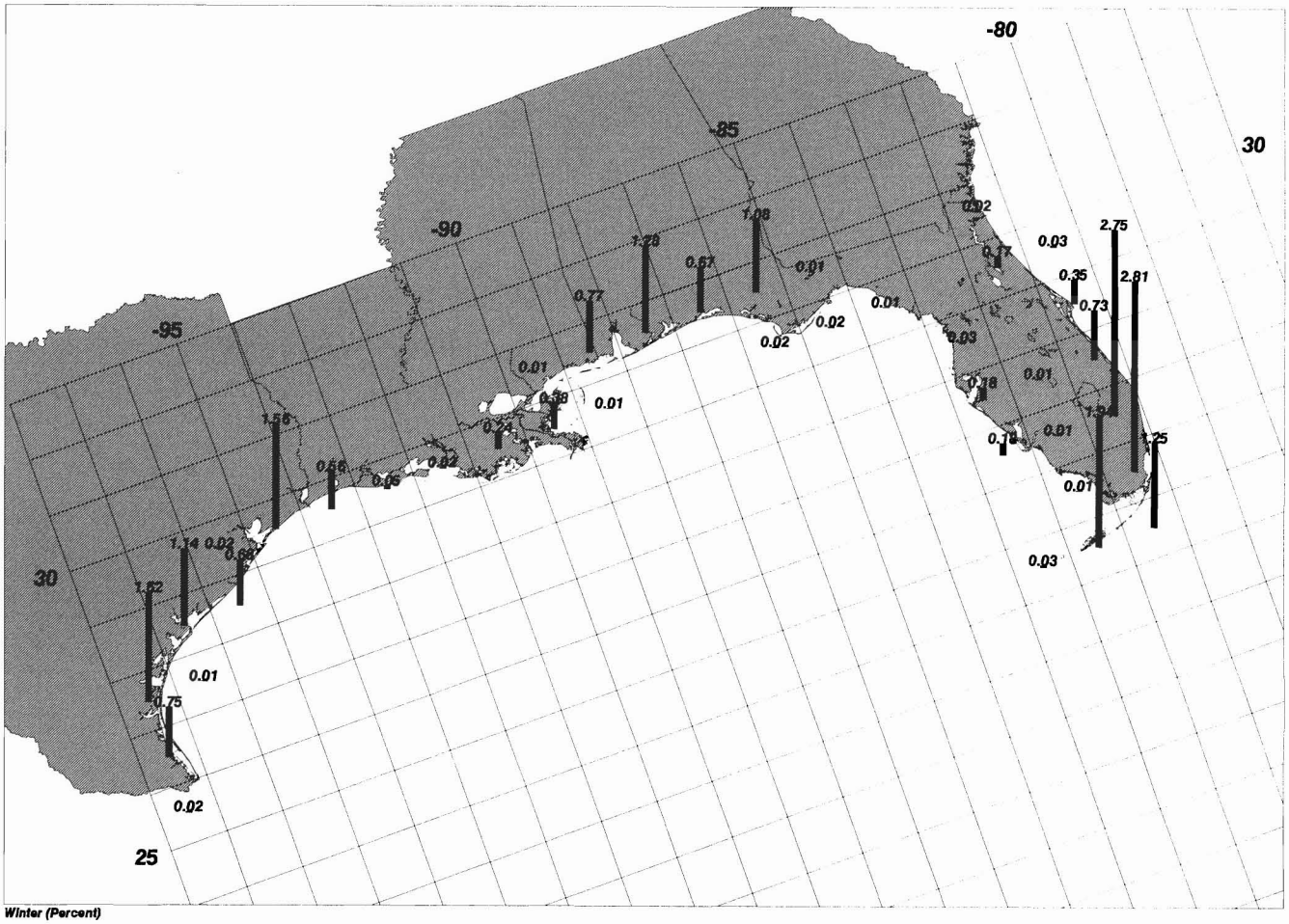

Figure 12. Landfall probabilities estimated using the recovered drifters during winter.

reached Texas after leaving the northeastern shelf off the Delta and flowing west along the shelf break. Others moved out of the Gulf, after been caught in the Loop Current, through the Straits of Florida and landed along eastern Florida. These trajectories provide additional evidence of few landings on western Florida. Since these drifters are tracked by satellite they show that lack of drifter landings on the Big Bend and south western Florida coast is not due to lack of people at the coast. YANG *et al.* (1999) provide a dynamical explanation of why this region has low drifter landings using vorticity conservation. Their arguments show that a coastal wind-driven jet tends to separate from the coast and prevent drifters from landing on the coast, creating a "forbidden zone" on the west Florida coast.

This work suggest that the Gulf surface drift is divided by the interplay of the westward winds and associated surface currents (U.S. NAVY, 1986), and surface currents of the Loop Current. The eastern Gulf tends to receive drifters mainly from the east, but the western Gulf and the Texas-Louisiana coasts receive drifters from the western and eastern Gulf, Figure 8.

This work helps estimating landfall probabilities for surface pollutants in the Gulf. Our results show low landfall probabilities of $<3.0\%$ for events of long duration. This work helps to explain the marine debris accumulation in Texas. Another application of our work is the suggestion that stranded marine mammals and turtles in the Florida and Panhandle regions originate in the eastern Gulf. ROBERTS (1997) proposed that larvae reaching south Florida reefs originated from the Caribbean and south Gulf areas based on prevailing surface currents. For strandings along Texas and Louisiana, the implication is that they could have originated almost anywhere in the Gulf.

We believe our results are robust because the data (1) represents the climatological (data period 1955–1987) regime of the Gulf of Mexico; and (2) account for interannual and seasonal variability. The results, however, were not corrected for drifter types (drag) and timing differences.

CONCLUSIONS

The main conclusions of this work are:

(1) Two seasons (winter and nonwinter), reflecting the Gulf

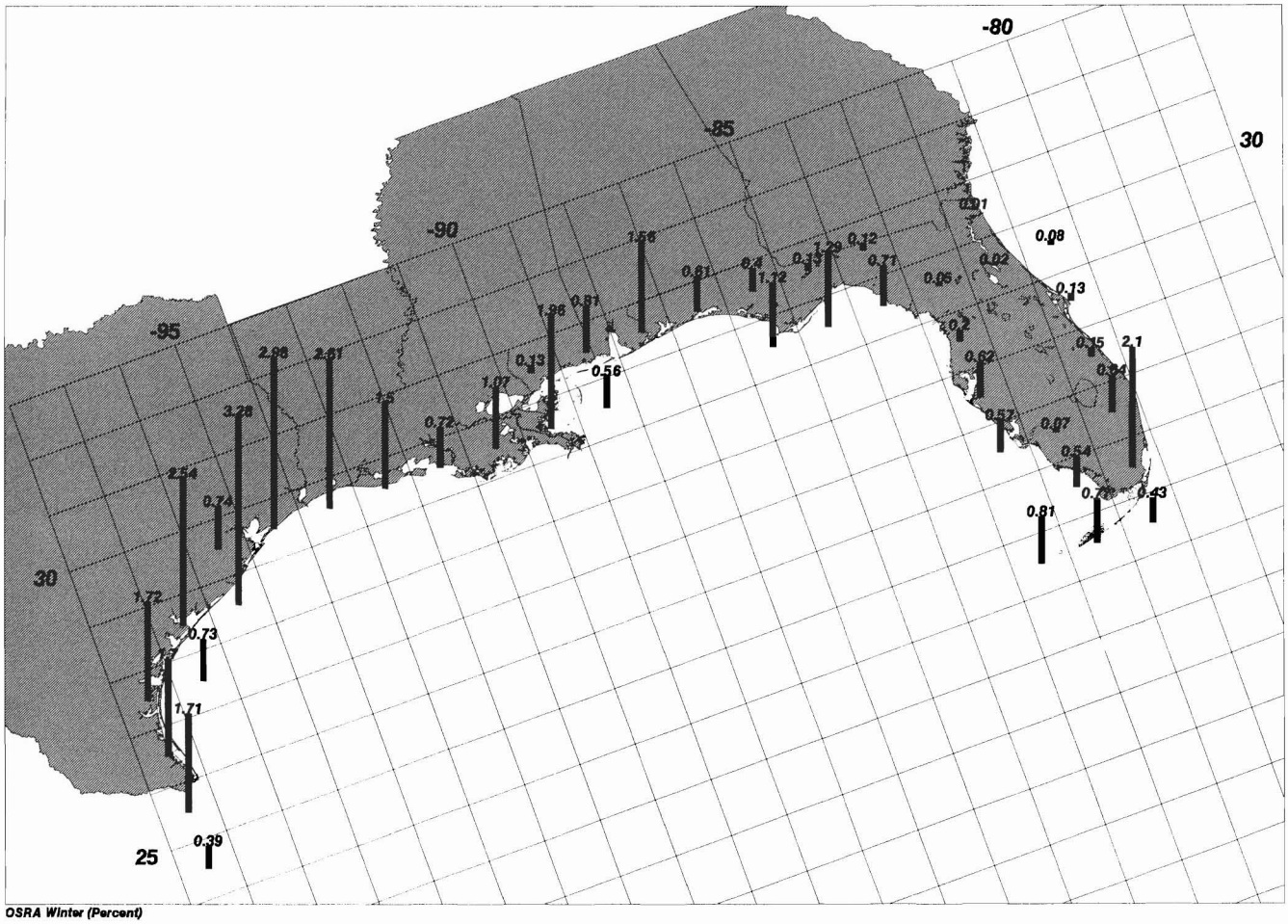

Figure 13. Landfall probabilities estimated with the OSRA model during winter.

of Mexico meteorology, are noticeable in the drifter recoveries. Five areas of high drifter landings in the Gulf are evident in both seasons. These areas of high landings are: southern Texas coast; the northwestern Gulf (Louisiana-Texas border); the northeastern Gulf of Mexico (Mississippi River Delta to the Cape San Blas); western Florida near Tampa; and southern and eastern Florida.

(2) Recovered distributions of drifters are not in the statistical sense, significantly correlated with human population and human marine activities along the Gulf coasts. Drifter landings are explained by other factors other than human activities along the coasts.

(3) Landfall probabilities from drifters and the OSRA model are equal to an order of magnitude level, and their spatial distributions have correlations of 0.44 to 0.49 (statistically significant at 80% confidence level) for all, winter, and non-winter seasons. The prevailing winds and surface currents in the Gulf explain the observed distributions of drifter landings.

(4) The observed drifter landing distributions show some correlation (0.25 and 0.31 respectively and statistically not significant) with the distributions of marine mammals and turtle strandings.

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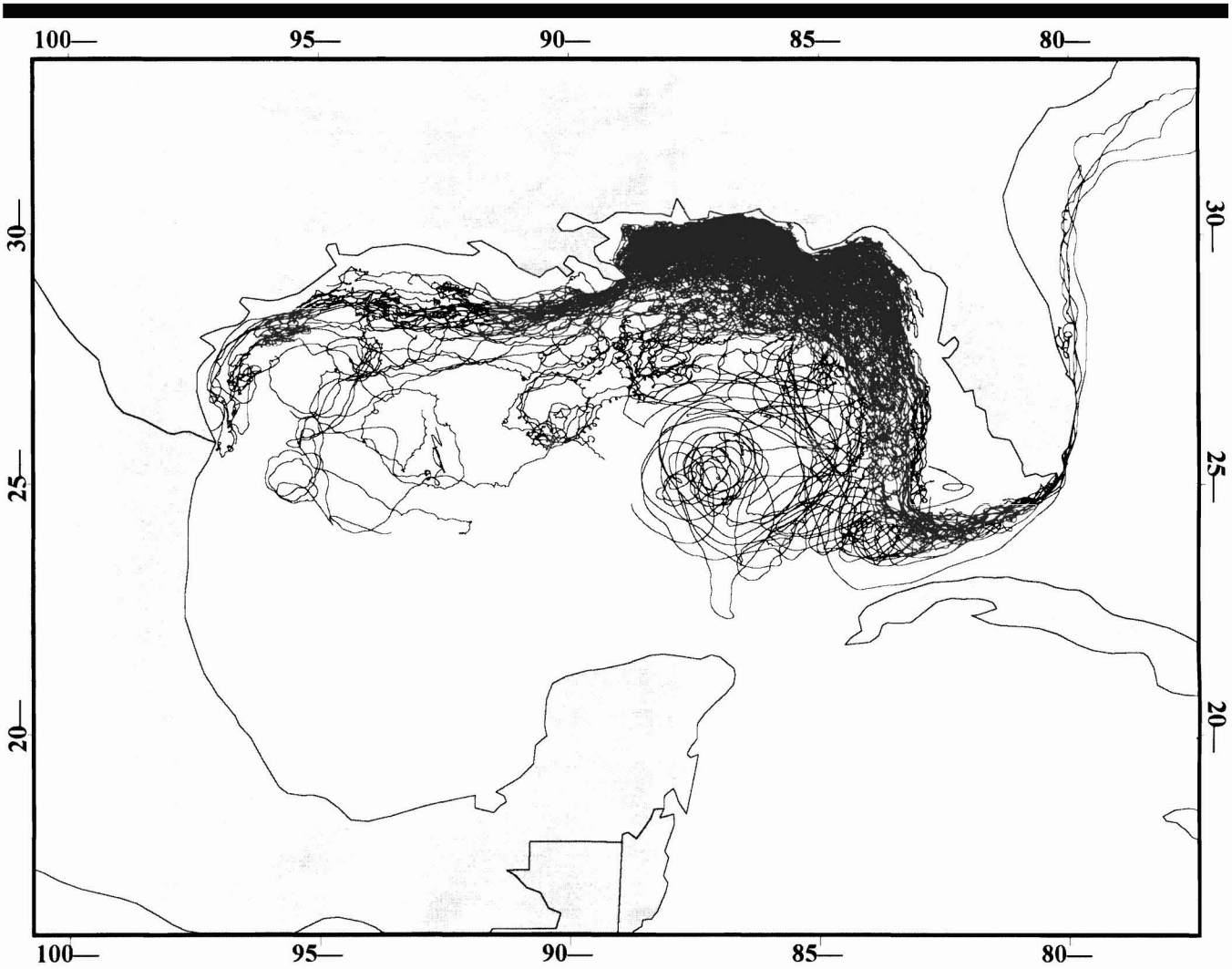

Figure 14. Trajectories of near-surface drogue drifters in the northeastern Gulf of Mexico during October 1996.

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