EFFECTIVENESS OF RELOCATION TRAWLING DURING HOPPER DREDGING FOR REDUCING INCIDENTAL TAKE OF SEA TURTLES

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ABSTRACT

Modified shrimp trawling equipment and techniques are used to capture and relocate threatened and endangered sea turtles from hopper dredging sites. This method of sea turtle protection was originally initiated in the early 1980s at Canaveral Harbor, Florida. In 1992, relocation trawling was implemented as a potential mitigation tool for incidental take (injury or mortality) of sea turtles for additional coastal hopper dredging projects in the southeastern United States. Although its effectiveness under various project conditions has been undocumented, this mitigation tool is now used extensively whenever sea turtles or Gulf sturgeon (*Acipenser oxyrinchus desotoi*) are potentially at risk for incidental take during hopper dredging projects. The National Marine Fisheries Service of the National Oceanic and Atmospheric Administration now recommends relocation trawling during many hopper projects throughout the southeastern United States and may recommend suspension of hopper dredging activities if weather or other conditions prevent trawling operations. This requirement impacts dredging schedules and inflates project costs. Relocation trawling is also a potentially hazardous undertaking for trawler crews and the species intended for protection. Other protected and non-protected organisms are also captured as by-catch and may be killed during the relocation trawling efforts. In light of the potential positive and negative impacts of relocation trawling during hopper dredging projects, it is crucial to evaluate the effectiveness of this technique as a mitigation option. Incidental take records from endangered species observer reports, relocation trawling reports, and hopper dredging project reports from 1995 through 2006 were analyzed to evaluate the effectiveness of relocation trawling for reducing incidental take of sea turtles. This study presents results related to sea turtles based upon: 1) analysis of species distribution; 2) analysis of catch per unit effort (CPUE) data; 3) spatial and temporal patterns of trawling captures and incidental takes; and 4) evaluation of effectiveness of trawling for reducing incidental takes.

Keywords: Endangered species, sturgeon, entrainment, mitigation, biological opinion

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INTRODUCTION

Five species of threatened or endangered sea turtles (loggerhead (*Caretta caretta*), green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempi*), hawksbill (*Eretmochelys imbricata*) and leatherback (*Dermochelys coriacea*)) are known to inhabit the southeastern United States coastline and are potentially at risk of being entrained by the suction from the draghead used by hydraulic hopper dredges. From 1980 through 2006, a total of 609 incidental takes (incidents of mortalities or injuries) of sea turtles have been documented from hopper dredging activities in this region. Loggerhead, green, and Kemp's ridley are the only sea turtle species identified by trained observers as incidental takes from hopper dredges. Substantial reductions in sea turtle entrainment rates occurred following implementation of equipment modifications, dredging operational measures, and management practice alternatives. These reductions and management alternatives are reviewed in Dickerson *et al*. (2004). One such method uses modified shrimp trawling equipment and techniques to capture and relocate sea turtles from the area of hopper dredging. The present study examines the effectiveness of relocation trawling for reducing incidental takes of sea turtles during dredging operations. For this paper, "incidental takes" refers to documented killed or injured sea turtles from the dredging activities and "relocated turtles" refers to the live turtles captured by the trawling vessel.

Sea Turtles and Hopper Dredging

In the United States, sea turtles occur in the Gulf of Mexico from Texas to Florida, Puerto Rico and the Virgin Islands; in the western Atlantic from Florida to Massachusetts; and in the Pacific along California, Hawaii, and U.S. territories (Spotila 2004). The five species of sea turtles potentially impacted by hopper dredging in the southeastern United States are listed as either threatened or endangered by the Endangered Species Act of 1973 (ESA). Kemp's ridley, leatherbacks, and hawksbills are listed as endangered throughout their ranges; green turtles are endangered in Florida and are threatened in all other locations; and loggerheads are listed as threatened throughout their range.

The mandate of the ESA is to ensure that endangered and threatened species are protected and that government departments and agencies should take all reasonable and prudent precautions to assure that their activities do not jeopardize the continued existence, or destroy or adversely modify the critical habitat, of listed species (Dickerson *et al*. 2004). To be in compliance, the USACE must consider all alternatives and protective measures necessary to conserve these species in order to minimize or eliminate sea turtle injuries and mortalities during dredging operations. The National Marine Fisheries Service (NMFS) is responsible for administering the ESA for all Federal actions which may impact endangered and threatened species at sea. Under the consultation process set forth in Section 7 (a)(2) of the ESA, when endangered or threatened species may be impacted by a dredging project, the USACE prepares a Biological Assessment which describes the proposed dredging activity, and identifies potential impacts to any listed species (USFWS 2007). The NMFS formulates a Biological Opinion which proposes reasonable and prudent measures to reduce negative impacts to the listed species and establishes incidental take limits. Hopper dredges currently operate under the Gulf Regional Biological Opinion (GRBO) for the U.S. Gulf of Mexico (GRBO 2003), the South Atlantic Regional Biological Opinion (SARBO) for the east coast of Florida through North Carolina (SARBO 1997), and the U.S. North Atlantic region manages hopper projects via individual project-based Biological Opinions. Incidental take limits defined by these Biological Opinions are shown in Table 1. Hopper dredging activities may be suspended or terminated whenever incidental take limits are reached for a given area.

Table 1. Annual incidental take allowed (injury or mortality) by NMFS biological opinions.

USACE Region	Biological Opinion	Loggerheads	Kemps	Greens	Hawksbills	Sturgeon (Gulf and Shortnose)
North Atlantic (North of North Carolina)	Varies by project and cubic meter (m^3) dredged					
South Atlantic (North Carolina – East Coast Florida)	25 Sep 1997	35	7	7	2	5 (shortnose)
Gulf of Mexico (Texas – West Coast Florida)	19 Nov 2003 (amended 2005 & 2007)	40	20	14	4	4 (Gulf)

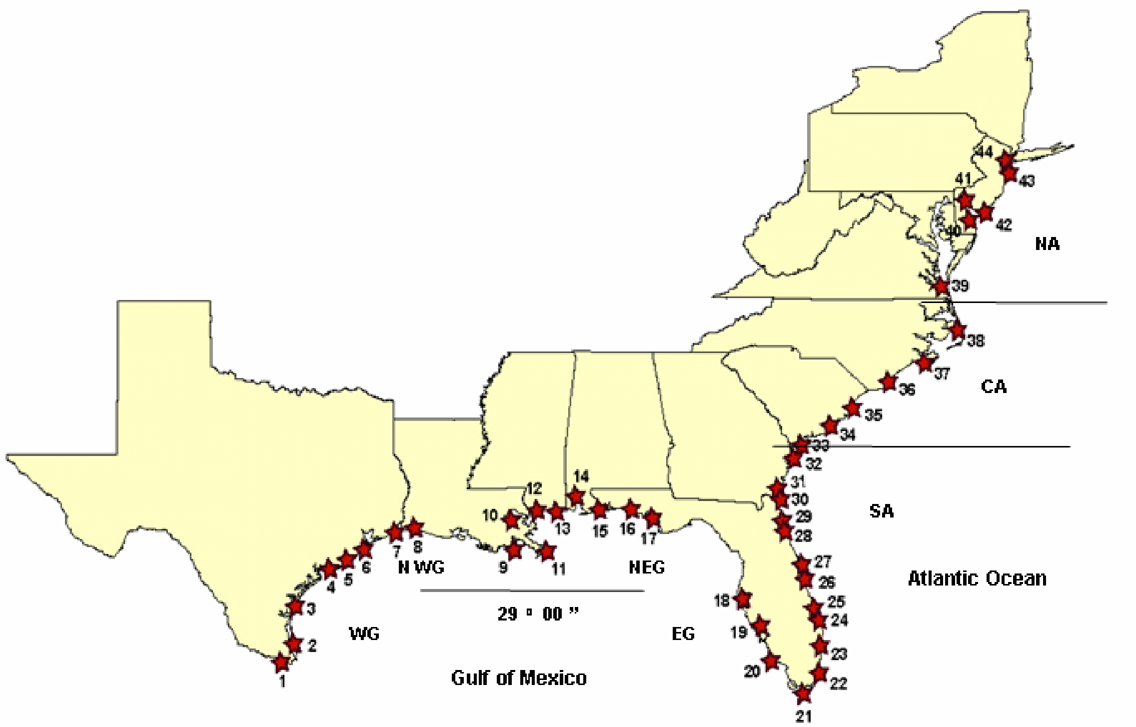
Over the last 26 years, an increasing number of navigation projects have been monitored for incidental takes. Currently, 77 project sites in the southeastern United States are monitored (Figure 1). Of these locations, 44 have had documented incidental takes of sea turtles. Thus sea turtle issues involve 11 USACE Districts, 4 USACE Divisions, and all hopper dredges operating from the Texas-Mexico border through New York.

From 1980 through 1985, Canaveral Harbor, Florida was the only channel monitored for sea turtle incidents (Rudloe 1981; Joyce 1982). From 1986 through 1990, Kings Bay, Georgia was also monitored. Four additional channels, (Savannah and Brunswick, Georgia; Charleston, South Carolina; and Wilmington, North Carolina) were monitored beginning in 1991, and the remaining south Atlantic channels were included in 1992. The North Atlantic channels above North Carolina began monitoring in 1994 and many of the channels throughout the Gulf of Mexico began monitoring in 1995. All incidental take monitoring efforts used comparable methodologies as of 1995. Differences in monitoring requirements over the past 26 years reflect differences in Biological Opinions issued by separate NMFS offices for distinct geographic regions as well as improved understanding of sea turtle biology and dredging impacts.

The USACE, NMFS, and dredging industry have worked closely to identify methods to minimize dredging impacts on sea turtles (Dickerson and Nelson 1990; USACE WES 1997). These methods have included modifications to dredging operations and equipment, establishment of environmental windows, and relocation of sea turtles. These methods are discussed in detail in Dickerson *et al*. (2004). Environmental windows (periods when dredging is allowed) for turtle protection generally involve winter months when sea turtle abundances are known to be low in inshore waters where water temperatures fall below16^{o}C and turtles are typically absent at temperatures below 12^{o}C (Dickerson *et al*. 1995). The environmental window for hopper dredging within the southeastern United States has evolved but is now recommended by NMFS as 1 December through 31 March (whenever possible) with slight modifications for specific channel or coastal regions, reflecting differences in spatial and temporal occurrences of sea turtles in coastal channels and temperature regime variations between regions. A lack of seasonally low water temperatures precludes environmental windows for many locations along the Gulf of Mexico. Environmental windows are designated in the Biological Opinions by the NMFS after considering the available biological and dredging data (SARBO 1997; GRBO 2003). Therefore, continued efforts are needed to collect the necessary data to refine the environmental windows for dredging activities. Restricting hopper dredging to winter months extremely complicates dredging schedules and causes safety issues for dredge crews working under severe winter sea conditions.

Relocation of Sea Turtles

Relocating sea turtles away from dredging sites is one management practice developed by the USACE Engineer Research and Development Center (ERDC) and recommended by NMFS in the GRBO as a potential method to reduce incidental take (GRBO 2003). Modified shrimp trawling equipment is used to sweep bottoms to remove turtles that might be encountered by an approaching dredge, and relocate captured sea turtles three to five miles from the dredging area. This management technique was originally initiated in the early 1980s at Canaveral Harbor, Florida (Rudloe 1981). Relocation trawling has since been implemented to: 1) remove sea turtles (and/or Gulf sturgeon) from project sites with elevated sea turtle populations; and 2) prevent additional incidental takes to avoid potential interruption of dredging. Dredging activities may be suspended if sea-state conditions prevent trawlers from operating. This step can severely impact hopper dredging schedules and inflate project costs. Relocation trawling conducted during the early 1980s in Canaveral Harbor, Florida was considered impractical and ineffective due to the high number of relocated turtles that immediately returned to this channel and its high cost ($300,000 U.S.) (Studt 1987). More recent trawling efforts at Canaveral Harbor has not demonstrated high numbers of recaptured turtles. Since 1992, relocation trawling has been used as a mitigation tool at other hopper dredging locations throughout the southeastern United States based on anecdotal accounts and speculative assessments of its effectiveness for reducing incidental take of sea turtles.



West Gulf (WG)
1. Brazos Island/Brownsville Channel*
2. Port Mansfield
3. Corpus Christi Channel*
4. Matagorda Ship Channel*
5. Freeport Harbor*

Northwest Gulf (NWG)
6. Houston-Galveston Channels*
7. Sabine-Neches Waterway*
8. Calcasieu Pass*
9. Houma Navigational Channel
10. MS River Gulf Outlet*
11. Southwest Pass

Northeast Gulf (NEG)
12. Gulfport*
13. Pascagoula*
14. Mobile Bay*
15a. Pensacola*
15b. Navarre Beach*
15c. Gulfshores*
16. Walton County Beaches*
17. Panama City Beaches*

East Gulf (EG)
18a. Tampa Bay-Egmont Channel*
18b. St. Petersburg Harbor
18c. Venice Beach
18d. Longboat Key*
18e. Siesta Key*
19. Charlotte Harbor
20a. Collier County Beaches*
20b. Captiva & Sanibel Beaches

South Atlantic (SA)
21. Key West
22a. Miami-Dade Beaches
22b. Bal Harbor
23a. Broward County Beaches
23b. Port Everglades
24. Palm Beach
25a. Jupiter Island Inlet
25b. Martin County Beaches*
25c. Fort Pierce
25d. Hutchinson Island
26. Brevard County Beaches*
27a. Cape Canaveral*
27b. Patrick Air Force Base
28. St. Augustine Harbor
29a. Jacksonville Harbor
29b. St. Johns River
29c. Mayport Naval Station
29d. Duval County Beaches
30. Kings Bay Channel*
31. Brunswick Harbor*
32. Savannah Harbor*

Central Atlantic (CA)
33. Port Royal
34. Charleston Harbor*
35a. Georgetown Harbor
35b. Debidue Beach*
35c. Myrtle Beach
36a. Wilmington Harbor*
36b. Kure & Carolina Beaches
36c. Military Ocean Terminal Sunny Point
37a. Morehead City Harbor*
37b. Bogue Banks*
38. Oregon Inlet

North Atlantic (NA)
39a. Cape Henry*
39b. York Spit-River*
39c. Thimble Shoal*
39d. Virginia Beach*
39e. Sandbridge Beach
39f. Atlantic Ocean Channel
39g. Chincoteague Inlet
39h. Assateague Island
40a. Bethany Bay-Beach
40b. Dewey Beach
41. Delaware River
42. Cape May
43. Sandy Hook to Barnegat Inlet
43b. Seabright to Ocean Township
44a. Ambrose Channel
44b. New York Harbor

Figure 1. Hydraulic hopper projects monitored for incidental takes. Kennebec River doubling point and San Juan Harbor not shown on map. (* = projects with relocation trawling.)

Relocation trawling has typically been held as a last resort due to high costs, logistical difficulties, and potential safety risks. Trawling vessels can cost over $5,000 per day (per vessel) to operate, specialized nets run a minimum of $9,000 per project, and personnel costs average $500 per person per day. A slow-moving trawler frequently cannot work safely close in front of a faster moving dredge; therefore, trawling is usually conducted far ahead (about 0.25 nautical miles or greater) of the dredge and other channel traffic. At some locations, the trawl nets frequently become clogged with large clay balls, by-catch, and debris in the channel and can cause the trawler to lose steerage and subject the vessel to damage, collision with the dredge or other vessels, or lead to loss of trawl gear. Trawling vessels cannot operate effectively or safely in as rough seas as hopper dredges, therefore, relocation efforts are not possible in all weather conditions. Relocation trawling can also be potentially hazardous for the threatened and endangered species intended for protection due to the rigors and stress of trawling and on-deck handling. It is still unknown what long-term effects may occur to sea turtles when they are relocated. Other protected and non-protected organisms (e.g. sharks, rays, dolphins) are also captured as by-catch and may be killed during trawling. In light of the potential impacts from using relocation trawling during hopper dredging projects, it is crucial to evaluate the effectiveness of this technique as a mitigation tool.

METHODS AND STUDY SITES

Incidental take records from endangered species observer reports, relocation trawling reports, and hopper dredging project reports from 1995 through 2006 were analyzed to evaluate the effectiveness of relocation trawling for reducing incidental take of sea turtles. This study presents results related to sea turtles based upon: 1) analysis of species distribution; 2) analysis of catch per unit effort (CPUE) data; 3) spatial and temporal patterns of trawling captures and incidental takes; and 4) evaluation of effectiveness of trawling for reducing incidental takes. Data used for these analyses are archived in the USACE Sea Turtle Data Warehouse http://el.erdc.usace.army.mil/seaturtles/. Size-class distributions and environmental parameters (e.g., water temperature, sediment type) were not evaluated in these analyses.

The 77 Gulf of Mexico and Atlantic coast project sites used for these analyses are shown in Figure 1. Gulf and Atlantic regions are evaluated separately because of differences in habitat use by sea turtles, differences in implementation of mitigation and monitoring requirements between the SARBO and GRBO, and potential differences in dredging environments and requirements. The two regions were divided into 7 subregions: west Gulf (WG), northwest Gulf (NWG), northeast Gulf (NEG), east Gulf (EG), south Atlantic (SA), central Atlantic (CA), and north Atlantic (NA). Subregions WG, NWG, NEG, and EG were defined using the 29^{o} 00" latitude and Mississippi River outlet as boundaries (Figure 1). SA includes Florida and Georgia, CA includes North and South Carolina, and NA includes Virginia through New York.

For a typical trawling effort, two sixty foot trawl nets covering an average channel width of 100 feet are dragged across the bottom for an average of 35 minutes (42 minutes maximum time allowed by SARBO and GRBO for nets in the water). The nets are designed with an 8-inch (20.3-cm) stretch mesh to allow as much by-catch and debris to pass through as possible, resulting in far less bycatch than standard shrimp trawling nets and practices. Specifications for trawling equipment and relocation protocols can be found at http://www.saj.usace.army.mil/pd/trawl.htm. Because the level of effort for relocation trawling projects varies greatly due to site-specific implementation requirements, a series of "levels" were developed to distinguish between the amount of effort applied. These levels assume that the dredge(s) worked 24 hours per day. All relocation trawling projects can be placed into one of six levels based on the number of tows completed for a given project, from least to most aggressive independent of the number of trawlers on-site (Table 2).

Table 2. Definitions of sea turtle relocation trawling effort levels (mean tow=35 minutes).

Trawling Effort	Hours/Day Trawled	Mean Tows/Hour	Mean Tows/Day
Level 1	12	Up to one	Up to 12
Level 2	24	Up to one	Up to 24
Level 3	12	1.01 to 1.70	12.1to 20.4
Level 4	24	1.01 to 1.70	24.2 to 40.8
Level 5	12	Over 1.70	Over 20.4
Level 6	24	Over 1.70	Over 40.8

RESULTS

Quantitative Analysis by Location and Species

From 1980 through 2006, 377 hopper dredging projects have been monitored. These include 77 sites (Figure 1); 34 with relocation trawling and 43 without relocation trawling. Of these locations, 44 have had documented incidental takes of sea turtles. Data were used only from 1995 through 2006 when monitoring methodologies throughout the southeastern United States were consistent. From 1995 through 2006, 319 hopper dredging projects used endangered species monitoring (Regions: Gulf=128; Atlantic=191) (Subregions: WG=31; NWG=60; NEG=27; EG=10; SA=86; CA=68; NA=37); one 2006 Atlantic project (Brunswick Harbor) was excluded since it extended into 2007. Of these 319 projects, 70 conducted relocation trawling during some portion of the project (Regions: Gulf =44; Atlantic=26) (Subregions: WG=13; NWG=12; NEG=14; EG=5; SA=13; CA=8; NA=5).

Of 609 documented sea turtle takes (1980 - 2006), 4 fatalities (green=1, loggerhead=2, leatherback=1) resulted from injuries sustained during trawling capture and not dredging. A total of 358 dredging-related sea turtle takes (Regions: Gulf=147; Atlantic=211) (Subregions: WG=45; NWG=73; NEG=13; EG=16; SA=96; CA=63; NA=52) (1995-2006) were used for the analyses in this study (Figure 2). During the 70 projects with relocation trawling efforts, 1239 sea turtles (Regions: Gulf=844; Atlantic=395) (Subregions: W=169; NWG=174; NEG=236; EG=265; SA=311; CA=27; NA=57) were relocated (Figure 3). Sea turtles were the only species evaluated for this paper. However, since relocation trawling has also been used to prevent sturgeon entrainment, it should be noted that 24 dredging-related incidental takes of 3 species of sturgeon (shortnose (*Acipenser brevirostrum*)=11; Atlantic (*Acipenser fulvescens*)=11; and Gulf (*Acipenser oxyrinchus desotoi*)=2) have been documented (Dickerson *et al*. In preparation).

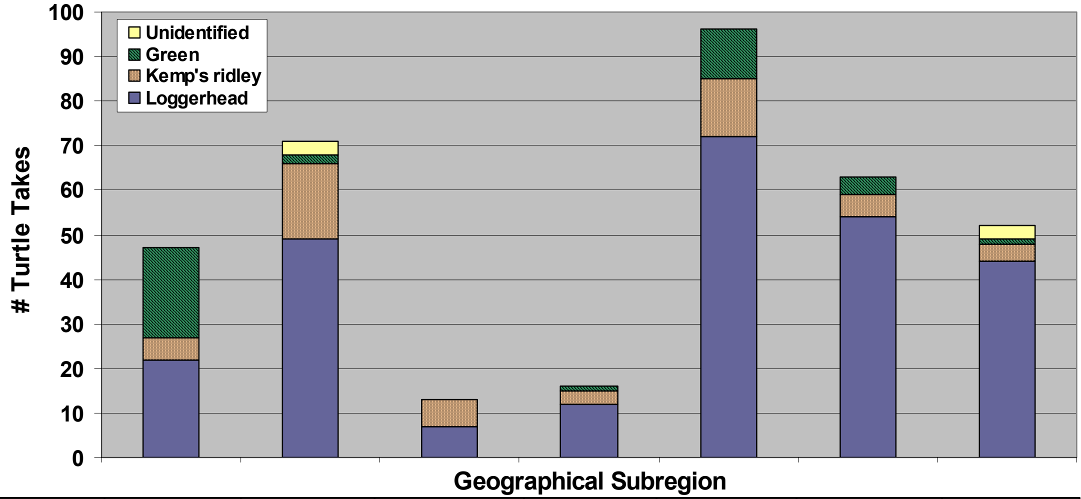
Distribution of dredging-related incidental takes and relocated turtles by species and subregion are also provided in Figures 2 and 3. For each subregion, loggerhead is the predominant species for both dredge takes and relocated turtles with Kemp's ridley and greens ranking second and third respectively. Green sea turtles are captured more often in WG and SA than any other subregion. Although two hawksbills and 6 leatherbacks have been relocated during 1995-2006, neither of these species have ever been documented as a dredge-related take. However, one leatherback was killed accidentally by debris in a trawl net during a Destin-Ft. Walton Beach, Florida beach nourishment project in December 2006.

Catch Per Unit Effort (CPUE) Comparison

The SARBO and GRBO require reporting of absolute numbers of incidental takes and relocated turtles by region annually (SARBO 1997; GRBO 2003), but not in conjunction with data on the quantity of dredging or trawling conducted (e.g., number of projects, number of days of dredging or trawling, volume of material dredged, or number of trawling tows). Therefore, it is difficult to evaluate differences in annual turtle takes without taking into consideration the amount of dredging done relative to the documented takes. Annual total incidental takes, dredging projects, and catch (take) per unit effort (CPUE) for the Gulf and Atlantic regions are shown in Figure 4. Annual CPUE per project for each subregion is given in Figure 5. Cumulative CPUE comparisons for each region and subregion are given in Table 3.

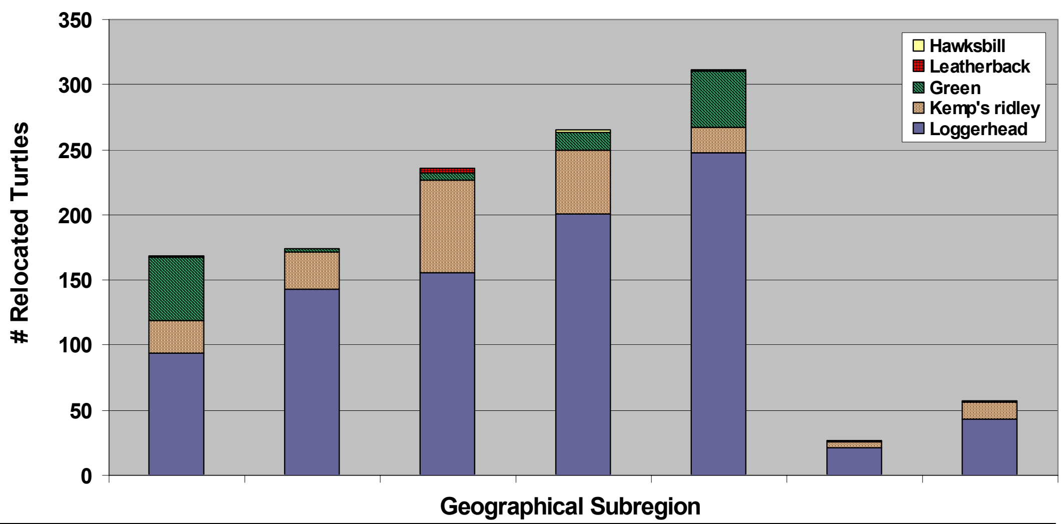
Table 3. Cumulative CPUE (takes per project) comparisons by geographic region/subregion (1995-2006).

CPUE	Gulf of Mexico Region					Atlantic Region			
Measure	WG	NWG	NEG	EG	Combined	SA	CA	NA	Combined
Mean	1.48	1.06	0.46	1.72	1.21	1.19	0.85	1.19	1.05
n (years)	11	12	5	6	12	12	12	11	12
SD	0.83	0.96	0.71	1.51	0.45	0.65	0.70	0.97	0.53
Var	0.69	0.92	0.50	2.28	0.20	0.42	0.49	0.95	0.29



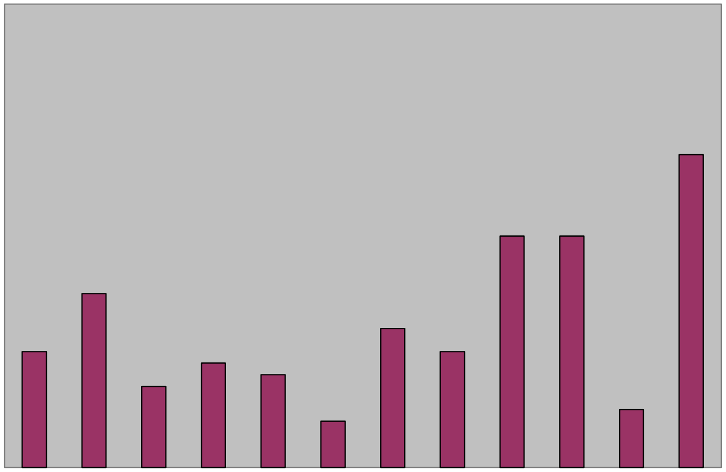
Species	WG	NWG	NEG	EG	SA	CA	NA
Unidentified (6)	0	3	0	0	0	0	3
Green (39)	20	2	0	1	11	4	1
Kemp's ridley (53)	5	17	6	3	13	5	4
Loggerhead (260)	22	49	7	12	72	54	44
Total (358)	45	73	13	16	96	63	52

Figure 2. Total sea turtle takes by geographic region (1995-2006). (WG=west Gulf; NWG=northwest Gulf; NEG=northeast Gulf; EG=east Gulf; SA=south Atlantic; CA=central Atlantic; NA=north Atlantic.)

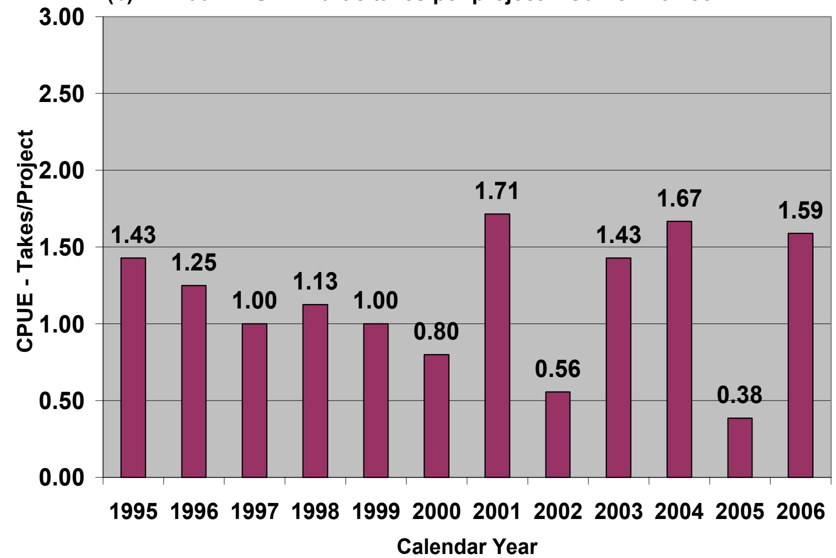


Species	WG	NWG	NEG	EG	SA	CA	NA
Hawksbill (2)	0	0	0	2	0	0	0
Leatherback (6)	1	0	4	0	1	0	0
Green (115)	49	3	5	13	43	1	1
Kemp's ridley (210)	25	28	71	49	19	5	13
Loggerhead (906)	94	143	156	201	248	21	43
Total (1239)	169	174	236	265	311	27	57

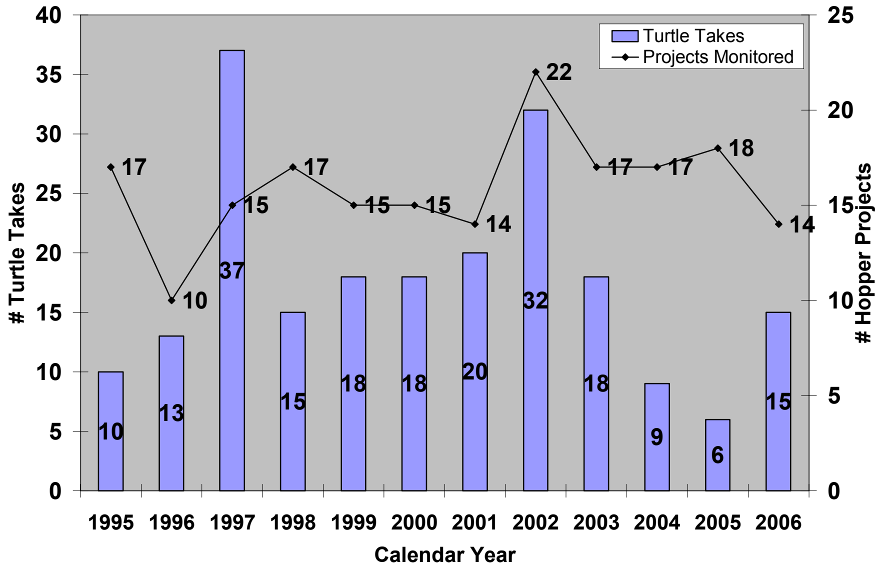
Figure 3. Total relocated sea turtles by geographic region (1995-2006). (WG=west Gulf; NWG=northwest Gulf; NEG=northeast Gulf; EG=east Gulf; SA=south Atlantic; CA=central Atlantic; NA=north Atlantic.)



(b). Annual CPUE – Turtle takes per project – Gulf of Mexico



(c). Annual turtle takes and hopper projects monitored - Atlantic



(d). Annual CPUE – Turtle takes per project - Atlantic

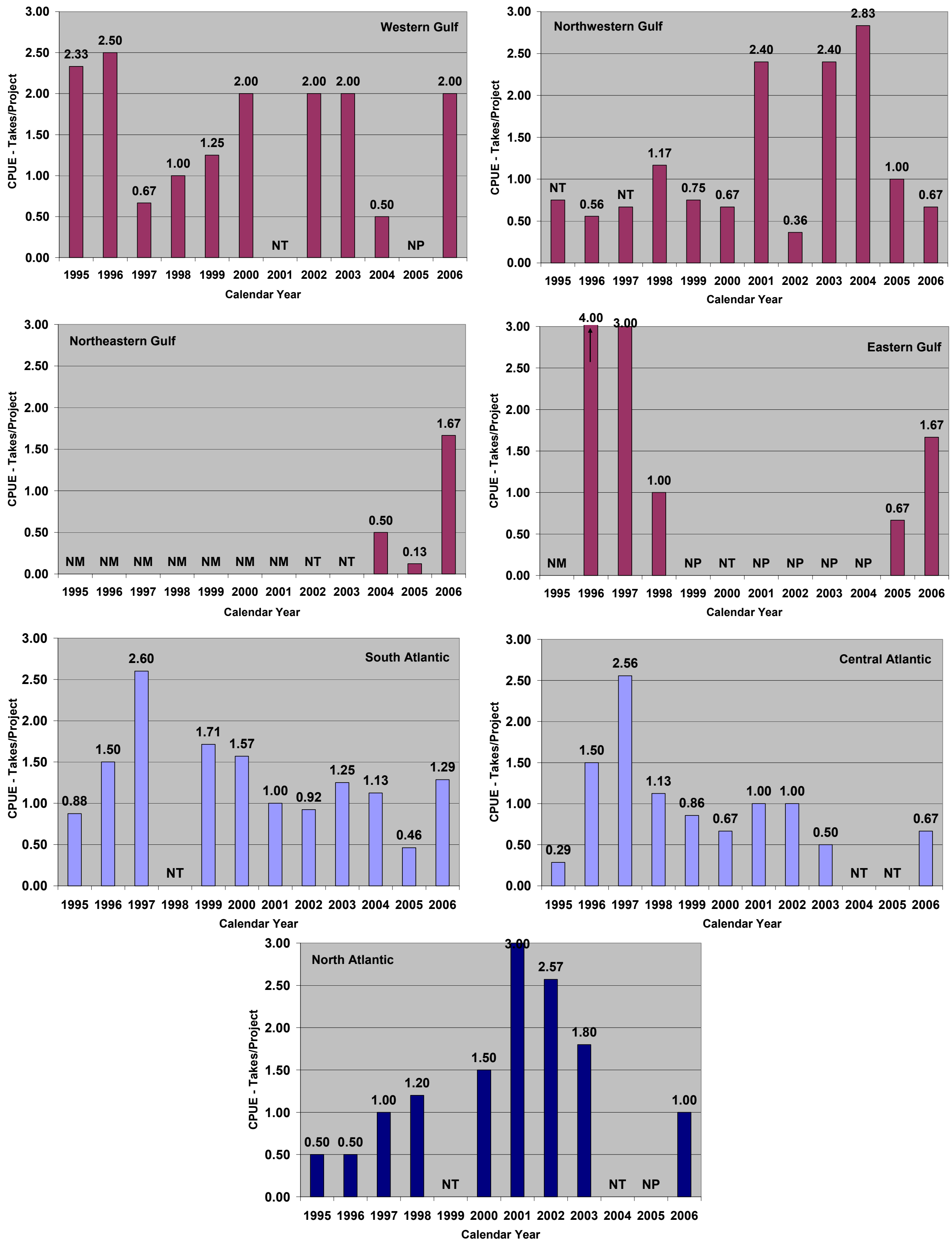


Figure 5. Annual CPUE takes per project by subregions. (NP = No dredging projects; NT = No turtle takes documented; NM = No monitoring required during dredging.)

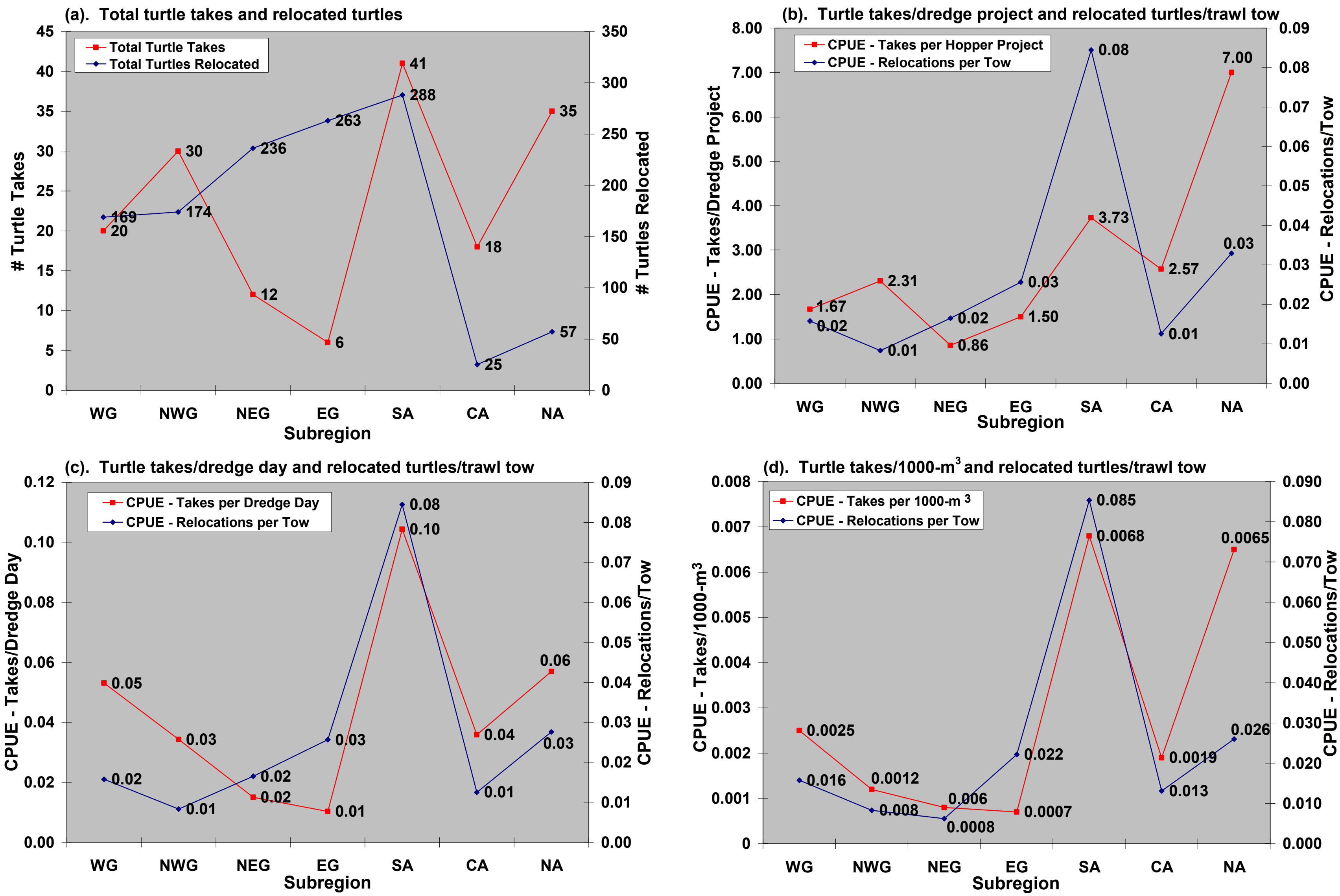


Figure 6. CPUE comparison between turtle takes and relocated turtles for each geographic subregion (1995-2006). (WG=west Gulf; NWG=northwest Gulf; NEG=northeast Gulf; EG=east Gulf; SA=south Atlantic; CA=central Atlantic; NA=north Atlantic.)

CPUE per project does not account for the volume of sediment dredged during each project. Figure 6 compares differences among subregions for absolute numbers of turtle takes and relocated turtles versus CPUE. Figure 6a provides comparisons between absolute numbers of turtle takes and relocated turtles. CPUE comparisons between relocated turtles per trawl tow and takes per project, takes per dredge day, and takes per 1000 m^3 (cubic meters) material dredged are provided in Figure 6b-d.

Spatial and Temporal Patterns of Incidental Takes and Trawling Captures

The distribution of absolute numbers of turtles by month and species for each region is given for incidental takes in Table 4 and relocated turtles in Table 5. Loggerheads consistently remain the predominant species captured each month for both trawling and incidental takes. Kemp's ridley turtles have been captured during every month within the Gulf region, but are typically collected from September through May on the Atlantic coast. Green turtles have only been trawled during December through March in the Gulf regions (primarily WG), whereas, green turtles have only been trawled during February, April, September, and October in the Atlantic region. Absolute numbers of takes per month for each region show similar distributions to trawling captures except green turtle takes have been documented across more months in the Atlantic region than captured by trawling.

Table 4. Absolute numbers of incidental turtle takes per month by geographic region. (Cm=greens; Lk=Kemp's ridley; Cc=loggerheads; UN=unidentified; Unk=unknown dates.)

Month	Gulf of Mexico Region					Atlantic Region				
	Cc	Lk	Cm	UN	Total	Cc	Lk	Cm	UN	Total
Jan	0	1	4	0	5	5	1	1	0	7
Feb	0	1	4	0	5	16	3	1	0	20
Mar	3	6	7	0	16	42	10	0	0	52
Apr	10	8	0	0	18	19	2	0	0	21
May	17	2	0	0	19	13	0	0	0	13
Jun	13	2	0	1	16	4	0	1	0	5
Jul	7	1	0	0	8	3	0	0	1	4
Aug	10	5	0	0	15	10	0	0	1	11
Sep	4	2	1	0	7	13	1	4	1	19
Oct	15	2	0	2	19	20	3	3	0	26
Nov	7	1	0	0	8	10	0	0	0	10
Dec	4	0	5	0	9	10	2	2	0	14
Unk	0	0	2	0	2	5	0	4	0	9
Total	90	31	23	3	147	170	22	16	3	211

The distribution of dredge projects by month for the Gulf region, SA and CA subregions combined, and NA subregion are provided in Figure 7. Spatial and temporal CPUE comparisons of incidental takes per dredge project by month, region and subregion are shown in Figures 8 and 9. Similar comparisons are provided for relocated turtles per relocation project in Figures 10 and 11. Seasonal differences can be seen in overall CPUE takes per project for each region (Figure 8). An increase in turtle takes per project is clearly seen in spring (March - May) and fall (September - November) for the SA and CA subregions. A similar increase in takes per project occurs in the Gulf region in spring (March - June) and fall (October) but the bimodal pattern is not as well-defined for the Gulf as for the Atlantic region. A distinct peak in takes occurs from August through October in the NA subregion. Seasonal differences can also be seen in Figures 10 and 11 with the capture rates of turtles for relocation, but these patterns are not as distinct as those for take rates in Figures 8 and 9. An increase in capture rate of turtles per trawling project is shown from February through June throughout the Gulf region and February through May for the SA and CA subregions. Trawling capture rates increased in September and October for the SA and NA subregions, but not in the Gulf subregions (Figure 11). A peak in trawling capture rates was observed in October and November for the NWG subregion.

Table 5. Absolute numbers of relocated turtles per month by geographic region. (NR=No relocation projects) (Cm=greens; Lk=Kemp's ridley; Cc=loggerheads; Dc=leatherbacks; Ei=hawksbills.)

	Gulf of Mexico Region						Atlantic Region					
Month	Cc	Lk	Cm	Dc	Ei	Total	Cc	Lk	Cm	Dc	Ei	Total
Jan	6	6	7	0	0	19	-	-	-	-	-	NR
Feb	31	21	21	0	1	74	88	0	14	0	0	102
Mar	70	27	23	0	0	120	39	14	0	0	0	53
Apr	74	29	0	2	0	105	22	6	1	1	0	30
May	94	19	0	2	0	115	28	1	0	0	0	29
Jun	65	3	0	0	0	68	-	-	-	-	-	NR
Jul	23	10	0	0	0	33	-	-	-	-	-	NR
Aug	89	21	0	0	0	110	-	-	-	-	-	NR
Sep	16	3	0	0	0	19	90	2	19	0	0	111
Oct	46	6	0	1	0	53	36	11	11	0	0	58
Nov	61	16	0	0	0	77	5	2	0	0	0	7
Dec	20	11	19	0	1	51	4	1	0	0	0	5
Total	595	172	70	5	2	844	312	37	45	1	0	395

Effectiveness of Relocation Trawling for Reducing Incidental Takes

CPUE comparisons of takes per dredge day between dredging periods with and without relocation trawling can be used to evaluate the effectiveness of relocation efforts for reducing incidental take of sea turtles. Although CPUE comparisons of takes per 1000 m^3 dredged would provide a more refined comparison, data for the volume of material dredged were unavailable for many projects. Therefore, CPUE comparisons of takes per dredge day were used to provide a larger sample size. An evaluation of the effect of relocation trawling on the turtle take rate per dredge day for each subregion is shown in Figure 12. Overall entrainment rate was reduced after relocation trawling was implemented in the WG, NWG, NEG, and SA subregions. Very slight increases in takes per dredge day were seen for the EG (0.0041) and CA (0.0029) subregions and a moderate increase in takes per dredge day was found for the NA (0.0411) subregion.

Although trawling protocols are standardized, the effectiveness of trawling can vary depending on when trawling is initiated during a dredging project or the level of trawling effort used. Figure 13 provides an evaluation of the effect of relocation trawling on the overall take rate per dredge day based on when trawling was initiated during the project. A total of 249 projects were conducted without relocation trawling because overall entrainment rate was considered low (mean 0.0110 takes per dredge day). For projects utilizing relocation trawling, the lowest overall CPUE (0.0222 takes/dredge day) was seen when relocation began at the onset of dredging and continued throughout the entire dredging project. The next lowest take rates were found for projects that either initiated relocation trawling prior to the start of dredging (0.0667 takes/dredge day) or early in the first third of the dredging project (0.0642 takes/dredge day) and continued relocation throughout the remaining dredging project. Smallest reductions in take rates were seen when relocation trawling was initiated either late (during second third) (0.1070 takes/dredge day) or very late (during last third) (0.1808 takes/dredge day) of the dredging project.

Figure 14 demonstrates the effectiveness of relocation in reducing the overall take rate for a dredging project based on the level or aggressiveness of trawling effort conducted. No relocation trawling projects were identified as Level 5 effort but projects were identified for each of the other levels of effort defined. The overall CPUE of takes per dredge day for Level 2 projects showed a very slight increase in take rates after trawling was initiated, however, this may not be interpreted as a substantial increase in overall take rate. Take rates for Levels 1, 3, 4, and 6 were all reduced after relocation trawling was implemented and the amount of reduction increased as the level of trawling effort increased.

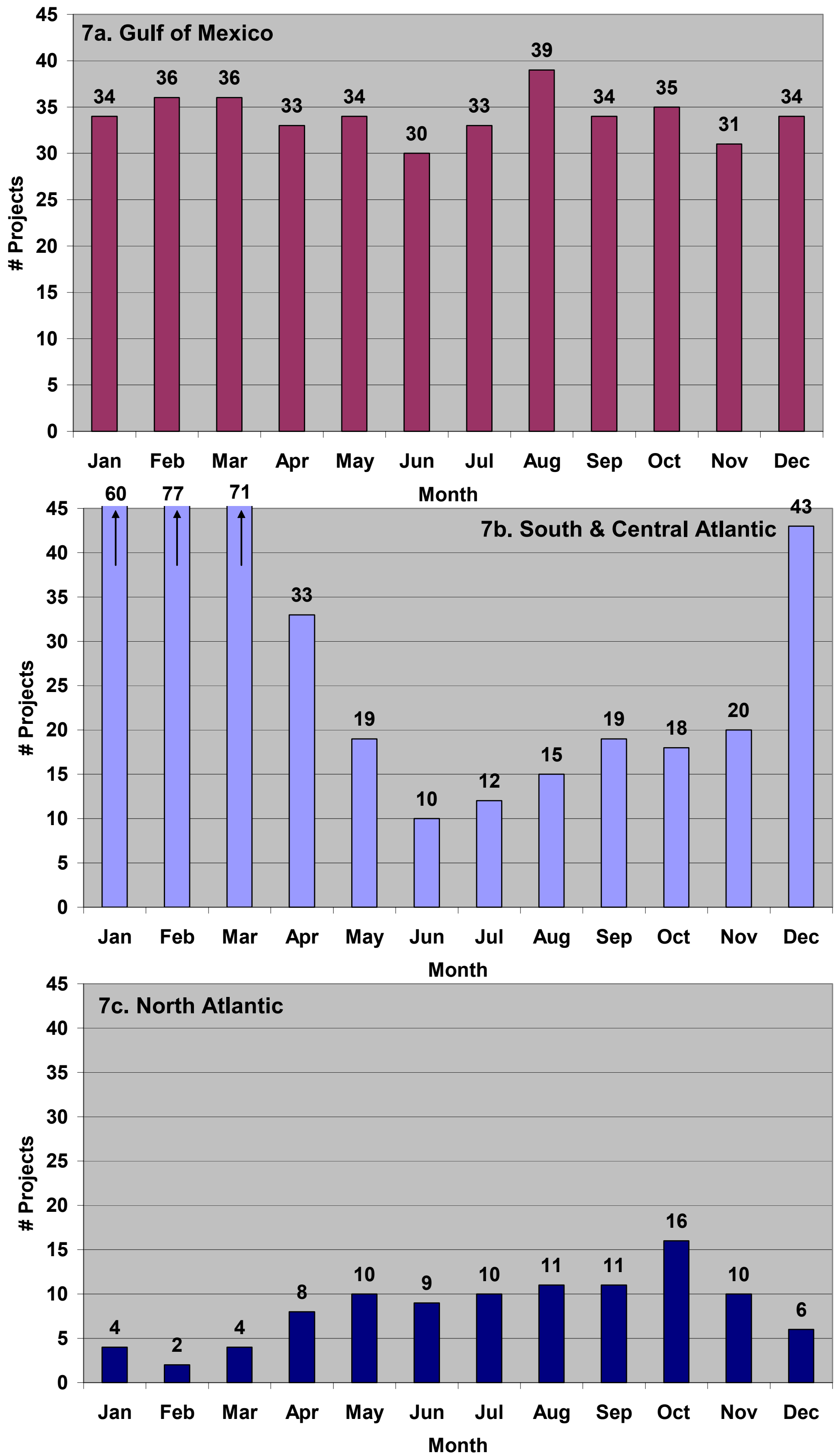


Figure 7. Monthly distribution of dredge projects by region.

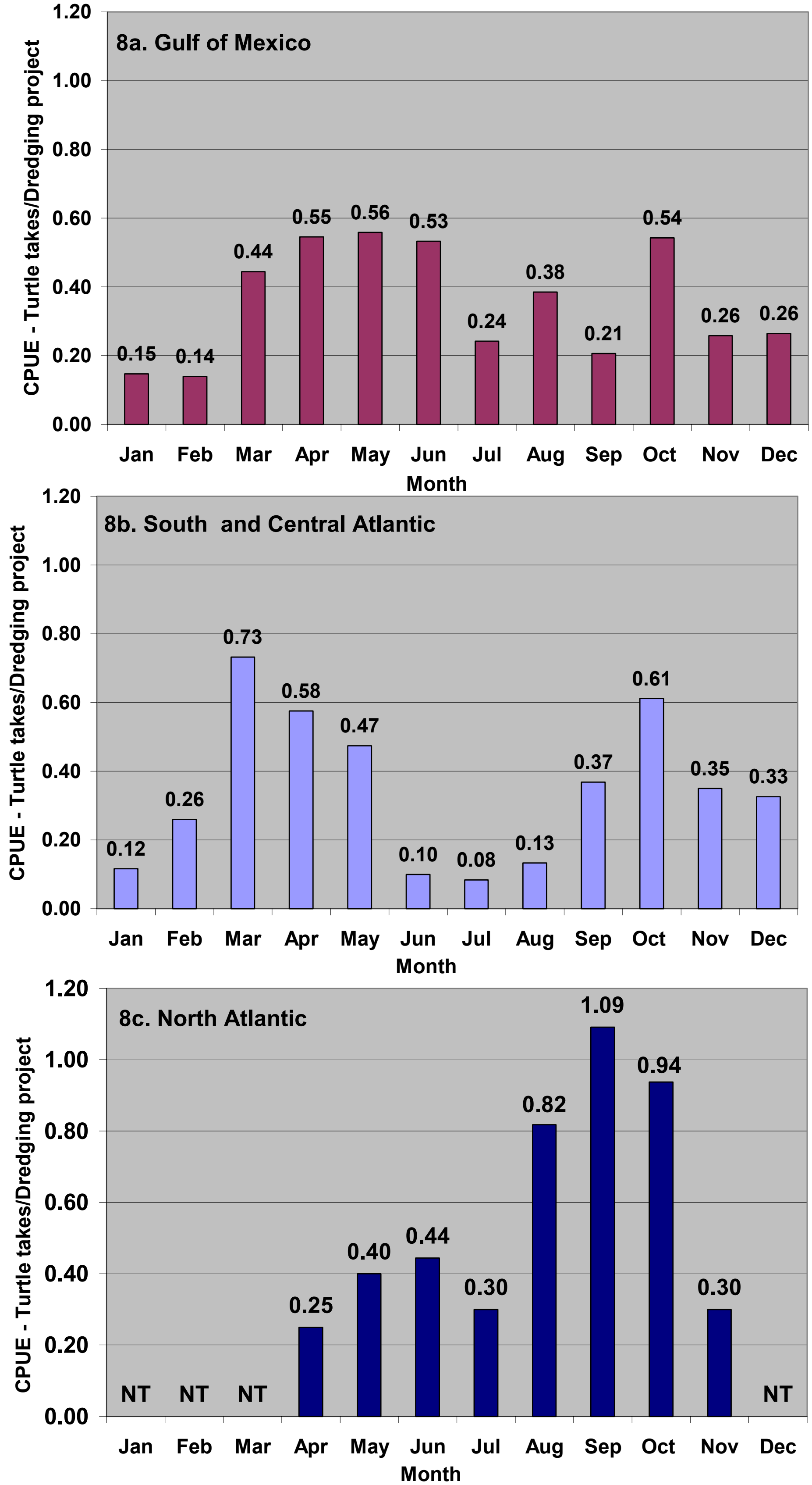


Figure 8. Monthly CPUE takes per project by region. (NT = No turtle takes documented.)

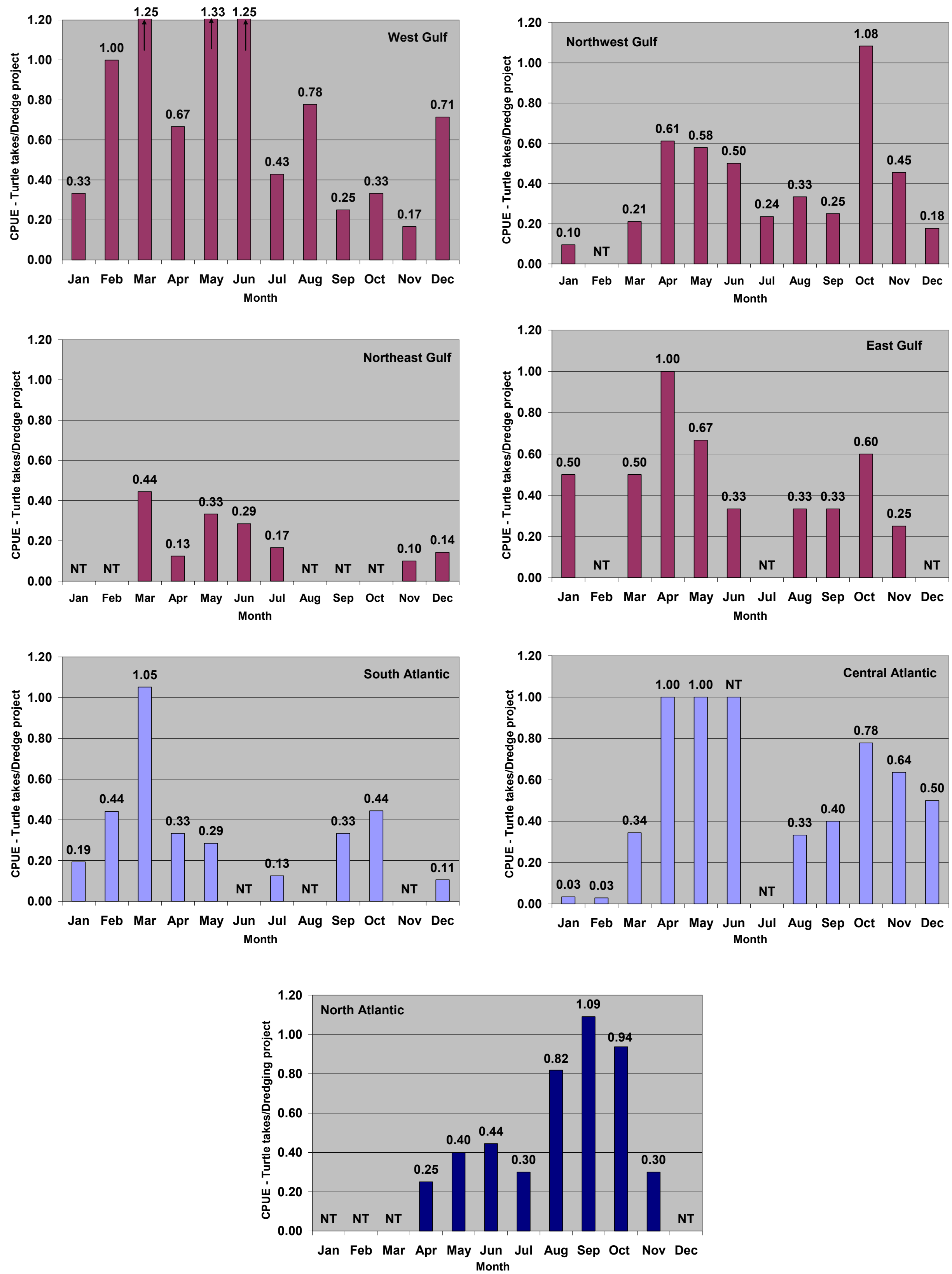


Figure 9. Monthly CPUE takes per project by subregion. (NT = No turtle takes documented.)

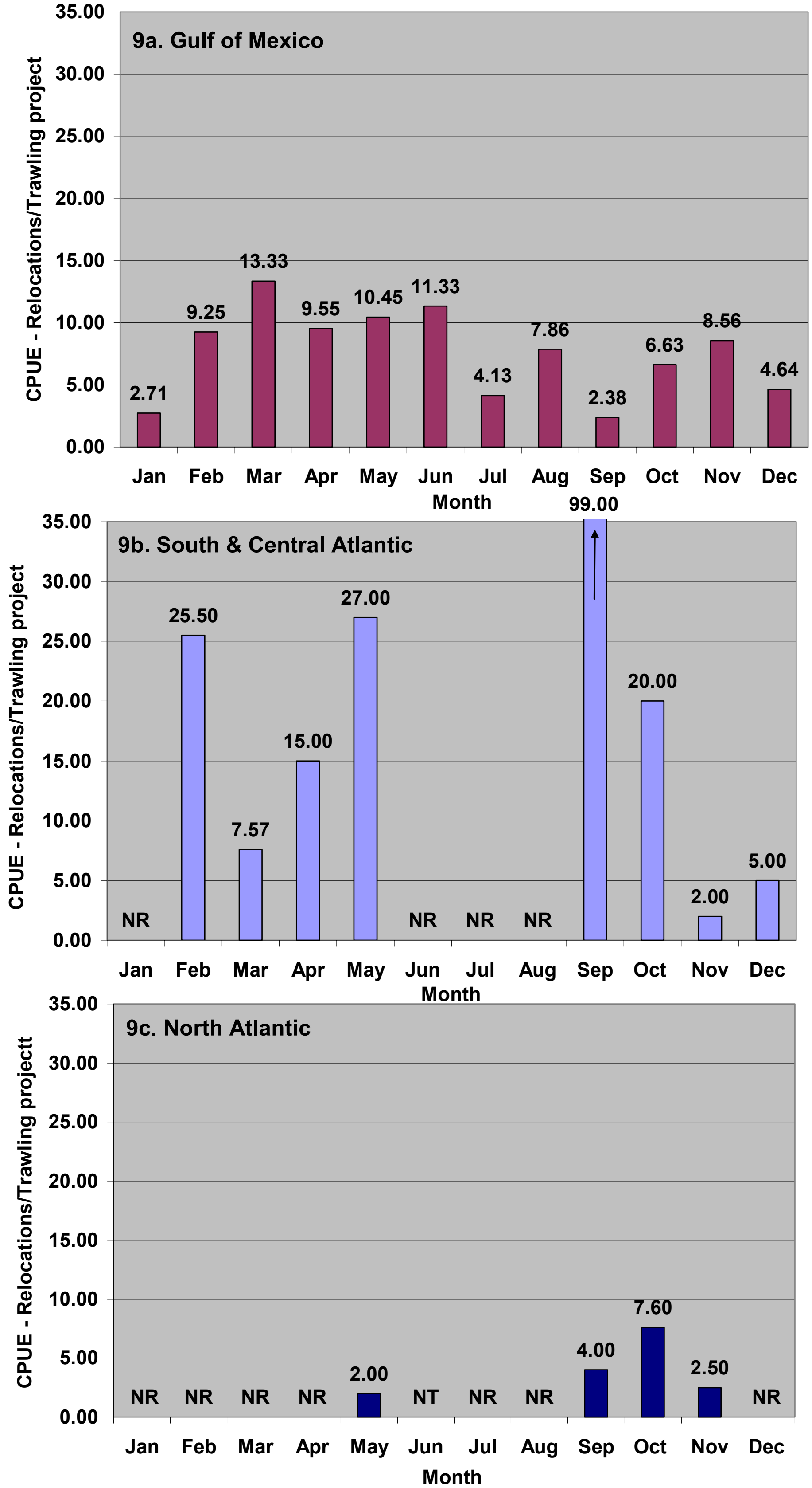


Figure 10. Monthly CPUE relocations per trawling project by region. (NR = No relocation effort; NT = No turtles relocated.)

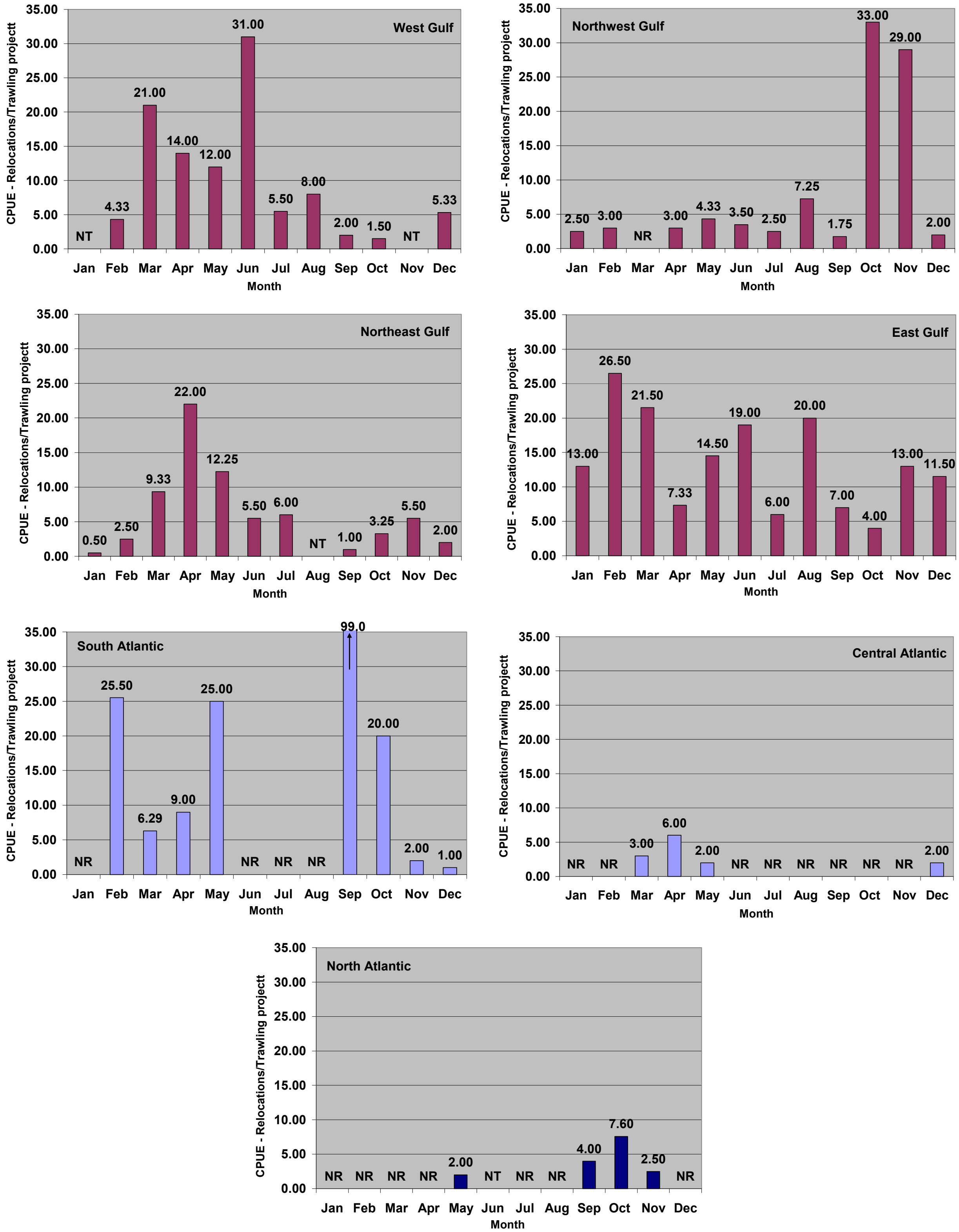
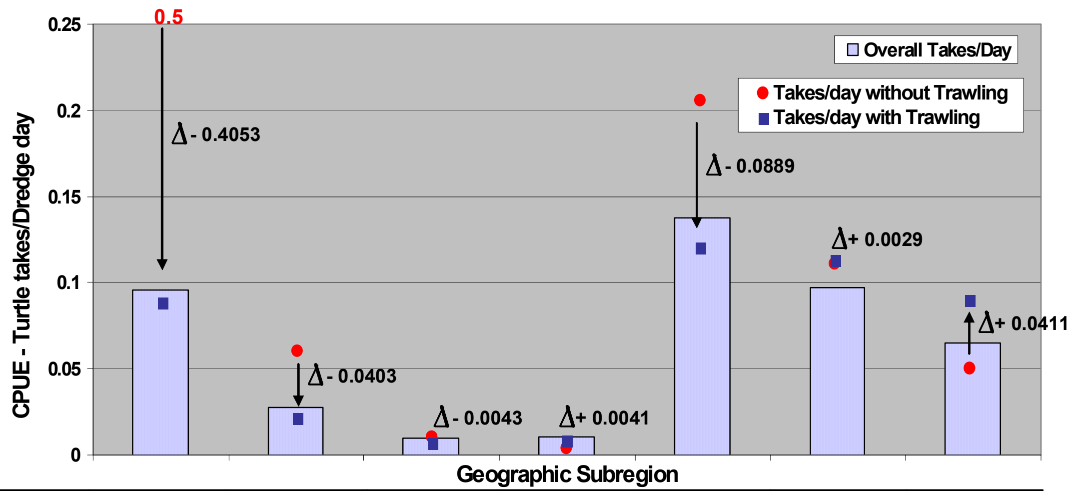
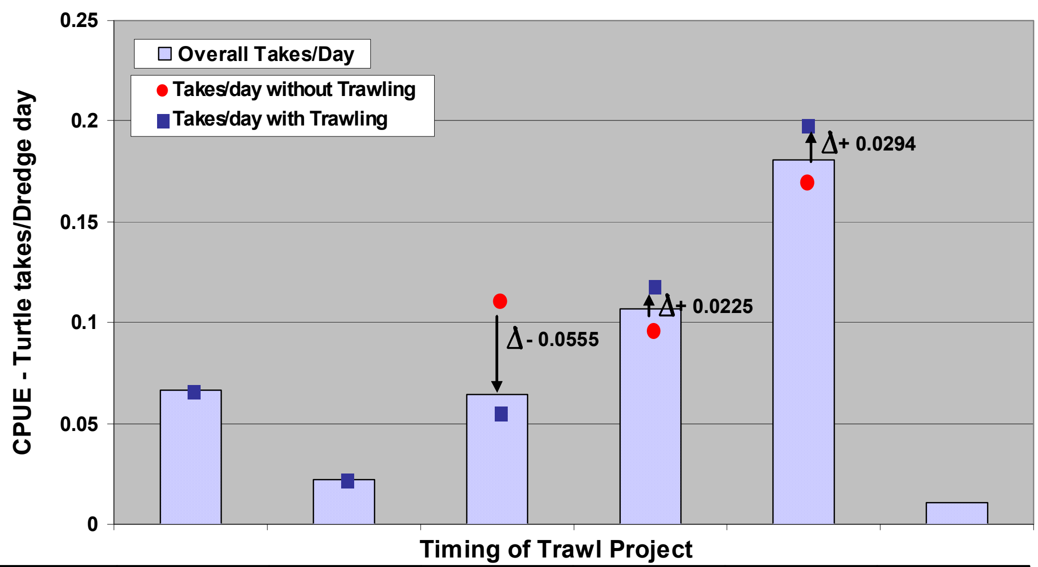


Figure 11. Monthly CPUE relocations per trawling project by subregion. (NR = No relocation effort; NT = No turtles relocated.)



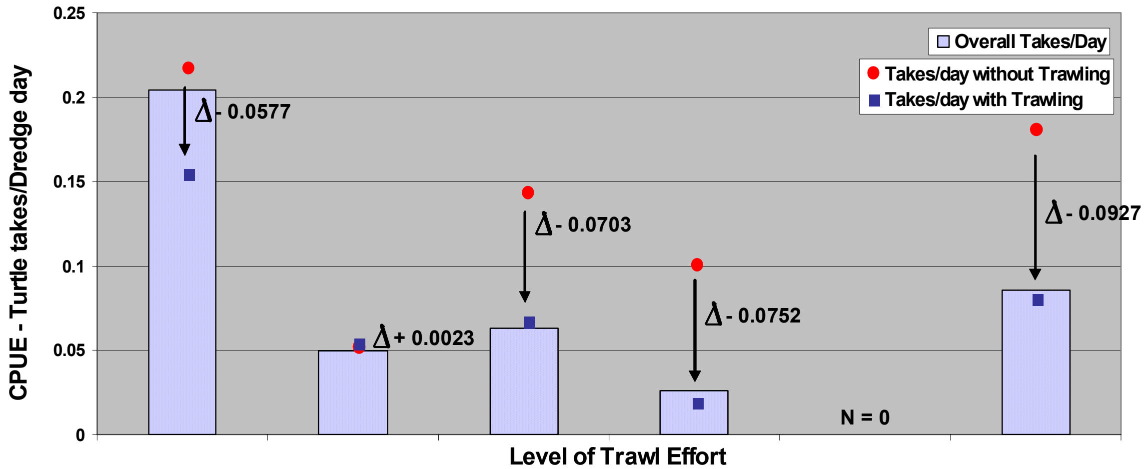
CPUE Take Rate	West Gulf	Northwest Gulf	Northeast Gulf	East Gulf	South Atlantic	Central Atlantic	North Atlantic
Overall Takes/Day	n = 12 0.0956	n = 13 0.0275	n = 14 0.0095	n = 4 0.0107	n = 13 0.138	n = 8 0.0972	n = 5 0.0652
● Takes/Day w/out Trawling	n = 1 0.5	n = 4 0.0648	n = 4 0.0132	n = 1 0.0064	n = 10 0.2164	n = 6 0.1175	n = 5 0.0547
■ Takes/Day w/ Trawling	n = 12 0.0947	n = 13 0.0245	n = 14 0.0089	n = 4 0.0105	n = 13 0.1275	n = 8 0.1204	n = 5 0.0958
■ - ● = Δ	- 0.4053	- 0.0403	- 0.0043	+ 0.0041	- 0.0889	+ 0.0029	+ 0.0411

Figure 12. Effect of relocation trawling on CPUE takes per dredge day by subregion.



CPUE Take Rate	Pre	Onset	Early	Late	Very Late	None
Overall Takes/Day	n = 15 0.0667	n = 23 0.0222	n = 13 0.0642	n = 8 0.107	n = 7 0.1808	n = 249 0.011
● Takes/Day w/out Trawling	N/A	N/A	n = 13 0.1115	n = 8 0.0966	n = 7 0.1706	N/A
■ Takes/Day w/ Trawling	n = 15 0.0667	n = 23 0.0222	n = 13 0.056	n = 8 0.1191	n = 7 0.2	N/A
■ - ● = Δ	N/A	N/A	- 0.0555	0.0225	0.0294	N/A

Figure 13. Effect of relocation trawling on CPUE takes per dredge day by timing of trawling project. (Pre = prior to dredging and entire project; Onset = start of dredging and entire project; early = first third of project; late = second third of project; very late = last third of project; none = no trawling.)



CPUE Take Rate	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Overall Takes/Day	n = 6 0.2039	n = 22 0.0496	n = 10 0.0627	n = 21 0.0261	n = 0	n = 7 0.0853
● Takes/Day w/out Trawling	n = 6 0.2099	n = 8 0.0578	n = 8 0.1419	n = 5 0.1027	n = 0	n = 1 0.1765
■ Takes/Day w/ Trawling	n = 6 0.1522	n = 22 0.0601	n = 10 0.0716	n = 21 0.0275	n = 0	n = 7 0.0838
■ - ● = Δ	- 0.0577	+ 0.0023	- 0.0703	-0.0752	N/A	- 0.0927

Figure 14. Effect of relocation trawling on CPUE takes per dredge day by level of trawling effort (35 min tows). (Level 1 = 12 hr trawling, up to 12 tows/day or 1.0 tows/hr; Level 2 = 24 hr trawling, up to 24 tows/day or 1.0 tows/hr; Level 3 = 12 hr trawling, 12.1 to 20.4 tows/day or 1.01 to 1.70 tows/hr; Level 4 = 24 hr trawling, 24.2 to 40.8 tows/day or 1.01 to 1.70 tows/hr; Level 5 = over 20.4 tows/day or over 1.70 tows/hr; Level 6 = 40.8 tows/day or over 1.70 tows/hr.)

DISCUSSION

Quantitative Analysis by Location and Species

The South Atlantic subregion has had more documented turtle takes and relocated turtles during hopper dredging projects than the other Gulf and Atlantic subregions. This may reflect higher sea turtle densities and nesting frequencies in this region. Although loggerheads are consistently the predominant species captured by entrainment and trawling in all subregions, no consistent pattern is seen between trawl captures and entrainment for greens, Kemp's ridley, leatherback and hawksbill. Hawksbill and leatherbacks have rarely been collected by trawlers, and none have been documented as incidental takes by dredges. No clear relationship can be seen between the absolute number of turtle takes and relocated turtles among the subregions (Figures 2 and 3). Consideration of absolute numbers of takes and captures alone provides few insights regarding entrainment risk beyond an indication of sea turtle species presence at a particular location. Additional site-specific factors such as time of year, water temperature, habitat use, dredging protocols, and mitigation efforts should also be considered.

Catch Per Unit Effort Comparison

Since the number of hopper dredging projects conducted varies each year and each project varies in duration and volume of material dredged, it is inappropriate to treat every calendar year equally when interpreting absolute numbers of sea turtles entrained. CPUE calculations for entrainments (takes per dredge project, takes per dredge day, or takes per 1000 m^3) and relocated turtles (turtles per trawl tow) provide more equitable measures for spatial and temporal comparisons than absolute values typically reported annually for the SARBO and GRBO. When evaluating annual CPUE of turtles per dredge project, no pattern was identified among the regions or subregions for any particular years. For example, the elevated rate of takes per project seen in 1997 for the Atlantic region did not coincide with high rates in the Gulf region. Annual take variations may be a reflection of: 1) annual variations in water temperature; 2) fluctuations in the amount and method of dredging; 3) inconsistent implementation of mitigation tools; and/or 4) changes in habitat utilization by sea turtles.

Although the absolute numbers of entrained turtles is higher for the Atlantic region (211 turtles) than the Gulf region (147 turtles), the mean annual (1995-2006) take rate for the Gulf (1.21 takes per project) is higher than in the Atlantic (1.05 takes per project). Differences in regional take rate may be due to differences in habitat use between the regions by sea turtles as well as differences in amount of dredging, method of dredging operations, and implementation of mitigation tools. Biological data are critically needed regarding sea turtle use of habitats throughout the Gulf region. More is known about their use of habitats along the Atlantic than the Gulf coasts, although, very little is still known about the aquatic phase of sea turtle life history. The estuaries of the Gulf region may serve as nursery grounds for sea turtles, whereas, the South Atlantic coast (i.e. Florida, Georgia) hosts more mature adults and nesting activities (Spotila 2004). This could cause different interactions between turtles and dredging activities between the two regions.

These data illustrate the inherent difficulty in comparing absolute numbers of turtle takes with absolute numbers of relocated turtles as a basis for evaluating effectiveness of relocation trawling. One might attribute the low number of turtle takes in the northeastern and eastern Gulf to the high number of relocated turtles in these two subregions and the high number of turtle takes in the central and north Atlantic subregions to the low number of relocated turtles. However, these trends are not consistent across all the subregions (Figure 6a). Relocation trawling may not be equally effective throughout all subregions and should be evaluated more closely for site-specific application.

A relationship between turtle takes and relocated turtles does emerge when expressed as CPUE comparisons (relocated turtles per trawl tow, takes per dredge project, takes per dredge day, and takes per 1000 m^3 dredged) (Figure 6b-d). As the data are refined from large scale (takes per project) to small scale (takes per 1000 m^3) CPUE comparisons, it is easier to see a relationship between relocated turtles and turtle takes. Each graph provides an increasing level of refinement in the expression of CPUE (Figure 6). Although many factors influence the time required to dredge 1000 m^3, the dredging CPUE of takes per 1000 m^3 would be more comparable in time required for effort to the trawling CPUE of relocated turtles per 35 minute trawl tow. When entrainment rates and relocation rates are thereby evaluated, very similar patterns in capture rate are seen across the subregions. This may reflect the relative abundance of the turtles in a subregion and that entrainments occur in a similar proportion to those turtles collected by relocation trawling for a given location. Therefore, relocation rates may serve as an indicator of sea turtle relative abundance in the area and a predictor of the risk of turtle-dredge encounters for that location. However, evaluations such as those presented in Figure 6 do not provide insight into the effectiveness of trawling in reducing turtle takes.

Incidental take monitoring data typically do not include the quantity of material dredged. Dredging data (i.e. volume of material dredged) for a given project have not typically been archived with the biological entrainment data. Consequently, reconstructing these records for this study has been a difficult task. Because CPUE for takes per 1000 m^3 provides the most appropriate comparison with relocated turtles per trawl tow, dredging data should be simultaneously archived with the biological data in the future.

Spatial and Temporal Patterns of Incidental Takes and Trawling Captures

Higher entrainment and relocation rates occurred in spring and fall in all Gulf subregions and the two southern Atlantic subregions. This may reflect seasonal movements of sea turtles to warmer waters during spring and fall (Epperly et al. 1995). High entrainment rates during fall in the north Atlantic may be due to an influx of turtles from warmer southern regions to utilize rich sources of benthic food of this area. Of particular interest are the low take rates during summer (July - September) for the Gulf region and the south and central Atlantic regions (June - September) that are comparable to the take rates for these same regions during the cold months of November through February. Although turtles are typically much more abundant during the warm summer months in these regions, they may not spend large amounts of time on or in the bottom sediments. During these warmer months, the turtles may be far more active due to nesting activities and a need to surface more often in the warmer water to breathe. It has been demonstrated that turtles resting on or in the sediment are far more vulnerable to being entrained by a trailing suction draghead than turtles swimming in the water column above the draghead (USACE WES 1997).

The increased trawl capture rates in spring (March - June) for the west Gulf subregion may result from turtles moving back into the area that wintered farther south. The increased trawl capture rates in fall (October, November) for the northwest Gulf may also be as a result of seasonal migrations. The increased trawl capture rates in spring (March - May) for the northeast Gulf may be a reflection of turtles dispersing from wintering areas along the east Gulf subregion. The lack of distinct seasonal patterns in the trawling capture rates in the east Gulf subregion may suggest a year-round presence of turtles in these waters of relatively stable temperature. These interpretations are strictly speculative since data are so severely lacking regarding sea turtle utilization of habitats throughout the northern Gulf of Mexico. Seasonality of sea turtle occurrence is difficult to interpret for the Atlantic subregions in Figures 9 and 10 since sampling is lacking for many of the months. Data from Dickerson *et al*. (1995) may provide a better assessment of seasonal occurrence of sea turtles in these Atlantic project sites.

Observed seasonal differences in entrainment and trawling CPUE rates provide new evidence that the existing environmental window could be widened outside the winter months for some locations. Hopper dredging should avoid operating during the critical spring and fall peaks of entrainment and trawling CPUE rates, but opportunities may exist to safely dredge during summer months in some areas. Although it seems counter-intuitive to dredge during summer months coincident with high sea turtle occurrences (Dickerson *et al*. 1995), turtles may actually be less vulnerable to entrainment due to minimal time spent near the substrate as illustrated in Figure 8. Trawl nets are dragged along the bottom in a manner similar to a draghead but trawl nets typically sample higher into the water column than a draghead. This may account for higher turtle capture rates for trawlers during warmer months than are entrained by dredges (Dickerson *et al*. 1995). Hopper dredging projects using beach disposal should not be considered during the warm summer months because of sea turtle nesting activities on the beach. This study provides evidence that hopper dredging not requiring beach disposal may be able to operate in some regions during summer months when entrainment rates have been comparable to that found during winter months. Site-specific factors (e.g., habitat use, dredging site and protocols, sediment type, and mitigation efforts) should be additionally considered before attempting dredging during the warm months with high sea turtle occurrences.

Effectiveness of Relocation Trawling for Reducing Incidental Takes

Relocation trawling resulted in reductions in entrainment rate (takes per dredge day) but this effect was not similar across all subregions (Figure 12). This management technique appears to be most effective in the west Gulf, northwest Gulf, and south Atlantic subregions and least effective for the north Atlantic subregion. These differences may result from differences in when relocation trawling was initiated and the level of trawling effort used for each dredge project. Relocation trawling initated at the onset of dredging resulted in projects with the lowest take rates. Many of the relocation projects for the Gulf region (particularly west Gulf subregion) as well as south Atlantic subregion were initiated either at the onset or during the first third of the dredging project. Relocation projects for the north Atlantic subregion tended to be initiated much later in the dredging project. The level of trawling effort does influence the effectiveness of the relocation trawling on reducing entrainment rates. However, it is unclear why entrainment rates were not reduced for projects using 24 hour trawling at a rate of one tow per hour (Level 2) but entrainment rates were reduced for all other levels of trawling effort. Trawling projects with the highest number of tows (mean 35 minutes per tow) completed per day (over 1.7 tows per hour) resulted in the highest reduction in entrainment rates, whereas, those averaging less than one tow per hour had the least effect on reducing entrainment. The greater amount of time the nets were actually sweeping the bottom the more effective this management practice became. The effect of substrate type and channel parameters on relocation trawling was not evaluated in this study but these factors influence whether trawling can be conducted successfully and may influence its effectiveness in reducing incidental take. These factors must also be weighed when deciding to utilize relocation trawling.

CONCLUSIONS

The effectiveness of relocation trawling in terms of reducing incidental take of sea turtles may not be determined as much by the number of turtles relocated as by the amount of time the trawl nets are able to sweep the bottom as well as when trawling is initiated relative to the onset of dredging. Due to the modifications implemented to hopper dredging equipment and protocols for protecting turtles during dredging, turtles swimming off the sediment bottom are at extremely minimal risk for entrainment (USACE WES 1997). Turtles that are on or in the sediment would be most vulnerable and should be collected or dispersed by the trawl nets. These turtles may not actually be captured and relocated but would likely be moved off the bottom and out of harms way. This study concludes that relocation trawling is an effective management option for reducing incidental take of sea turtles during hopper dredging in some locations provided aggressive trawling effort is initiated either at the onset of dredging or early in the project. Since entrainment rates (takes per project) for the warmer summer months (June through September) are similar or lower than the entrainment rates during the winter months of the current dredging window (December through March) in the south and central Atlantic subregions, this may provide an additional period of relatively safe hopper dredging for at least some locations provided beach disposal is not required. Where trawling can feasibly and safely be used, aggressive and consistent use of relocation trawling may provide effective reductions in sea turtle entrainment. Less aggressive trawling effort implemented during the latter phase of a dredging project may have minimal effect on reducing entrainments.

Additional analyses are critically needed to evaluate the effectiveness of relocation trawling in reducing incidental take rates among varying site-specific circumstances. These more refined evaluations may provide a clearer understanding of the effectiveness of relocation trawling in reducing incidental takes of sea turtles under different conditions of dredging operations. The merits of using relocation trawling as a mitigation tool must also be weighed against human safety and potential trawling-related impacts to the sea turtles or other species captured as bycatch.

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