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# POTENTIAL IMPACTS OF ARTIFICIAL REEF DEVELOPMENT ON SEA TURTLE CONSERVATION IN FLORIDA

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## ABSTRACT

Artificial reefs have been constructed and deployed worldwide to enhance marine habitat, primarily to increase socio-economic benefits stemming from associated fishing and diving activities, but also for habitat restoration and mitigation purposes. As a result, the majority of studies focused on artificial reefs to date have centered on measuring performance, with metrics such as species' richness and abundance compared to natural reefs, or economic benefits to local users. While there may be demonstrable benefits to artificial reef development, there may also be unforeseen consequences. This study investigates the impacts Florida artificial reefs may have on sea turtle populations, such as increased predation stemming from altered predator complexes, mortality due to entrapment, and entanglement issues. Based on some of the associated effects artificial reef development may have on sea turtles, management recommendations to minimize potential impacts are offered for consideration.

## ARTIFICIAL REEFS AND THEIR DEVELOPMENT IN FLORIDA

In its broadest sense, an artificial reef is any manmade structure that mimics the attributes of a natural reef. Florida Administrative Code Chapter 68E-9.002(2) defines an artificial reef as "one or more manufactured or natural objects intentionally placed on the bottom in predominantly marine waters to provide conditions believed to be favorable in sustaining, or enhancing the spawning, breeding, feeding, or growth to maturity of Florida's managed reef associated fish species as well as to increase the productivity of other reef community resources which support fisheries. Included in this definition are artificial reefs developed with one or more of the following additional objectives: enhancement of fishing and diving opportunities, fisheries research, and fisheries conservation/preservation purposes." The Florida artificial reef program is the largest and most active program in the United States. It is also unique in that it is not a singular program run by a state resource agency. Instead, artificial reef development in Florida occurs on the county level with funding and technical guidance provided by the Florida Fish and Wildlife Conservation Commission (FWC) Artificial Reef Program.

The two primary goals of artificial reefs in coastal habitats have been to enhance the production of reef-associated species (i.e., macroalgae, invertebrates, and fishes) and to increase the convenience or efficiency of harvesting those species (Seaman et al. 1989; Seaman and Sprague 1991; Pratt 1994, Carr and Hixon 1997). Shipwrecks in particular have long been noted to attract marine wildlife and provide exceptional fishing sites. In fact, several fishing piers in North Carolina were constructed over the sunken hulls of Civil War blockade runners in the 1930s and 1940s to take advantage of the submerged structure and facilitate recreational fishing activities (Wilde-Ramsing and Angley 1985). lnterest in formal artificial reef development in the United States began in the 1950s and was primarily driven by recreational fishermen (Jørgensen 2009). The scuttling of the 56 meter (m) long former yacht *Mizpah* in April 1968 off Palm Beach could be considered the start of official artificial reef development in Florida, though other vessels and materials were intentionally sunk years before, unpermitted and clandestinely. In subsequent years, artificial reef activities in Florida would significantly expand.

As of October 2015, the various Florida county artificial reef programs have deployed more than 627,497 tons of concrete material and 258,817 tons of limestone rock and rubble, as well as over 18,769 prefabricated artificial reef modules and 513 vessels in coastal waters (FWC database 2015). In addition, there have been several hundred small, "private reefs" deployed off Escambia, Okaloosa, and Bay Counties in the Florida Panhandle, as well as countless more unpermitted, covert deployments of various materials elsewhere off Florida, not to mention thousands of Florida shipwreck events that have transpired throughout history (Figure 1). In some permitted artificial reef areas, the amount of material can be quite dense (Figure 2).

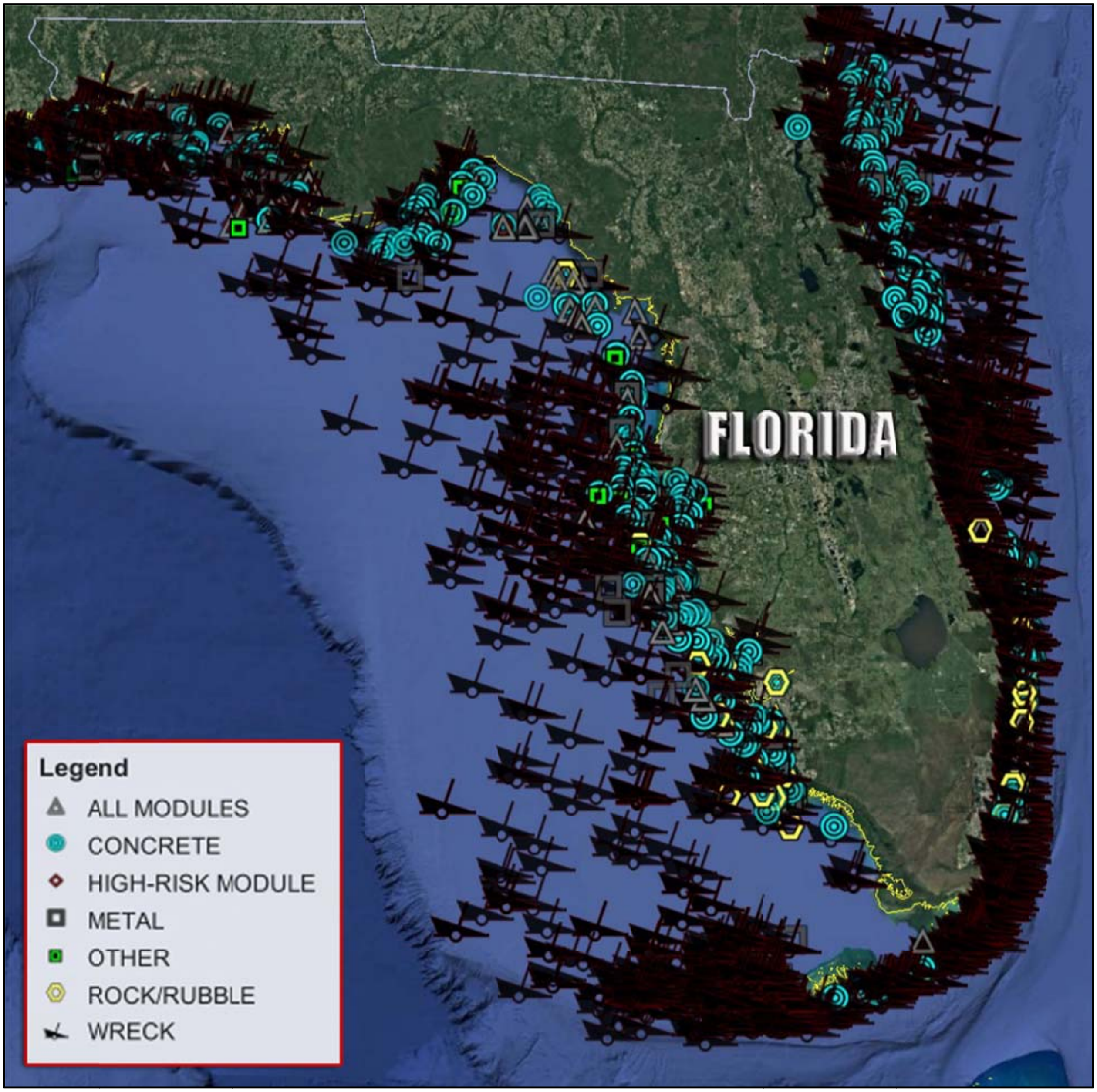


**Figure 1.** Map illustrating abundance of artificial reef material and shipwrecks off Florida, with over 7,000 sites in the author's database.

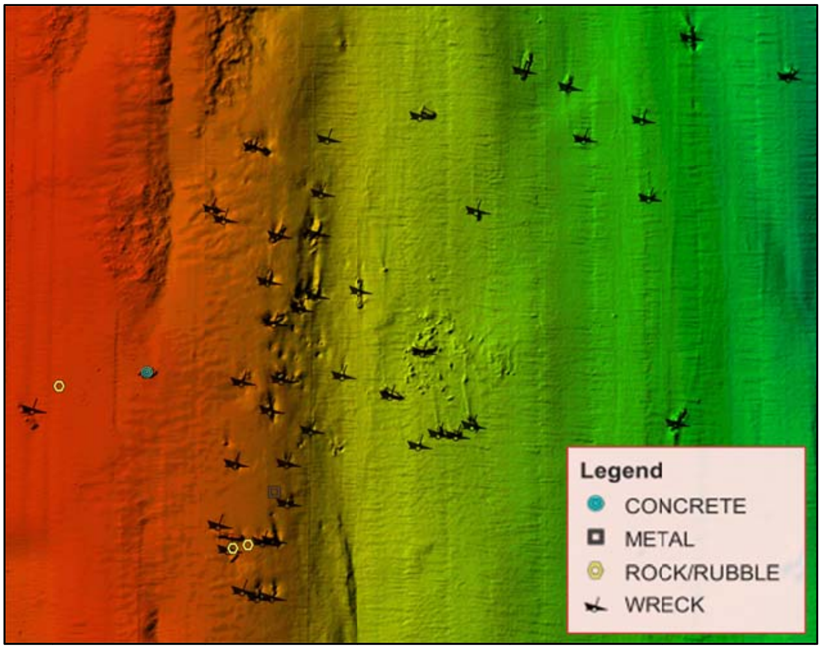

**Figure 2.** Artificial reef site off Miami-Dade County, illustrating the density of material in one discrete (~1.6 x 1.1 kilometer) area.

While artificial reefs are generally limited to material intentionally deployed, this study encompasses all manmade materials, including "natural" shipwrecks, when referring to artificial reefs as it applies to sea turtle mortality threat. This was done to allow a comprehensive analysis of the issues related to artificial reefs and sea turtles, which in an abstract sense could be considered a submerged marine debris issue, particularly given that manmade material may persist in the marine environment several decades to several centuries. While intentionally-deployed material is cleaned and "prepared" for the marine environment, which removes contaminants and other toxic materials (e.g., fuel, oils, asbestos, etc.) that could be found in unintentional vessel sinkings, such as those losses associated with war, weather, or accidental issues, this study asserts there is no significant material difference between intentional and unintentional vessel deployments in terms of entanglement and entrapment issues. Given artificial reefs are generally designed and advertised to promote fishing opportunities, sea turtle entanglement issues from lost gear may be exacerbated on designed artificial reefs. Regardless, sea turtles are unable to differentiate between intentionally and unintentionally deployed materials. These issues are discussed in more detail later in this study.

## SEA TURTLE UTILIZATION OF ARTIFICIAL REEFS

Sea turtles typically spend the majority of their time underwater (Lutcavage and Lutz 1991, Renaud and Carpenter 1994, Spotilla 2004), much of which is spent resting (Schofield et al. 2006). Artificial reefs and shipwrecks provide resting and foraging habitat, as well as other services, to sea turtles species, similar to sea turtle use of natural ledges and outcroppings

**Figure 3.** Loggerhead sea turtle resting under shipwreck material in approximately 30 m of water off St. Johns County.

(Balazs et al. 1987, Makowski et al. 2006). Sea turtles, particularly loggerheads (*Caretta caretta*), are commonly observed resting in and around artificial reefs and shipwrecks (Patterson 2010, Nuttall and Wood 2012, Author, personal observations, Figure 3). By hiding under overhanging structure, sea turtles are less exposed to the influence of currents and, more importantly, less vulnerable to potential predators. In areas of widespread homogenous sand bottom, these artificial sites may provide important resting and foraging habitat, particularly during inter-nesting periods. Stoneburner (1982) tracked eight female loggerhead sea turtles off Georgia between June 1979 and July 1980. Satellite tracking revealed the turtles did not wander randomly, but rather they moved directly to small patches of natural substrate and artificial reef complexes on which abundant prey organisms exist (e.g., mollusks, crabs, urchins). Addison et al. (2002) suggested the lack of nearshore structure as a possible explanation for the post-nesting dispersal of sea turtles observed along the southwest coast of Florida.

Sea turtles may also use structure afforded by artificial reefs and shipwrecks to remove fouling biological growth from their carapace. Green (*Chelonia mydas*) (Heithaus et al. 2002), hawksbill (*Eretmochelys imbricata*) (White 2013), and loggerhead (Schofield et al. 2006) sea turtles have all been documented to self-clean their heads, flippers, and carapace against submerged rocks, sponges, overhanging ledges, and anchors. Archaeological reports indicate sea turtles may utilize exposed shipwreck material to self-clean. A significantly eroded iron frame member on an unknown shipwreck site off Vaca Key suggest sea turtles may use the exposed hull member as a “scratching station” (McClarnon et al. 2007), similar to the documented use of rocks and anchors in the aforementioned studies. Likewise, Shefi et al. (2009) documented several shipwreck components that were rubbed down due to likely sea turtle self-cleaning on an unknown shipwreck site off Grassy Key; the self-cleaning behavior was observed during the study but not published in the report (B. Altmeier, personal communication, May 2, 2016).

Hardy et al. (2014) examined satellite-tracking datasets from 125 tagged adult female loggerhead sea turtles to determine residency areas on the West Florida Shelf. That study ultimately pooled the data of 81 individual turtles and summarized residence area use within five-kilometer diameter hexagonal grid cells to determine the number of individuals present within each cell. In many areas of the West Florida Shelf, these cells overlap with permitted artificial reefs and shipwreck sites (Figure 4). It is unclear how often sea turtles utilize artificial reef material off Florida, but in some areas their utilization could be quite significant. As a result, those sea turtles may be exposed to potential threats associated with artificial reefs (e.g., entanglement) discussed further in this study.

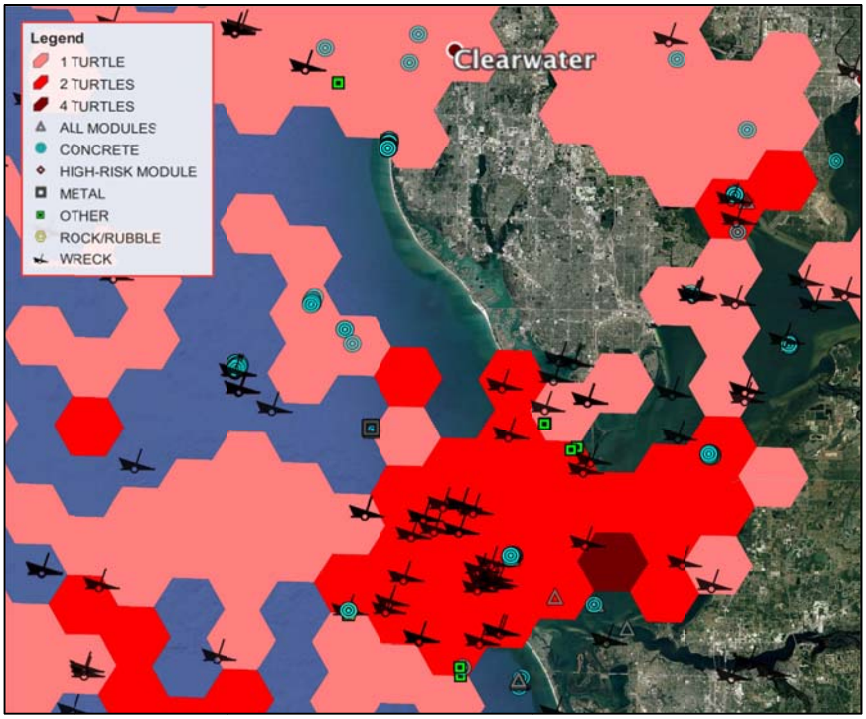


**Figure 4.** Artificial reefs and shipwrecks off Tampa Bay, in relation to overlapping residence areas of individual adult female loggerhead sea turtles represented as counts of unique individuals within five-kilometer hexagonal cells (from Hardy et al. 2014).

In summary, sea turtles likely benefit from the presence of artificial reefs and shipwrecks due to the resting and foraging habitat that the material provides, particularly in areas lacking abundant natural reef or hard bottom habitat. Furthermore, the removal of algae and barnacles from the shell of turtles is likely advantageous because of drag reduction and possible control of infections (Losey et al. 1994). Those benefits, however, need to be weighed against potential negative effects artificial reefs may introduce due to entrapment and entanglement issues.

## INCREASED PREDATION OF HATCHLINGS

The reproductive pattern of sea turtles involves travel over long distances to specific beaches in order to make multiple deposits of large numbers of eggs, which separates them from almost all other reptiles (Hendrickson 1980). The relatively high fecundity of sea turtles is likely an evolutionary tactic to address significant mortality in early life stages (Van Buskirk and Crowder 1994). Several studies have noted that sea turtle hatchlings may be especially vulnerable in shallow, nearshore waters just off the nesting beach due to an abundance of predators (Witherington and Salmon 1992, Gyuris 1994). Mortimer (1982) suggested that the intensity of predation in these nearshore waters may be influenced by the type of habitat hatchlings must cross. Generally, more structurally complex habitats are likely to have greater species diversity and abundance, including predatory species (e.g., barracuda, shark, jacks, snapper, etc.) than less complex habitats (Mortimer 1981, Tews et al. 2004, Cole 2012). Therefore, it has been postulated that nearshore artificial reefs sited directly off nesting beaches could increase hatchling predation due to the anticipated habitat enhancement of deployed reef material.

Several studies have investigated sea turtle hatchling predation over various habitat types. Gyuris (1994) found significant mortality of green sea turtle hatchlings crossing reef habitat off Heron Island, Queensland, Australia. Predation rates varied among trials (combinations of tide, time of day, and moon phase) that used 1,740 tethered and 57 free-swimming hatchlings, ranging from 0% to 85% with a mean of 31% for tethered hatchlings and 93.6% for free-swimming turtles. Observations of the free-swimming hatchlings noted that many of the successful predation events were preceded by attacks from fish too small or weak to be successful. Conversely, numerous studies off Florida have found much lower predation rates on sea turtle hatchlings over a variety of habitats. Witherington and Salmon (1992) evaluated three sites off the central east coast of Florida that possessed different offshore habitat characteristics: saballerid reef 130-170 m offshore, occasional low-profile patch reefs, and uniform sand bottom. Although the sample sizes were small, observed predation rates were 13.6% for the saballerid reef sites, 6.3% for the patch reef sites, and 0% for the sand sites. Glenn (1996) reported 9% of hatchlings crossing patch reef were taken by predators, while only 4.5% of hatchlings were lost to predators crossing over sand bottom; interestingly, no predation was observed over submerged breakwaters. Likewise, Stewart and Wyneken (2004) examined predation rates of hatchlings crossing over sand, nearshore reef, and transitional areas of sand and rock. Resulting predation rates were 2.7% for transitional sites, 4.3% at sand sites, and 8.1% at reef sites. Although the differences in rates were not found to be significant, hatchling predation was greater at reef sites when compared to the sand and transitional sites.

Evaluating predation over a larger area, Whelan and Wyneken (2007) investigated sites on both the east and west coasts of Florida. The study included a nesting beach on Hutchinson Island with a nearshore area consisting of sand and patches of sabellarid reefs, a beach at Boca Raton with sandy bottom and bands of nearshore reef, and a site at Naples characterized by a nearshore homogenous sand bottom. The authors documented a significant difference in total hatchling predation rates between the Boca Raton site (9%) with adjacent reef habitat and their Naples site (1%) that was composed entirely of sand; predation at Hutchinson Island with mixed benthic habitat was 3%. Specific to predator assemblages at the various sites, the authors documented tarpon (*Megalops atlanticus*), snappers (lutjanids), and jacks (carangids) at both their Boca Raton and Hutchinson Island sites, but only common snook (*Centropomus undecimalis*) at their Naples site. The lack of predator diversity can be directly attributed to the general paucity of significant nearshore bottom structure along large swaths of the Florida west coast. While there appears to be a direct correlation between predation rates and benthic habitat adjacent to nesting beaches, Whelan and Wyneken (2007) also offered other factors that could influence the results including water clarity, water depth, temporal differences in nesting and migratory predatory fish populations, photopollution, and hatchling orientation.

Artificial reefs deployed in shallow nearshore waters consisting of predominately homogenous sand bottom are likely to increase finfish species' diversity and abundance—that is the desired goal of artificial reefs. But in doing so, they may also increase the predation risk of hatchling sea turtles if the artificial reefs are sited nearshore and directly off sea turtle nesting beaches. These effects could be minimized, however, if artificial reef planning takes into consideration the initial behavior of sea turtle hatchlings upon departing their nesting beach, as discussed later in the management recommendations.

## SEA TURTLE ENTRAPMENT IN ARTIFICIAL REEFS

As previously mentioned, sea turtles may spend a significant amount of time underwater resting and are known to utilize artificial reefs and shipwrecks in lieu of natural habitat as sheltering habitat. As air-breathing animals, sea turtles obviously are vulnerable to drowning if they are unable to return to the surface to breathe. Bycatch and forced submergence has been documented as a significant source of mortality in several fisheries (Poiner and Harris 1996, L.L. Lum 2006, Finkbeiner et al. 2011), but there have also been numerous documented incidents of sea turtles becoming trapped inside artificial reef material and perishing (Table 1, Figure 5).

**Table 1.** Documented instances of sea turtle mortalities due to confirmed or suspected entrapment in artificial reef material or shipwrecks.

| SPECIES | YEAR | MATERIAL | COUNTY | CONDITION | SOURCE |
|---|---|---|---|---|---|
| LOGGERHEAD | 1989 | QUALMANN TUGS - SHIPWRECK | BROWARD | FRESH DEAD | STSSN |
| UNKNOWN | ~1990 | DC-3 - AIRCRAFT | COLLIER | NOT SPECIFIED | LUKENS AND SELBERG 2004 |
| LOGGERHEAD | 2001 | RHEIN - SHIPWRECK | MONROE | DECOMPOSING | AUTHOR |
| UNKNOWN | 2002 | FISH HAVEN MODULE | ESCAMBIA | SKELETAL | FWC |
| LOGGERHEAD | 2005 | METAL, OPEN-BOTTOM MODULE | ESCAMBIA | DECOMPOSING | R. TURPIN |
| UNKNOWN | 2009 | OPEN-BOTTOM PYRAMID MODULE | ESCAMBIA | SKELETAL | PATTERSON 2010 |
| LOGGERHEAD | 2009 | OPEN-BOTTOM PYRAMID MODULE | ESCAMBIA | DECOMPOSING | PATTERSON 2010 |
| HAWKSBILL | 2010 | USCGC DUANE - SHIPWRECK | MONROE | FRESH DEAD | STSSN |
| LOGGERHEAD | 2016 | OPEN-BOTTOM PYRAMID MODULE | OKALOOSA | FRESH DEAD | FWC |

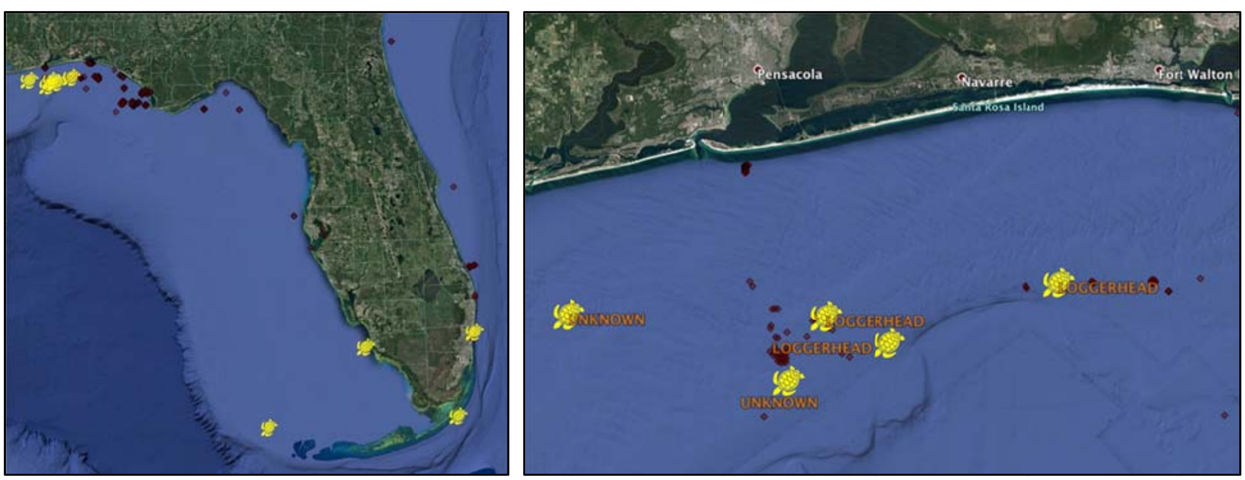


**Figure 5.** Map at left illustrating locations of documented sea turtle mortalities due to confirmed or suspected entrapment in artificial reef material or shipwrecks; at right, five mortalities associated with artificial reef modules off Escambia and Okaloosa Counties. The red symbols are the locations of artificial reef modules that present a high risk of sea turtle entrapment.

Of the documented instances of entrapment in vessels, only two may be definitive (i.e, DC-3 aircraft and *Rhein* shipwreck). Lukens and Selberg (2004) noted the entrapment of a sea turtle in a recently deployed aircraft fuselage, which apparently entered through an open door of the aircraft. They concluded the "turtle became disorientated, was too large to escape through the windows, and drowned inside the fuselage." The second instance occurred in 2001 when the author observed an entrapped sea turtle decomposing in the far recesses of a World War II shipwreck's engine room. While there was open-water access to the vast interior of the wreck, that interior was a maze of obstructions with no ambient light. It was assumed the sea turtle swam farther into the shipwreck and was unable to find an adequate exit before drowning. It is worth noting that both of these sites have since collapsed due to hurricane damage and no longer present significant entrapment threats to sea turtles. This demonstrates that each artificial reef has a unique effective lifespan (varying by material type and local marine conditions) that presents an entrapment risk to sea turtles. Over time the risk of entrapment is reduced, in contrast to the risk of entanglement that increases over time, which is discussed later in this analysis.

The other two reports of sea turtle mortality entrapment in vessels were largely based on a lack of other evidence to indicate a clear cause of death. The 1989 Sea Turtle Stranding and Salvage Network (STSSN) report on the "Qualmann Tugs" off Ft. Lauderdale documented a fresh dead loggerhead with "scuff marks" on left side of the animal; there was no mention of entanglement or other injury with this incident. The "Qualmann Tugs" consist of 2 small (i.e., ~10 m long) pusher tugs sunk in 1985. Given the small size of these tugs and lack of any meaningful interior, it is highly questionable this turtle perished due to entrapment. Similarly, a 2010 STSSN report associated with the wreck of the USCGC *Duane* noted a fresh dead hawksbill sea turtle found just inside a hatch amidships. The *Duane* was scuttled off Key Largo in 1987. There was no trace of entanglement and no visible signs of trauma. As a result, evidence that the death of either turtle was the result of entrapment in artificial structure is lacking.

**Figure 6.** Various artificial reef modules: at left, a modified fish haven with open top, while center and right are restricted top pyramid modules.

Entrapment in artificial reef modules, incidents which consist of over half the documented instances in Table 1, appear to be restricted to materials that possess an open bottom and closed top (see Figure 6 for some examples). Artificial reef modules have been constructed in this fashion to allow efficient stacking on a barge's deck for transport to an offshore artificial reef site. This, however, also allows a sea turtle to potentially gain access to the module's interior if sand around the bottom edge of the module is washed out or excavated by a turtle or other marine species (Figure 7). It is assumed that light entering the module from above, added with the turtle's inherent desire to surface to breath, potentially prevent the turtle from exiting the module before drowning. Other circumstances may prevent proper deployment of a particular module, which could exacerbate (e.g., a module coming to rest on top of other artificial reef material that produces a gap under the module's edge) or eliminate (e.g., a module coming to rest on its side) these entrapment issues. In addition, degradation of artificial reef material over time may reduce the entrapment threat.

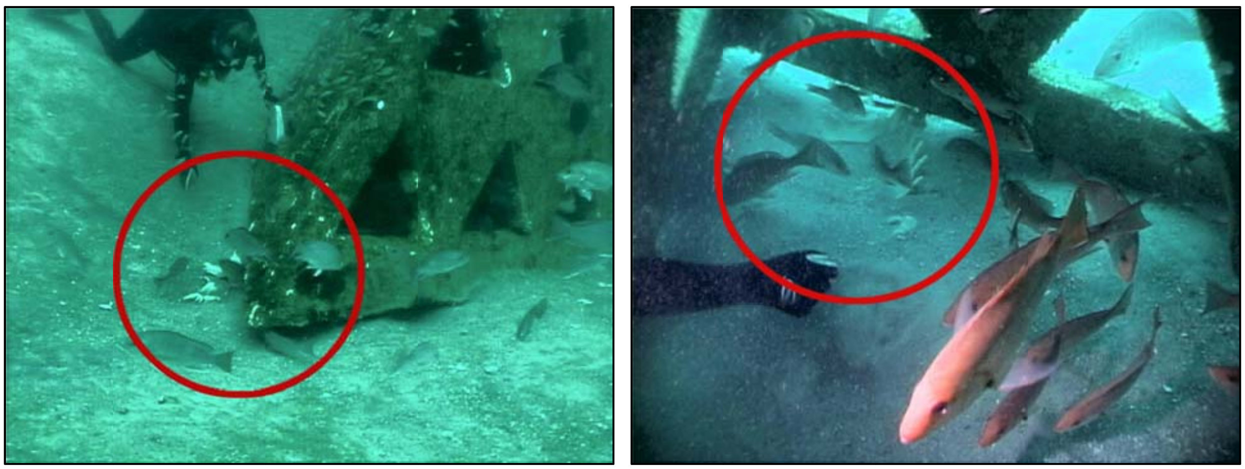

**Figure 7.** Images of sea turtle skeletal remains under a fish haven module off Escambia County (Images courtesy of FWC Artificial Reef Program).

As of October 2015, over 18,769 prefabricated artificial reef modules have been permitted and deployed off Florida (FWC database). Based on the documented sea turtle entrapment events in Table 1, modules possessing the aforementioned characteristics of an open bottom and closed top were deemed to present a high risk for sea turtle entrapment. A total of 2,924 permitted artificial reef modules fit this description. The remaining artificial reef modules were determined to present no risk of sea turtle entrapment due to designs that prevent their access into the module interior.

There has been little in-water research focused on these sea turtle issues, as the topic is difficult, time consuming, and expensive to study. There are a significant number of artificial reef modules deployed over large areas off Florida, most of which are unattractive to recreational divers due to the average small size of modules and lack of features, as compared to larger artificial reefs and shipwrecks. Therefore, anecdotal information from that sector is generally non-existent. Furthermore, feedback has implied that outreach information (e.g., who and where to report an observed sea turtle mortality) has not adequately penetrated the recreational diving community; observations have been reported to the U.S. Coast Guard, local counties, and the FWC, and not all reports have migrated successfully to the Sea Turtle Stranding and Salvage

Network database. Compounding these issues is the fact that evidence of a mortality event may not be easily recognized, particularly if skeletal remains are scattered and get sanded over. Lastly, artificial reef monitoring effort is generally low. In 2015, there were only 39 FWC and 78 county, university, and non-governmental organization site monitoring surveys conducted on artificial reefs across Florida. This low effort makes detection of these mortality events extremely unlikely. Yet, some records of these events do exist and entrapment could present a significant source of mortality on adult sea turtles. Additional research, however, is needed to investigate this issue.

As mentioned, there is a general paucity of published data on sea turtle interactions—specifically entrapment—with artificial reefs; however, Patterson (2010) does provide some insight into this issue while examining the ecological function of unreported artificial reef modules deployed off the Florida Panhandle in 2003. During 2009-2010, surveys were conducted quarterly on 27 total sites comprising three designs: nine sites with single pyramid modules 3.05 m in height; nine sites with two fish haven modules, each 1.83 m in height; and nine sites with two reef ball modules, each 1.45 m in height. The pyramid design had an open bottom and a closed top, while the fish haven had an open bottom and a small open top; these designs are considered high risk for sea turtle entrapment due to the likelihood an adult turtle would be unable to exit if it had gained access to the interior. In contrast, the reef balls, while having small openings in the sides and top to allow fish entry/exit, have closed bottoms to prevent sea turtle access to the interior.

During the survey period, Patterson (2010) recorded 15 sea turtle observations, 10 of which were unique entries, and two sea turtle mortalities; repeated observations of dead, decomposing, or skeletal remains comprised six entries from two separate modules. Five of the unique sea turtle entries were identified as loggerheads, three as greens, and two were unknown species. Both sea turtle mortalities were associated with the pyramid design, yet one of the documented mortalities was already skeletal upon the module's first survey in 2009. Because the turtle was already skeletal at the start of the survey year, even though the cause of death is suspect due to the turtle's proximity to a single artificial reef module, it will be excluded when calculating a proposed mortality rate. Based on the total number of observations on all artificial reef modules during the period, assuming all mortalities were observed during that year, there was a 0.556% documented annual mortality rate (1 mortality / 45 total modules x 4 surveys per year). This includes the reef ball modules that present no risk to sea turtle mortality through entrapment. Therefore, to get a more accurate estimate of sea turtle mortality due to entrapment, I now exclude those modules (1 mortality / 27 total modules x 4 surveys per year), resulting in a 0.926% mortality rate for the pyramid and fish haven modules. Patterson (2010) estimated annual mortality differently. Using data collected from 2004-2010, he documented 23 unique sea turtle observations from a total of 513 surveys, resulting in 4.5% of all surveys having turtles present. Extrapolating that out over the entire 5.5-year period with the two observed mortality incidents, he calculated a 0.015% (95% CI = 0.011-0.024%) annual mortality rate for all artificial reef modules combined (i.e., including the no-entrapment risk reef balls). It is worth noting that almost half (43.5%) of all unique sea turtle observations occurred in the last year of the study. This may be a result of the artificial reef sites "maturing" since their 2003 deployment, sea turtles increasingly utilizing the artificial reefs, changes in local sea turtle populations, or some other factor. Regardless, I believe the 0.926% mortality rate is more appropriate for calculating mortality associated with high-risk artificial reef modules. Therefore, based on the 2,924 total estimated high-risk modules permitted and deployed in Florida waters, I estimate 27 sea turtles may be entrapped and drowned per year as a result of these deployed artificial reef modules. As sea turtle populations change and modules deteriorate, this estimate may change over time. Furthermore, there is much uncertainty in this estimate, as the underlying data are based on a single study conducted in the Florida Panhandle.

These documented issues have been presented to the U.S. Army Corps of Engineers, which issues permits to establish or enhance artificial reef sites, as well as to FWC and private artificial reef companies. FWC and the artificial reef companies have implemented new measures to address these concerns in Florida. Specifically, they have required new open-bottom pyramid-style modules that have their tops removed to allow sea turtles to exit the module's interior.

While intentionally deployed material intended to enhance habitat and local ecosystems may have deleterious effects on threatened and endangered species, sea turtles have been documented to drown after becoming entrapped in natural habitat as well, such as in the numerous submerged sinkholes and caves off Florida. Both fresh dead and skeletal remains of sea turtles were documented in 2007-2009 at a cave aptly named Dead Turtle Cave in approximately 37 m of water off Pinellas County, and a dead turtle was also found inside Glory Hole, a submerged sink hole in approximately 22 m of water off Pasco County. In both instances, it was assumed the turtles entered the cave entrances and proceeded farther into the caves' periphery, but were unable to exit either due to constrictions or absence of ambient light to indicate the point of egress (J. Culter, personal communication, March 17, 2016).

Entrapment in artificial reefs, notably in certain prefabricated module designs, has been documented as a source of mortality for sea turtles in Florida waters. While the identified high-risk module designs are no longer used in Florida, they are used in other states and in other parts of the world. Furthermore, the 2,924 permitted high-risk modules previously deployed off Florida will likely maintain their structural integrity for several more decades. Sea turtles will continue to interact with these modules, and it is possible entrapment mortality events may occur well into the future at some level. The majority of these high-risk modules have been deployed off the Florida Panhandle (Figure 5). Thus, given some of the modules' proximity to sea turtle nesting beaches, there may be additional cause for concern if female sea turtles utilize them during inter-nesting periods (Hart et al. 2013).

## SEA TURTLE ENTANGLEMENT IN ARTIFICIAL REEFS

Artificial reefs attract fishermen—that is one of the primary goals of artificial reef development. In turn, fishing activities on artificial reefs and shipwrecks invariably attract monofilament and anchor lines that get fouled on the material. Over time or with significant fishing pressure, monofilament and other lines can accumulate significantly on these structures, which now present a threat to sea turtles utilizing artificial reefs and shipwrecks as resting habitat. Sea turtles wedging themselves under structure to rest may encounter lost monofilament or anchor lines, which could become wrapped around a flipper or neck. If the line is fouled securely into the artificial reef or shipwreck, an unfortunate sea turtle may become effectively anchored to the bottom, unable to surface and breathe, and ultimately drown. Carr (1987) noted that sea turtles are "peculiarly prone to…tangle themselves in lines and netting discarded by fishermen, and records of such mishaps have increased markedly in recent years." Concern has been expressed that entanglement on artificial reefs and shipwrecks may be a source of mortality not previously recognized, particularly given that it is not well represented by available sea turtle stranding data (Foley et al. 2008).

Monofilament line is a prevalent form of marine debris and pollution, and entanglement in marine debris is a global problem affecting at least 200 marine species (NOAA 2014); all seven species of sea turtle have been reported entangled in marine debris globally (SCBD 2012). Balazs (1985), in one of the first comprehensive reviews examining the issues of marine debris as it relates to sea turtles, compiled 60 total documented incidents worldwide. Out of those incidents, 53 were likely fishery-related and 17 of those were cited as either "fishing line" or "monofilament line." For several cases, there was evidence that the turtles had become entangled in lost line snagged on the bottom. In contrast to this current study, only 38% of the entangled turtles in Balazs (1985) were dead or later died, though that is likely a significant artifact of the data availability from that study.

Foley et al. (2008) noted that monofilament line was the most common form of pollution found associated with stranded sea turtles (i.e., dead, injured, sick, tumored, or otherwise abnormal and sometimes seemingly normal and out of the water, usually along the shoreline) in Florida; during the period 1980-2007, 852 stranded sea turtles were found to have been entangled in or to have ingested monofilament fishing line. And the number and percentage of stranded sea turtles entangled in monofilament line has increased over that time (Foley et al. 2008). Sea turtle entanglement on artificial reefs and shipwrecks is highly unlikely to be captured in sea turtle stranding records due to the turtle's carcass effectively being anchored to the wreck and unable to wash ashore. Therefore, the significance and potential scale of this issue has eluded proper recognition and consideration. Furthermore, there are other circumstances that make observation of these interactions even more problematic.

Irrefutable evidence that entanglement is the source of mortality depends in large part on availability of a carcass anchored to an artificial reef or shipwreck by monofilament or other line. Decomposition of the carcass can erase that evidence in relatively short order. Rate of decomposition in sea turtles varies by water temperature, predation, sea turtle size, exposure, and other factors. There is little information in regards to sea turtle decomposition rates, particularly fully immersed sea turtles. Five turtles entangled in Virginia pound net leaders were examined during 1984 and none of these turtles became disentangled by natural causes, but instead completely decomposed in situ within five weeks (Bellmund et al. 1987). In 2002 and 2003, NOAA Fisheries observers left three documented dead entangled sea turtles in Virginia pound net leaders to monitor decompositional status. Initially, these turtles were fresh dead to moderately decomposed. One of the turtles was gone when observed three days later, another fell out after nine days when its flipper tore away from its body, and another turtle was still in the pound net leader five days later but in a severely decomposed condition (NMFS 2004). Higgins et al. (2007) documented the varying rate of decay in freshly dead juvenile Kemp's ridley sea turtles positioned in the Texas surf zone. They found that a juvenile sea turtle went from fresh dead (Code 1) to clean bones (Code 5) in 4 days in warm water (33-34°C water temperature), and 12 days to decompose similarly in colder water (14-21°C water temperature). It was also noted that the production of decompositional gasses, which results in the carcass becoming positively buoyant, were produced quicker in warmer water versus colder water (i.e., one day versus five days). Based on these results, and assuming an average bottom water temperature of 19-24°C throughout most of Florida, I expect most sea turtles fully immersed and effectively anchored to the bottom at depths ranging from 20 to 60 m will become fully skeletal within 9-12 days of mortality.

While it may be easy to determine entanglement in a freshly dead or decomposing sea turtle, it is less so when the turtle is fully skeletal. Monofilament or other line may no longer be visibly entangling the remains, predators may scatter bones to further confound the scene, or the bones become covered by sediments over time. In some instances, however, evidence lingers. In 2007, the author observed the fully-skeletal remains of a large loggerhead sea turtle underneath the wreck of the *Baja California* southwest of Naples at a depth of 35 m, with the humerus bone still suspended directly above in a loop of anchor line (Figure 8). Dead sea turtles observed on artificial reefs and shipwrecks, particularly when skeletal, may certainly have perished due to causes other than entanglement (or entrapment) when definitive evidence is lacking. For example, in 2013 the Sea Turtle Stranding and Salvage Network received information of a decomposing hawksbill sea turtle on the wreck of the *Mercedes*, an artificial reef deployed in 1985 off Broward County. Given that one-third of the rear shell was missing, it was concluded the mortality was due to shark predation. It is possible the turtle was preyed upon at the artificial reef or perhaps some distance away, with currents subsequently transporting the carcass into the wreckage. Nevertheless, entanglement can be suspected in many cases, even in the absence of more definitive evidence; this is typically the situation when skeletal remains are found in close proximity to abundant monofilament or anchor lines on artificial reef or shipwreck material, and other evidence indicating another source of mortality is lacking.

**Figure 8.** Skeletal remains of a loggerhead sea turtle; note humerus bone still hanging in a loop of lost anchor line.

The decompositional process may also hinder identification of sea turtles that drowned due to entanglement in other ways. Specifically, as decompositional gasses build, a sea turtle carcass may become buoyant. That buoyancy, coupled with current or surge, could result in a carcass "disappearing" from the scene. This scenario was documented following the observation of an entangled loggerhead sea turtle on the wreck of a World War II aircraft off Volusia County in 2010. While the site consisted of only a small, low relief debris field less than 15 m in length, a single fouled anchor line successfully entangled a large loggerhead turtle. When originally observed, the turtle was freshly dead; initially, it was thought the turtle was merely resting on the bottom. Upon closer examination, however, the mechanism of entanglement became obvious (Figure 9). While firmly anchored to the bottom when initially observed, upon revisiting the site two weeks later there was no trace of the turtle to be found. It is unclear if its disappearance was due to decompositional processes, predation, or some other scenario. Regardless, it demonstrated the ephemeral nature of some of these entanglement incidents and the short window of opportunity one has to properly document evidence on a fresh turtle carcass that is immersed in the marine environment.

**Figure 9.** Loggerhead sea turtle entangled in an anchor line on World War II aircraft debris. Two weeks later there was no trace of the carcass or skeletal remains.

Evaluating entanglement (and entrapment) interactions between sea turtles and artificial reefs and shipwrecks has proven problematic given the fact that artificial reef material is so widely dispersed in Florida waters coupled with the inherent difficulty of studying a widely-ranging endangered species, the brief window of opportunity available to properly document these interactions on site before the evidence disappears, and the time and expense of adequately studying this topic. Yet, even with all these hurdles, a growing number of reports of entangled sea turtles are being documented. By reaching out to active commercial divers, researchers, and county artificial reef managers, this current study was able to accumulate a total of 40 sites documenting sea turtle mortality due to observed or suspected entanglement (Table 2). Locations were included from 18 Florida counties (Brevard, Broward, Collier, Duval, Escambia, Franklin, Hernando, Hillsborough, Lee, Manatee, Martin, Monroe, Miami-Dade, Palm Beach, Pasco, Sarasota, St. Lucie, and Volusia; Figure 10). Of the reported sources of entanglement, 14 were cited as monofilament line, 8 were due to ropes or anchor line, 4 were associated with trawl nets, and 3 listed cast or gill nets. Fifteen entries listed the entanglement source as unspecified or unknown; the majority of these were associated with skeletal sea turtle remains in proximity to material that had entanglement hazards present. Based on identified sea turtle species, loggerhead was the dominant species comprising 82% of the records, followed by green and hawksbill at 6% each. The oldest site was attributed to a vessel lost in 1872 (observation made in 2000), while the newest site was a vessel intentionally deployed as an artificial reef in 2007 (observation made in 2014). Fifteen of the sites were associated with permitted artificial reefs (14 in Florida and 1 in Alabama). Nine sites reported multiple turtle mortalities, either from the same observation or over time. Two of the documented entanglement interactions occurred with live turtles; had divers not intervened and removed the entanglement, the turtles would likely have drowned.

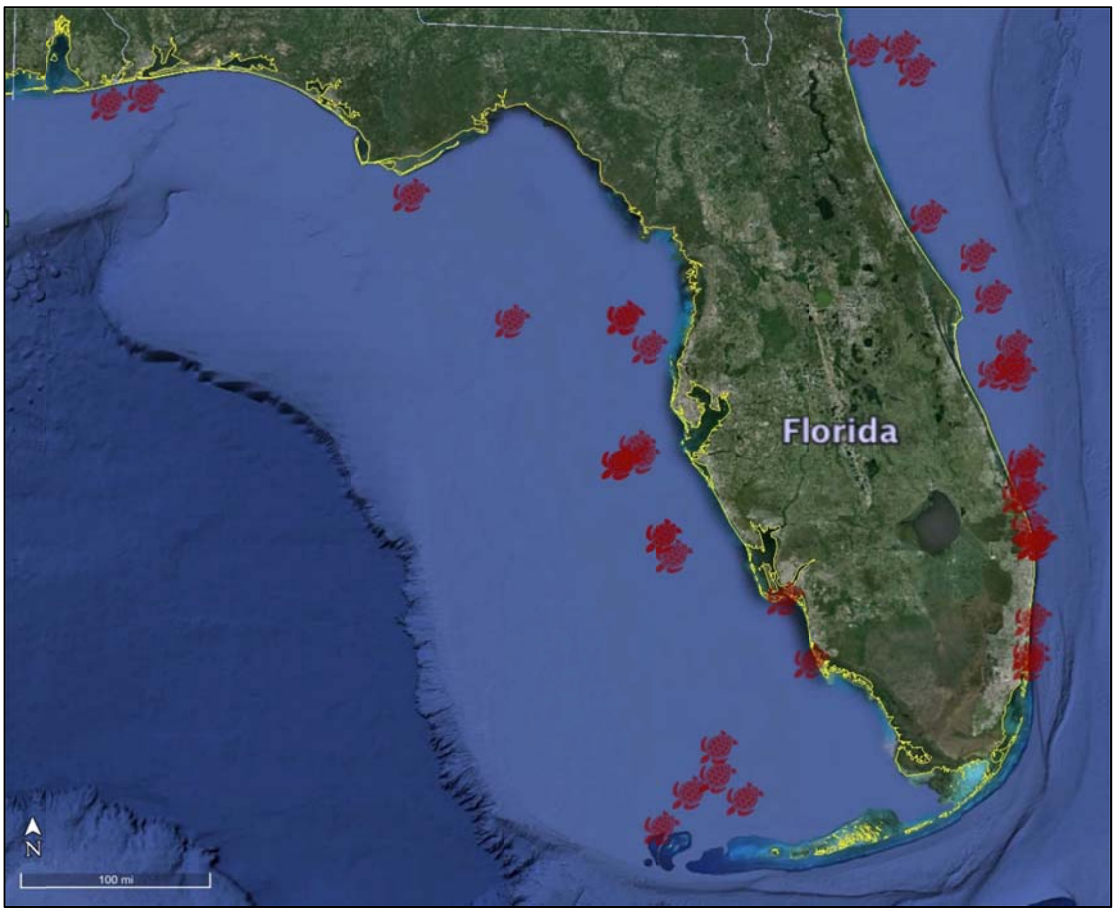


**Figure 10.** Map illustrating locations of over 40 documented sea turtle mortalities due to confirmed or suspected entanglement in artificial reefs or shipwrecks.

**Table 2.** Documented sea turtle entanglement or suspected entanglement issues on Florida artificial reefs and shipwrecks. An asterisk (*) indicates multiple observations of dead turtles at the same site—either at the same time or over time.

| SPECIES | YEAR | LOCATION | COUNTY | YEAR SUNK | CAUSE | CONDITION | SOURCE |
|---|---|---|---|---|---|---|---|
| LOGGERHEAD | ~1985-95 | KATHY* | MONROE | UNKNOWN | TRAWL NET; MONOFILAMENT LINE | SKELETAL DEAD | D. DEMARIA |
| UNKNOWN | ~1985-95 | BELLATRIX* | MONROE | 1964 | NOT SPECIFIED | SKELETAL DEAD | D. DEMARIA |
| UNKNOWN | ~1985-95 | BIG RED* | MONROE | 1970 | NOT SPECIFIED | SKELETAL DEAD | D. DEMARIA |
| LOGGERHEAD | 1989 | "ARTIFICIAL REEF" | MARTIN | UNKNOWN | MONOFILAMENT LINE | FRESH DEAD | STSSN |
| LOGGERHEAD | 1994 | WRECK | LEE | UNKNOWN | ROPES | DECOMPOSING | STSSN |
| LOGGERHEAD | 1996 | AMAZONE | MARTIN | 1942 | LONGLINE MONOFILAMENT LINE | FRESH DEAD | STSSN |
| UNKNOWN; LOGGERHEAD | 2000-08 | JOSEPH M. CUDAHY* | MONROE | 1942 | TRAWL NET | SKELETAL DEAD | AUTHOR; J. JOSEPH |
| LOGGERHEAD | 2000 | SHRIMP BOAT | FRANKLIN | UNKNOWN | TRAWL NET | FRESH DEAD | STSSN |
| LOGGERHEAD | 2000 | VICTOR | PALM BEACH | 1872 | ROPE | DECOMPOSING | STSSN |
| LOGGERHEAD | 2002 | HALSEY | ST. LUCIE | 1942 | ANCHOR LINE; MONOFILAMENT LINE | FRESH DEAD | AUTHOR |
| LOGGERHEAD | ~2003 | GWALIA | HERNANDO | 1925 | TRAWL NET | FRESH DEAD | D. MACMAHON |
| LOGGERHEAD | ~2004 | PECK BARGE | MARTIN | 1986 | GILL NET | DECOMPOSING | K. DILLON |
| UNKNOWN; LOGGERHEAD | 2004-2007 | D-9 CRANE BARGE* | SARASOTA | UNKNOWN | MONOFILAMENT; NOT SPECIFIED | SKELETAL DEAD; DECOMPOSING | C. JOHNSON; A. COLLINS |
| LOGGERHEAD | 2005 | LESLIE | BREVARD | 1942 | MONOFILAMENT LINE | FRESH DEAD | AUTHOR |
| GREEN; LOGGERHEAD | 2006-2009 | PILLSBURY* | MANATEE | UNKNOWN | MONOFILAMENT LINE; UNKNOWN | FRESH DEAD | AUTHOR; A. COLLINS |
| HAWKSBILL | 2007 | AMARYLLIS | PALM BEACH | 1968 | MONOFILAMENT LINE | ALIVE | L. WOOD |
| LOGGERHEAD; UNKNOWN | 2006-15 | BAYRONTO* | LEE | 1919 | UNKNOWN | SKELETAL DEAD | AUTHOR; J. JOSEPH |
| LOGGERHEAD | 2007 | BAJA CALIFORNIA | MONROE | 1942 | ANCHOR LINE | SKELETAL DEAD | AUTHOR |
| LOGGERHEAD | 2008 | MARCO PASS BARGE | COLLIER | 1987 | CAST NET | FRESH DEAD | COLLIER CO. |
| LOGGERHEAD | 2009 | MEISNER CRANE | HERNANDO | 1982 | ANCHOR LINE OR ROPE | FRESH DEAD | A. COLLINS |
| LOGGERHEAD | 2009 | MEISNER BOX | HERNANDO | 1982 | UNKNOWN | SKELETAL | A. COLLINS |
| LOGGERHEAD | 2009 | SULPHUR BARGE | HILLSBOROUGH | UNKNOWN | ANCHOR LINE | ALIVE | A. COLLINS |
| LOGGERHEAD | 2010 | WWII AIRCRAFT | VOLUSIA | 1944 | ANCHOR LINE | FRESH DEAD | AUTHOR |
| UNKNOWN | ~2011 | PASCO SITE 2 | PASCO | 1980s | UNKNOWN | DECOMPOSING | R. ZACKER |
| LOGGERHEAD; UNKNOWN | 2011 | BARBARA ANN* | BREVARD | 1990 | UNKNOWN | SKELETAL DEAD | AUTHOR; J. MARINKO |
| HAWKSBILL | 2011 | BRAZILIAN DOCKS | PALM BEACH | 1994 | MONOFILAMENT LINE | FRESH DEAD | L. WOOD |
| UNKNOWN | 2012 | RONALD B. JOHNSON | BROWARD | 1988 | UNKNOWN | SKELETAL DEAD | J. JOSEPH |
| SUSPECTED GREEN | 2012 | CASA BLANCA | DUVAL | 1972 | MONOFILAMENT LINE | FRESH DEAD | FWC VIA M. THOMPSON |
| UNKNOWN | ~2013 | WEE-II | BREVARD | UNKNOWN | UNKNOWN | SKELETAL DEAD | J. MARINKO |
| UNKNOWN | ~2013 | MOORE WRECK | BREVARD | 1980s | UNKNOWN | SKELETAL DEAD | J. MARINKO |
| UNKNOWN | ~2013 | STINK BOX* | BREVARD | 1980s | UNKNOWN | SKELETAL DEAD | J. MARINKO |
| LOGGERHEAD | 2013 | TENNECO TOWERS | BROWARD | 1985 | MONOFILAMENT GILL NET | SKELETAL DEAD | FWC |
| LOGGERHEAD | 2013 | FIN BARGE | MANATEE | UNKNOWN | UNKNOWN | DECOMPOSING | A. COLLINS |
| LOGGERHEAD | 2013 | SAN PABLO | ESCAMBIA | 1944 | MONOFILAMENT LINE | DECOMPOSING | FWC VIA R. WELLER |
| LOGGERHEAD | 2013 | ALLEN LIBERTY SHIP | ALABAMA | 1975 | UNKNOWN | DECOMPOSING | B. CLARK |
| UNKNOWN | 2013 | ANNA | DUVAL | 1986 | UNKNOWN | SKELETAL DEAD | T. HANCOCK |
| LOGGERHEAD | 2014 | COMMODORE | VOLUSIA | 1897 | MONOFILAMENT LINE | FRESH DEAD | AUTHOR |
| UNKNOWN | 2014 | KORIMU | PALM BEACH | 2007 | UNKNOWN | SKELETAL DEAD | D. FOLLAIN-GRISELL |
| LOGGERHEAD | 2015 | BARGE | DUVAL | UNKNOWN | MONOFILAMENT LINE | FRESH DEAD | J. KISTEL |
| LOGGERHEAD | 2015 | NARWAL | MIAMI-DADE | 1986 | ANCHOR LINE | FRESH DEAD | S. JOHNSON |

Based on the locations of the entanglement observations, some areas with concentrations of sea turtle entanglement issues appear. This was not a systematic survey of artificial reef material, however, but one that relied on opportunistic observations made by divers. Given that one site off Manatee County known locally as the "Pillsbury Wreck" accounted for multiple sea turtle mortalities over time, including two entanglement events observed on the same day in 2006 (Figure 11) and a subsequent suspected entanglement mortality observed in 2009, it is possible that some artificial reefs and shipwrecks present a more significant threat than others due to sea turtle habitat preferences, migration corridors, artificial reef structure or composition, or other environmental parameters.

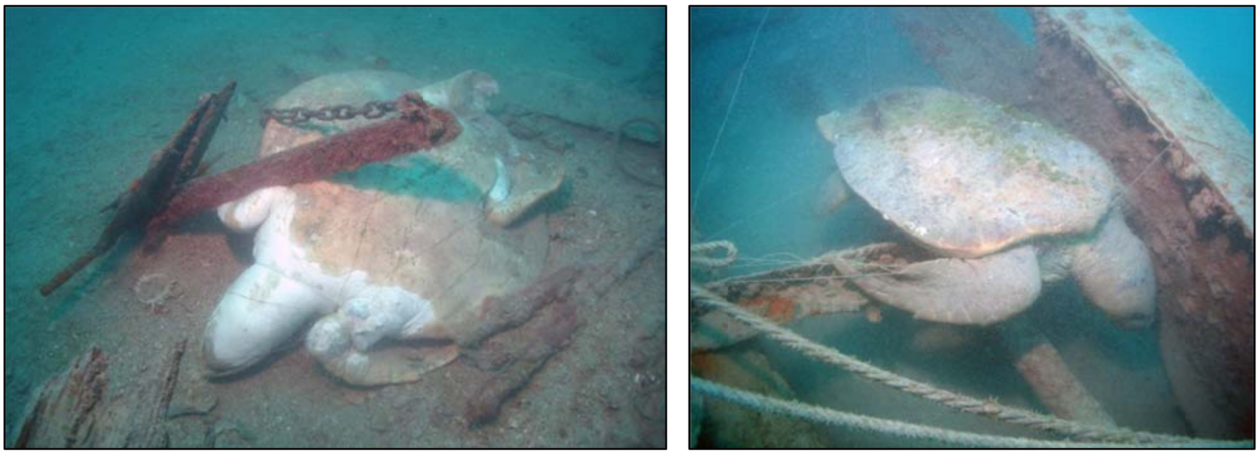

**Figure 11.** Images of two entangled sea turtles observed on the same day in 2006 on the "Pillsbury Wreck" off Manatee County.

There is also an apparent lack of entanglement issues documented in South Florida—an area hosting significant artificial reef material, intensive localized fishing pressure, and a large population of visiting and local recreational divers that may observe and report entanglement incidents. Palm Beach, Broward, and Miami-Dade Counties possess extremely active artificial reef programs and significant fishing pressure. In particular, these three counties have deployed 212 vessels, or over 41% of all permitted vessels sunk off Florida (as of October 2015). Yet, there were only seven total entanglement observations stemming from those counties. There are several potential explanations for this data trend including: bathymetry constricting habitat to a narrow band along the coast compared to other areas in the state; the proximity of the Florida Current that frequently bathes over these artificial reefs, which may prevent monofilament from accumulating and billowing in more static waters; the abundance of natural hard bottom habitat in close proximity to these county artificial reefs, which competes as sea turtle habitat; visibility; and/or some combination of these factors. An additional explanation may be the fact that many vessels deployed as artificial reefs in South Florida are still largely intact. These vessels have significant vertical relief and much of the monofilament snagged on vessel structure is found above the main deck in the rigging. Conversely, sea turtles seem to prefer the hull/seabed interface when resting. While sea turtles can occasionally be found resting on deck or are vulnerable to snagged monofilament in the upper portions of the vessel while swimming, the curve of a vessel's hull typically shelters the area around the hull's base from snagged monofilament and anchor lines, providing a fairly clear area for sea turtles to rest. While the majority of observed entangled turtles have occurred on older, broken-down shipwrecks and low-relief material, particularly where numerous turtles have been observed over time, it is important to remember that collapse of all artificial reef materials, particularly vessels, is inevitable. Therefore, sea turtle entanglement on these sites may become a more significant issue as the sites mature and deteriorate in the future.

Entanglement in lost or discarded monofilament line, ropes, or netting on an artificial reef or shipwreck is a form of ghost fishing, a significant issue that has been examined in other contexts (Laist 1996). But little has been done to date specific to artificial reefs. Matsuoka et al. (2005) noted that gill nets tangled around artificial reefs continued ghost fishing for a much greater extent of time compared to gill nets lost on flat bottom. In that study, they experimentally tangled a monofilament gill net on an artificial reef and it was found to still maintain ghost fishing mortality after three years, even though the netting was heavily fouled. This was further demonstrated when an apparently discarded gill net became fouled on the "Tenneco Towers" artificial reef site off Broward County in 2013. After becoming snared on the artificial reef structure, the netting continued to trap and kill marine life, including a loggerhead sea turtle. Given the complex habitat and vertical relief afforded by artificial reefs and shipwrecks, it is not uncommon for these sites to accumulate significant amounts of lost gear over time.

As with the entrapment issues discussed earlier, there have been a few instances of sea turtles becoming entangled in monofilament on natural bottom as well (Table 3). The two entangled turtles noted as alive were anchored to the bottom by the gear and would likely have drowned if it were not for diver intervention. While entanglement issues can occur on natural bottom, it does not appear to be as significant a problem compared to more complex artificial habitat. Artificial reefs typically have more relief, are more discrete compared to larger ledge, reef, and hard bottom areas, and, based on the material (e.g., metal), can more easily part fishers' lines. Furthermore, many artificial reefs are deployed and advertised to enhance fishing opportunities, thereby potentially attracting and accumulating more monofilament and anchor lines. These factors help explain the significant difference in observations of entangled sea turtle observations made on artificial reefs and shipwrecks versus natural bottom.

**Table 3.** Documented instances of sea turtle entanglement on natural bottom.

| SPECIES | YEAR | SITE DESCRIPTION | COUNTY | CONDITION | SOURCE |
|---|---|---|---|---|---|
| LOGGERHEAD | 1978 | WARSAW HOLE - LEDGE | BAY | FRESH DEAD | BALAZS 1985 |
| HAWKSBILL | 2008 | LYNN'S REEF | PALM BEACH | FRESH DEAD | M. TRUST |
| HAWKSBILL | 2009 | JUNO LEDGE | PALM BEACH | ALIVE | L. WOODS |
| GREEN | 2011 | BOYNTON REEF | PALM BEACH | ALIVE | REEF RESCUE WEBSITE |

Given the lack of regular monitoring on the thousands of artificial reef and shipwreck sites across Florida, it is not possible to quantify the number of sea turtle mortalities that could be occurring every year. Given the available information presented here, entanglement on artificial reefs and shipwrecks may well be a significant source of previously unreported mortality. Insight gleaned from other information sources also lends credence to this theory. An ongoing goliath grouper research project off the central west coast of Florida has conducted 441 surveys on artificial and natural habitat from 2007-2015. During the course of those surveys, seven incidents of sea turtle mortality confirmed or suspected to be a result of entanglement were documented; six were on artificial reefs or shipwrecks (A. Collins, personal communication, April 29, 2016). While not directly germane to the issue of artificial reefs, Bjorndal and Bolten

(1995) examined the prevalence of entanglement in sea turtles. In studying a pelagic loggerhead population in the Azores, they concluded that over 6% of 800 turtles dip-netted during tuna fishing operations in that area were entangled in debris. Similarly, they received more than 1,500 sea turtle observations throughout the world, in which 5% of those reports noted negative impacts by marine debris.

Even with low anticipated mortality rates, given the thousands of artificial reef and shipwreck sites off Florida that are constantly "fishing" due to the accumulation of monofilament and other entangled lines, it is likely these sites account for significant numbers of sea turtle mortalities every year. As these materials have effective lifespans well over 100 years, it is clear this is a sea turtle conservation issue that perhaps deserves more research attention. On a global perspective, the cumulative impact on sea turtle populations is certainly of consequence.

## CONSERVATION IMPLICATIONS

Given the number of observed sea turtle mortalities associated with artificial reefs, this issue may be a significant source of mortality previously unreported. It is unclear just how significant the level of mortality may be, either on an individual site, regionally, or globally. Given analysis of other activities, such as U.S. Army Corps of Engineers (USACE) dredging activities, artificial reef associated mortality is almost certainly not trivial. For example, in 2015 all USACE dredging projects from Texas through North Carolina, which have significant required monitoring oversight, documented only 12 lethal sea turtle takes. Regardless, as Balazs (1985) noted, "Considered separately, each of these lesser known impacts may not necessarily cause high rates of mortality or morbidity. However, their combined effect over an extended period could very well be a significant retardant to the recovery of certain populations. It is, therefore, imperative that each adverse element be adequately examined and understood."

It would appear from the compiled reports (Table 1), that loggerhead sea turtles may be especially vulnerable to the deleterious side effects of artificial reefs and shipwrecks, which may be associated with the species' habitat preferences. At this time, there is insufficient information to quantify or further refine these mortality threats. It is conceivable that entrapment and entanglement of adult loggerhead sea turtles in artificial reefs could negatively impact local populations, particularly if there are regional differences in the effects that could selectively impact females from smaller nesting populations (e.g., Florida Panhandle) or recovery units (e.g., Northern Gulf of Mexico Recovery Unit). Further investigation is definitely warranted.

## MANAGEMENT RECOMMENDATIONS

The following recommendations are based on the above analyses and offered for consideration in future artificial reef planning. They are focused solely at reducing potential sea turtle mortality associated with artificial reef development and do not factor in other concerns, such as enhancing marine habitat or maximizing socio-economic benefits from use of artificial reefs.

## MINIMIZING EFFECTS OF HATCHLING PREDATION

Hatchling sea turtles exhibit a "frenzy" period of swimming once in the water, whereupon they swim almost constantly in an offshore direction. For loggerhead sea turtles, this behavior likely serves to quickly extricate the hatchling from shallow coastal waters where predators may be more abundant (Wyneken and Salmon 1992) and disperse them into offshore waters that constitute their juvenile epipelagic habitat. Using the maximum documented swimming speed of 0.36 m/sec for hatchling loggerheads during their frenzy period (Salmon and Wyneken 1987; Witherington 1991) and based on an observed reduction of predation after 15 minutes of swimming from the beach (Glenn 1996, Wyneken and Salmon 1997, Wyneken et al. 2000, Stewart and Wyneken 2004), it is anticipated that initial hatchling predation rates, on average, should be reduced approximately 324 m off the nesting beach. Therefore, for any nearshore area that predominantly consists of sand and is directly offshore an identified nesting beach, at a minimum artificial reef development should be precluded within a 324 m buffer zone extending from the beach to avoid potential issues with increased predation of sea turtle hatchlings. Because artificial reef development is not expected to dramatically alter the predator complex in nearshore areas directly off nesting beaches that already have hard bottom or reef habitat in the immediate vicinity, a buffer would not be necessary in those areas.

## MINIMIZING ENTRAPMENT

Prefabricated modules such as open-bottom, closed-top pyramids can allow sea turtles to gain access to the interior and potentially drown. These modules should not be utilized due to this documented risk. Instead, solid or closed-bottom modules should be the standard parameters for prefabricated modules. Modified designs, such as open-top fish haven modules could also be considered as low risk, if the opening in the top is sufficient to allow an adult sea turtle to escape. For triangular modules, that opening should be a minimum of 4 feet on each side. Due to the lack of documented or anticipated interactions between artificial reef modules and leatherback sea turtles, this study employs a conservative opening size based on the maximum observed carapace width for loggerhead sea turtles (K. Hart, personal communication, May 9, 2016). It is also important that these modified modules not retain any lifting point lines that may restrict the module's opening at the top. Materials such as rock, rubble, and some secondary-use concrete materials also could be considered for preferential use due to an anticipated absence of entrapment hazards.

## MINIMIZING ENTANGLEMENT

Managers should consider the type and location of material that is deployed for artificial reef purposes. For example, use of vessels or metal structure in areas devoid of other habitat may initially introduce an oasis for marine life. Over time, however, the introduction and accumulation of monofilament and other lines presents a threat to sea turtles that could result in entanglement and drowning. Therefore, other materials such as rock and rubble, or low-profile artificial reef modules like reef balls, may result in a reduced likelihood of lost fishing gear, which, in turn, may reduce the likelihood of sea turtle entanglement. Even secondary-use concrete materials such as storm-water structures, highway barriers, and bridge material absent of any exposed rebar may present a lower risk to sea turtles compared to vessels. In 2014, an entangled sea turtle was noted on a historic shipwreck (i.e., foundered in 1897) site off Volusia County that had been expanded to include an abundance of concrete culverts immediately adjacent to the wreck. Little to no monofilament line was noted on the culverts, yet snagged tackle on the scant remains of the *Commodore* was sufficient to result in the drowning of a small loggerhead sea turtle. While vessels provide abundant and complex habitat, present a large target for fishermen to locate, and are generally more attractive for recreational divers, they typically accumulate significant amounts of fouled monofilament line and ultimately will deteriorate, which is expected to increase the entanglement risk to sea turtles. Therefore, the use of vessels as artificial reefs should be carefully considered, particularly if the proposed site is adjacent to nesting beaches or is located in proximity to identified sea turtle critical habitat.

Perhaps a more practical action that can reduce sea turtle entanglement risk is to require periodic artificial reef cleanup activities to remove monofilament and other lines entangled on artificial reef structure. As discussed earlier in this analysis, all it takes is one line to result in sea turtle mortality due to entanglement. Therefore, while reef cleanup activities would not totally eliminate the entanglement risk presented by lost line, it may help reduce the risk presented to sea turtles. Obviously, these activities would largely be restricted to recreational diving depths (i.e., $\leq$ 40 m). Therefore, managers may also want to reconsider deploying artificial reef material in deeper waters where sea turtles occur, but where monofilament line could significantly accumulate unabated.

<u>REPORTING</u>

Observations of dead sea turtles by recreational divers have not typically been reported, perhaps due to a lack of knowledge of where to submit such information. In some instances, it was reported that calls were made to the U.S. Coast Guard, FWC law enforcement, or county officials, all of whom (depending on the person or office that was contacted) were perhaps not the ideal principal contact or responder. Furthermore, those calls or information were not forwarded so that the information could be captured by the STSSN. Outreach similar to what has been conducted for incidentally captured sea turtles on fishing piers or for public sawfish sightings could be pursued. In addition, several dive agencies have environmental branches that could be utilized to help educate divers.

While working on this study, it also became clear that dissemination of information could be improved. In some instances, county programs—while submitting the information to the STSSN—may not share the reports with the FWC Artificial Reef Program. In other instances, individuals pursuing another field of research had documented artificial reef related sea turtle mortalities that were not submitted to the STSSN or other entities. In large part, serendipity was responsible for learning about their observations. It is hoped that further discussion, examination, and analysis of this issue will help improve data reporting and accessibility.

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