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Thesis of
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Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

M.S. Marine Biology

Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

October 2017

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Emerging Hotspot Analysis of Florida Manatee
(Trichechus manatus latirostris) Mortality (1974-2012)

By

Crystal Ann Bass

Submitted to the Faculty of
Halmos College of Natural Sciences and Oceanography
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology

Nova Southeastern University

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Abstract

The Florida manatee (*Trichechus manatus latirostris*) is a protected species that is vulnerable to both anthropogenic and natural causes of mortality. The ability of wildlife managers to oversee regulation of this species is based on available abundance estimates and mortality data. Using existing manatee mortality data collected by Florida Fish and Wildlife Conservation Commission (FWC) from 1974-2012, this study focuses on identifying significant spatial clusters of high values or “hotspots” of manatee mortality and the temporal patterns of these hotspots using the novel “emerging hotspot analysis” ArcGIS tool. The categories of manatee mortality included in this analysis were watercraft-related, perinatal, cold-stress, and other natural (which includes red tide) and were classified into five hotspot pattern categories. Of interest were the locations where consecutive or new hotspot patterns were identified among the four categories of manatee mortality included in this analysis. Consecutive hotspot clusters were found near Tampa Bay (which includes parts of Pinellas, Hillsborough, and Manatee Counties) and in the counties of Hernando/Pasco, Monroe, Palm Beach/Broward/Miami-Dade, St. Johns/Flagler, and Citrus. New hotspot clusters were found in Tampa Bay (which includes parts of Pinellas, Hillsborough, and Manatee Counties) and in the counties of Nassau, Wakulla, Charlotte/Lee, St. Lucie/Martin, Levy, Duval, Dixie, Volusia/Seminole, and Citrus. These mortality hotspots frequently overlapped areas of higher manatee and human population densities. These hotspot clusters indicate emerging patterns that highlight areas to focus future research by wildlife managers; specifically, on the relationship between human population density and concentration of watercraft activities in coastal areas, as well as the influence coastal development has on the vital resources utilized by manatees.

Keywords:

Florida manatee (*Trichechus manatus latirostris*), Manatee mortality, ArcGIS, Emerging Hotspot Analysis, Temporal spatial statistics
Section 1: Introduction

1.1: Taxonomy, Species Descriptions and Distribution

The order Sirenia, is comprised of two families, Trichechidae and Dugongidae. The Family Trichechidae includes the West Indian manatee (*Trichechus manatus*), the African manatee (*Trichechus senegalensis*), and the Amazonian manatee (*Trichechus inunguis*). The dugong (*Dugong dugong*) and the now extinct Stellar sea cow (*Hydrodamalis gigas*) belong to the family Dugongidae.

Fossil record shows that the earliest member of the order Sirenia, *Prorastomus sirenoides*, appeared during the Eocene epoch approximately 50 million years ago. *Prorastomus sirenoides* was a small, four-footed land mammal that lived a semi-aquatic lifestyle (Domning, 2001; Domning, 2005). Modern manatees have a vestigial pelvic girdle with absent pubic bones with the ischium and ilium fused together to form the innominate bone, which suggests their terrestrial origin (Fagon, Rommel, and Bolen, 2000; Berta, et al., 2006). Currently, the only species of Sirenians to be found in the Caribbean and the western Atlantic waters is the manatee, but previously both manatees and dugongs occupied much of this same habitat (Domning, 1982; Domning et al., 1983). Sirenian fossils have been found in Florida that date back millions of years, with the modern manatee appearing around 10,000 years ago (Domning, 2005).

The order Sirenia shares a common ancestor with superorder Afrotheria, which includes species such as elephants, hyraxes, and aardvarks (Berta, *Sumich, and Kovacs*, 2006). These species are generally herbivorous that utilize specialized bacteria to digest the cellulose contained in their plant-based diet (Reynolds and Rommel, 1996). Sirenians are the only strictly herbivorous marine mammal, which is evidenced by their dentition and digestive tract, having adaptations similar to those of its relatives (Powell, 2002). Like elephants, manatees have migrating molars which are worn down from chewing abrasive plant matter (Miller, Sanson, and Odell, 1980; Domning, 1983); teeth fall out the front of the jaw as the tooth roots are absorbed and are replaced by newer molars that erupt in the back of the jaw (Fortelius, 1985). As many as 30 molars may be used and lost during a manatee’s lifetime (Domning and Hayek, 1986).
In Sirenians, digestion of plant matter occurs in the hindgut, or colon, which is aided by anaerobic bacteria and an accessory digestive gland to break down the tough cellulose fibers (Parra, 1978; Burn, 1986). A slow metabolism and an enlarged gastrointestinal tract to accommodate large volumes of diverse types of consumed vegetation, allowing manatees to gain the maximum nutrition from a nutrient poor food source (Irvine, 1983; Lomolino and Ewel, 1984; Ledder, 1986; Hurst and Beck, 1988; Alves-Stanley et al., 2010; Allen & Keith 2015). Manatees consume 10-15% of their body weight in vegetation per day (Reep and Bonde, 2006). Large muscular prehensile lip pads aid the manatee with feeding on aquatic vegetation (Reep, et al., 2001), and specialized hairs called vibrissae on the snout serve many tactile functions such as explorations of their environment, feeding, and interacting with other organisms (Humphrey, 1992).

As a K-selected species, manatees have a long lifespan, are slow to grow and reproduce, and expend large amounts of energy caring for their offspring (Pianka, 1970; Bonde, 2009; Marmontel et al., 1996; Rathbun et al., 1995). After reaching maturity at around 3 to 7 years in age, manatees may give birth after a long gestation period of twelve to thirteen months. Manatee calves may stay with their mothers for up to two years, causing them to have a low reproductive rate of one calf every 3 to 5 years (Ronald et al., 1978; Humphrey, 1992; Marmontel, 1995; Bonde, 2009). Manatee calves are approximately 1.2-1.4 m long and weigh about 30 kg at birth (USFWS, 2009). Manatees are not social by nature with the only true bond occurring between a female and her offspring.

As a marine mammal, the manatee has evolved several adaptations to thrive in a fully aquatic habitat. Manatees have a dorsoventrally flattened fusiform body with no hind limbs and no external ear pinnae (Powell, 2002). Manatees use muscular valves to open and close their nostrils, located on the upper snout, before submerging (Powell, 2002). For propulsion, manatees have a paddle-like fluke and paddle shaped forelimbs or flippers, which can be used to steer or walk along the bottom substrate (Folkens and Reeves, 2002). Their skeleton is comprised of dense, heavy bones that lack marrow cavities (Bonde and Reep, 2006). The manatee’s diaphragm is located along the dorsum instead of the transverse plane of the body; diaphragmatic contractions through
specialized muscles compress gases in their lungs and gastrointestinal tract to help them maintain and control buoyancy (Rommel and Reynolds, 2000).

The West Indian manatee can be found in the warm waters of the southeastern United States, in the Gulf of Mexico and Atlantic Ocean, south from Mexico extending to Brazil, as well as the island nations of Trinidad and Tobago, Jamaica, Cuba, Haiti, the Dominican Republic, Puerto Rico, and the Bahamas (USFW Southeast Region, 2016) (Figure 1). The largest population of the West Indian manatee is located in the state of Florida, U.S.A., with small populations found throughout the rest of their range.

![Figure 1: West Indian manatee distribution map](https://www.fws.gov/southeast/wildlife/mammal/manatee/)

The Florida manatee (*Trichechus manatus latirostris*), a subspecies of the West Indian manatee, can be found throughout the United States, from Massachusetts to Texas during summer months (Lefebvre et al., 1989). In Florida, they are restricted to coastal waters and connected inland waterways, preferring estuarine and fresh water habitats (Garrot et al., 1994). Here, they can be divided into two subpopulations based on their
relative isolation from each other: Atlantic coast, from the Georgia/Florida border south to the Florida Keys, and the Florida Gulf of Mexico coast, from Wakulla River south to Cape Sable (Hartman, 1974; Powell and Rathbun, 1984).

Florida manatees are the largest of the Sirenians, weighing around 400-550 kg with average length of 2.7-3.5 m (Reep and Bonde, 2006). Sexual dimorphism exists between males and females, with females often being larger than males (Reep and Bonde, 2006). They are migratory, with a seasonal variation in their distribution observed during colder months, as they have an increased risk of acute and chronic cold-related mortality in water temperatures colder than 20 ºC (Irvine, 1983; Kochman et al., 1985; Allen, 2013, Allen et al., 2014). During this period, aggregations of manatees can be seen in warm water refuges such as passive thermal basins, natural springs, or power plant effluents. Manatees show strong site fidelity and will return to the warm water refuges year after year (Powell and Rathbun, 1984; Deutsch et al., 2003; Allen, 2013). Aggregations of manatees can also be observed during mating season. Manatee habitat selection is influenced by many factors including food availability, thermal conditions, and freshwater resources (Irvine, 1983; Kochman et al., 1985; Lefebvre et al., 1989).

### 1.2: Population Status

Due to natural and anthropogenic causes, the Florida manatee is listed as protected under the United States’ Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), as well as Florida Statutes 379.2431(2) (f), 370.12(2), and the Florida Manatee Sanctuary Act 379.2431(2)(g) (ESA, 1973; MMPA, 1972; Garrott et al., 1994; Buckingham et al., 1999; Read and Wade, 2000; Allen et al., 2014). The United States Fish and Wildlife Service (USFWS) and the Florida Fish and Wildlife Conservation Commission (FWC) are responsible for research, management, and conservation of the Florida manatee. Since 1974, state and federal agencies have conducted research on manatees, including population counts and mortality statistics. This information is used by managers to implement protection measures for this endangered species. FWC has been collecting data regarding manatee mortality since 1985 and has conducted population counts during cold weather surveys since 1991.
Each winter, the Florida Fish and Wildlife Conservation Commission (FWC) conducts synoptic surveys, which are statewide aerial surveys that cover all of known manatee wintering habitats in Florida (USFWS, 2009; FWC, 2014a; Kleen and Breland, 2014; Sattelberger et al., 2017). These surveys take place during the coldest periods of the year, usually from January through March. A synoptic survey aims to present a general view of the whole population and provides a minimum count of manatees; it is not a population estimate (FWC, 2014a). Surveys concentrate on known areas of manatee aggregations during cold weather and do not cover areas such as the Florida panhandle, or areas of deep, cold water or the open ocean (FWC, 2014a). Climatic conditions and water clarity conditions (among other metrics) can vary from year to year, affecting manatee detectability and making direct comparisons and statements regarding anything other than long-term general trends difficult (FWC, 2014a).

In general, based on these aerial synoptic surveys conducted by FWC, a trend in the numbers of Florida manatees appear to have increased fourfold in Florida, from 1,267 in 1991 to 6,620 in 2017 (FWC, 2017a, Runge et al, 2007). However, these observed increases in manatee counts could in part be due to improved methods utilized by the aerial survey crews and increased observer skills (Allen et al., 2014). Surveys will only be conducted if the following conditions are met (FWC, 2014a):

1. Air temperatures forecast to be less than or equal to 49°F near most of major manatee aggregation sites on at least 3 of 5 days prior to the survey.
2. Water temperatures below 68°F near most major manatee aggregation sites.
3. No winds forecast above 15 knots in the entire survey area on survey days.
4. No sky conditions forecast as “mostly cloudy” or “rainy” in the entire survey area on survey days.

In the winters of 2008, 2012, and 2013 these requirements were not met; therefore, no synoptic surveys were conducted in those years.

Recently, Martin et al. (2015) published the first statewide population estimate for the Florida manatee. Their estimate combines double-observer protocol, repeated passes, and collection of detailed diving behavior data in order to account for the unreliable detection of manatees during surveys. Previously conducted surveys did not take into
consideration the errors of spatial variation in distribution and imperfect detection of manatees. The estimation method used by Martin et al. (2015) factored these two sources of error into their population estimates and calculated the abundance level per plot.

Based on the analysis by Martin et al. (2015), an estimated 6,350 (95%CI: 5,310-7,390) manatees reside in Florida (Figure 2). On the west coast, they estimated 2,790 (95%CI: 2,160-3,540) manatees, with 30% (95%CI: 20-40%) of the manatees aggregated in Lee County and 20% aggregated in Tampa Bay during their survey. On the east coast of Florida, they estimated 3,560 (95%CI: 2,850-4,410) manatees, with 70% (95%CI: 60-80%) of the manatees aggregated in Brevard county during their survey. This study should be interpreted as a snapshot of manatee distribution as manatees are a migratory species and there is seasonal variation in their distribution.

Figure 2: Distribution map of manatees in Florida – Distribution map of manatees in Florida during aerial surveys conducted on the west coast (in 2011) and east coast (in 2012). Predicted abundance values are reported in each plot; colors indicate the abundance level per plot (from 0 to >20 manatees). The insets show zoomed in versions of the Tampa Bay, Lee County and Brevard County.

(Source: Martin et al., 2015)
1.3: Manatee Mortality

Mortality statistics for the Florida manatee, including the number of deaths in each Florida county and probable cause of death, have been collected since 1974 by the FWC through the Manatee Carcass Salvage Program (O’Shea et al., 1985; Bossart, 1999; USFWS, 2009, Allen et al., 2014). This data comes from necropsies conducted on manatee carcasses recovered across the state. Necropsy results from these mortalities are classified by cause of death. These include anthropogenic causes: watercraft, flood gate/canal lock, human-other, and natural causes: perinatal (manatees <150 cm), cold stress, natural (including morbillivirus and red tide), and unrecovered/undetermined (Bonde et al., 1983; FWC, 2014b). Over 50% of subadult and adult manatee mortality, where a cause of death could be determined, is the result of anthropogenic causes (FWC, 2007). Of the previously listed categories, the anthropogenic causes of mortality are most frequently the focus of conservation efforts by wildlife managers because these causes can more readily be addressed than natural causes of death (O’Shea et al., 1995).

Watercraft mortalities classified as watercraft cause of death refer to injuries caused from collision with boats and ships that result in manatee mortality (Rommel et al., 2007). Some manatees are killed by being drowned or crushed in flood gates and canal lock structures (Odell, 1979). These mortalities are classified as human-related structure deaths (category: flood gate/canal lock). All other anthropogenic manatee deaths are classified “other human-related”. Other human-related deaths include those caused by entrapment in pipes and culverts, complications due to entanglement in ropes, lines, and nets, or ingestion of fishing gear or debris, as well as other incidental human causes of mortality (Buergelt et al., 1984; Beck and Barros, 1991; USFWS, 2009).

From 1976-2006, Calleson and Frohlich (2007) calculated that approximately 25% of all documented manatee mortalities in the state of Florida resulted from watercraft collisions, as watercraft collisions are the most common cause of anthropogenic mortality in manatees (Runge et al., 2007). Classification of a manatee death into this mortality category is based on external wound patterns and internal pathological indicators that are diagnostic of watercraft-related trauma (Lightsey et al, 2006). Watercraft strikes can cause fractures and fatal hemorrhages with most mortalities resulting from blunt trauma from impact with no visible external propeller lacerations.
(Buergelt et al., 1984). According to a study conducted by Bossart, et al. (2004); 59% of the manatee carcasses classified as traumatic deaths in Florida between January 1996 and January 2004, were found to be subadults. This finding raises important concerns due to possible negative effects on the future breeding population; if a high portion of manatee mortalities are subadults that do not become a part of the breeding age class, then future generations are threatened.

Ackerman et al. (1995) found a direct correlation between the number of watercraft-related manatee mortalities and the total number of commercial and recreational watercraft registered in the state of Florida. Florida ranks number one in the nation for recreational boating registrations with 905,298 registered boats (USCG, 2016). With increased use of Florida waterways by both boaters and manatees, the potential for fatal interactions increases (Ackerman et al., 1995).

Canal locks are used to raise vessels from sea level to the various water levels of connecting inland waterways in Florida and vice versa. Floodgates are a specialized structure used to lower or raise this water level within the canal locks and spillways by controlling the flow of water and are used to control rainwater and flooding (U.S. Army Corps of Engineers, 1995). Manatees often wait for a vessel to enter a gate then will follow behind it entering the lock (Chiang, 2008; Barrett, 1979; Reynolds, 1981). Manatees are slow swimmers, at 5 to 8 km per hour, and may not make it through the canal locks or floodgate in time. Thus, they risk being crushed or drowned by the closing gates (FWC, 2014b). The classification of a manatee into this mortality category is based on proximity to a floodgate/canal lock structure, gross physiological signs of crushing (such as broken ribs, hemorrhaging, and associated trauma) and impressions of floodgates on their bodies if freshly dead (Odell, 1979).

Perinatal mortality refers to deaths of manatees less than 150 cm in total length in which the determined cause of death cannot be attributed to human-related causes. This category includes stillborn, neonates that failed to thrive, and diseased or orphaned calves (Irvine et al., 1981; Bonde et al., 1983; O’Shea et al., 1995). Classification into this category is not based on a determination of cause of death but distinguish these mortalities as different from the general undetermined category of manatee mortality.
Manatees are not physiologically well adapted to handle colder temperatures and during prolonged cold weather, cold stress syndrome and mortality may often occur due to exposure (Reep and Bonde, 2006). Manatees are dependent on warm water or thermal refuges to survive cold winter months and show a strong fidelity to these sites (Laist, et al., 2013). These refuges are frequently warm water discharges from power plants and natural springs along with thermal basins (Figure 3). Laist, et al. (2013) determined that in years 1999-2011, of the manatees counted, 48.5% were at power plant outfalls, 17.5% at natural springs, and 34.9% at passive thermal basins or sites with no warm-water characteristics. Once temperatures reach 20-22 °C, if a manatee cannot reach a warm water refuge soon, its internal processes start to shut down and abscesses will begin to form on the skin (Deutsch et al., 2003; Bossart et al., 2002). These animals are frequently found emaciated and malnourished (O’Shea et al., 1995; FWC, 2014b). Cold stress related manatee mortalities are of great concern to wildlife managers due to the high number of cold-weather related mortalities observed in the winters of 2008-2009 and 2009-2010 (FWC, 2014b).

Figure 3: Manatee warm water refuge locations in Florida
(Source: Laist, et al., 2013)
Natural causes of death include environmental cataclysms (e.g., harmful algal blooms such as red tide), cold stress syndrome (CSS), infectious and non-infectious diseases (e.g., morbillivirus or papilloma), birth complications, and natural accidents not directly related to human causation (Duignan et al., 1995; Bossart, et al., 2004; FWC, 2014b). Red tide is a naturally occurring event that results from episodic blooms of Karenia brevis, a marine dinoflagellate which releases a neurotoxin (brevetoxin) into the water and air. Red tides have been documented in Florida since the 1800s, but data regarding manatee mortality related to red tides were first recorded starting in the 1970s. Exposure to K. brevis can result in marine mammal deaths and fish kills along with potentially adverse effects on humans (Fleming et al., 2005). In 1996, an epizootic red tide resulted in the mortality of 149 manatees along the southwest coast of Florida in a one-month period (Bossart et al., 1998). Analysis of this event suggests mortality is not immediate but may occur after chronic exposure through inhalation and/or ingestion of brevetoxins, leading to death days (acute) or weeks (chronic) after exposure (Bossart et al., 1998). During a red tide, manatees may consume the algae attached to the plants they eat or may breathe in the algae since it can be dispersed in the air in aerosol form.

Manatee mortality can be influenced by naturally occurring types of emerging diseases. Morbillivirus is a pathogen that predominately affects two orders of marine mammals, pinnipeds and cetaceans. Morbillivirus occurs in lymphoid tissue and often occurs with lymphopenia (low level of lymphocytes in blood) and immunosuppression, which frequently results in marine mammal mortality due to secondary opportunistic infections (Ohishi et al., 2008). The disease was first discovered and described in manatees by Duiganan et al. (1995). The term “immunologically naïve” was coined because they lacked exposure to the harmful pathogen due to their previous isolation, which would invoke a protective immunological response. Although this may not always be the exact cause of mortality, it may have synergistic consequences to impair a manatee’s immune system (Walsh et al., 2005).

Not all causes of death can be ascertained. Occasionally, manatee carcasses are verified but cannot be recovered. These mortalities are categorized as “unrecovered” in the manatee mortality database. When a manatee carcass is too badly decomposed for cause of death to be identified, it is categorized as an undetermined manatee mortality.
1.4: Conservation

The Florida manatee is managed through many conservation efforts under guidelines from the USFWS Manatee Protection Plan. Under this plan, subpopulations of manatees are divided into four regional management units by the USFWS: an Atlantic Coast unit, an Upper St. Johns River unit, a Northwest unit, and a Southwest unit (USFWS 2001 and 2009). The division of these management units results from previous studies on the regional wintering sites of manatees in Florida, which suggest that there is little movement between units during winter (Rathbun et al. 1990, Reid et al. 1991, Weigle et al., 2001). This allows wildlife managers to determine population trends and threats specific to each unit. The Atlantic Coast unit includes the entire east coast of Florida, extending from the lower St. Johns River north of Palatka, down to the Florida Keys. The St. Johns River, south of Palatka, makes up the Upper St. Johns River unit. From the Florida Panhandle, south to Hernando County is the Northwest unit. The Southwest unit is comprised of the area from Pasco County south to Whitewater Bay within Everglades National Park.

In 1989, the Governor and Cabinet’s Policy Directive identified thirteen counties in Florida designated as key areas of concern for manatee conservation efforts due to their high percentage of manatee mortalities. Florida Statute 370.12(2)(t) and the Florida Manatee Sanctuary Act require that these counties develop Manatee Protection Plans (MPPs) that meet FWC manatee protection criteria (Broward County, 2007). Current county-by-county geographic application of the rules and how the FWC must comply with them is outlined in Florida Statue 379.2431(2)(g) (Broward County, 2007; Marine Mammal Commission, 2007).

Approximately 25% of all documented manatee mortalities in the state of Florida since 1976 were the result from boat collisions (Calleson and Frohlich, 2007). It has been proposed that reduced vessel speeds would allow for increased reaction time, for both vessel operators and the manatees, along with reducing severity of injuries if a manatee is struck by the vessel (Laist, 2006; Lightsey et al., 2006; Calleson and Frohlich, 2007; FWC Manatee Mortality Statistics). The FWC reviews manatee distribution and boating data to make recommendations concerning restriction of the operation and speed of vessels in areas frequented by manatees. These recommendations are then
implemented at the county level. Habitat, critical to manatees’ survival, may also be protected via manatee sanctuary and refuge areas (Allen et al., 2014; Sattelberger et al., 2017). Manatee sanctuary and refuge areas limit or prohibit vessel entry along with other activities allowed in that area. Florida Statue 379.2431(2)(f) establishes protocols for the FWC and county governments in the adoption of these rules regulating motorboat speed and operation (FWC, 2014c).

To prevent canal locks or floodgates and other such structures from closing on and killing manatees, protection devices/safety systems have been developed to detect manatees as they enter these structures. According to Chiang (2008), sound transmitters are installed along the opening edge of the doors in the canal lock with a receiver installed along the opposite door. This manatee safety system activates whenever the gate begins to close. Each transmitter emits a sound wave that is then detected by the receiver when a manatee passes through the lock and blocks some of these sound waves. If three or more of these sound waves are blocked and detected by the receivers, it suggests that a large animal such as a manatee is in the lock and causes the gate to halt its closing movement, allowing the animal to swim through the open gate (Chiang, 2008).

1.5: Hotspots

In wildlife management, there are often finite resources allotted for the conservation of an endangered or protected species. One of the key issues in wildlife conservation is how to allocate limited conservation resources. One method used by conservation researchers is to identify ‘hotspots’ or statistically significant clusters of biogeographic data. It can be used to determine clusters of endemic species, disease outbreaks, mortality, high habitat loss, lack of food and resources, etc. (Myers. et al., 1999). By using a hotspot analysis, researchers can identify statistically significant areas of high incidence versus areas of low incidence in terms of statistical confidence (GIS Lounge, 2014). To mitigate wildlife mortality, the ability to identify statistically significant hotspots of mortality is vital. This allows researchers to focus limited resources on areas where they will have the greatest conservation impact. Mortality hotspot analysis may also identify new areas of concern previously unknown to wildlife managers that may warrant future research.
1.6: Study Significance

The purpose of this study is to provide an overview of temporal and spatial trends of anthropogenic and natural means of manatee mortality in Florida with relation to geographic location and cause of death. Results from this study will aid wildlife managers in the management of this protected species by identifying significant spatial clusters of high values or “hotspots” of manatee mortality and how these hotspots have changed over time. Hotspot patterns can indicate problem areas where wildlife managers can focus efforts through positive management of anthropogenic means of mortality, and provide an increased understanding of where manatees may face greater environmental threats.

Section 2: Methods

2.1: Study Area

The state of Florida is the 22nd largest state for total area in the United States. Florida has a total area of 94,243.185 km² with 87,123.4 km² total land area and 7,119.748 km² total water area (FDOS, 2015). Manatees use both fresh and saltwater habitats in Florida, which include rivers, estuaries, saltwater bays, canals, and coastal areas (FWC, 2017b). Florida has 1926.38 km of coastline and a tidal shoreline of 3,662.87 km. With an estimated population of 19,421,200 people living in 67 counties, Florida is ranked as the fourth most populous state in the United States (FLEDR, 2010). It is estimated that the human population in Florida will reach 20,216,600 by 2020 (FDOS, 2015).
2.2: Data

Data for this study was provided by the FWC’s Fish and Wildlife Research Institute (FWRI), based on manatee mortality information that is made available to the public. Information from recovered manatee carcasses was collected as GIS point data specific to each county in the state of Florida and stored as a shapefile. The spatial distribution of manatee carcasses collected over 38 years (1974-2012) were plotted in ArcGIS with the associated recovery location, date of recovery, size/gender of manatee, and the subsequent cause of death category that was determined from necropsy. All manatee mortality data remains the property of the Florida Fish and Wildlife Conservation Commission, and all maps and reports created are to be submitted to FWC simultaneously with Nova Southeastern University Oceanographic Center.

2.3: Data Analysis

Data analysis employed ArcGIS (version 10.4) as the computational environment. Designed by ESRI, ArcGIS is a comprehensive software system that allows researchers to collect, organize, manage, analyze, communicate, and distribute geographic information. It is used to examine relationships and test predictions in order to solve problems, make better use of resources, and anticipate and manage change.

The manatee mortality shapefile was loaded into ArcGIS as a data layer and then the select attributes feature was used to separate each category of mortality into individual data layers. All of the data maintained the projected coordinated system associated with the shapefiles: WGS 1984 Web Mercator Auxiliary Sphere. In order to identify spatial-temporal hotspots, the data was first structured into a data cube using the “create space-time cube” tool. A spatial-temporal hotspot analysis was run on the resulting input cube via the novel “emerging hotspot analysis” tool. ArcGIS added this analysis tool with the 10.3 update in 2014 and only two journal articles have been published by researchers utilizing this analysis tool. Zhu and Newsam (2016) used the emerging hotspot analysis tool to detect spatio-temporal sentiment/emotion hotspots using geotagged photos. Harris, et al. (2017) used it to determine emerging hotspots of forest loss. To date, there have been no published papers using this analysis tool to determine emerging hotspots of wildlife mortality.
2.4: Space-Time Cube

Using the “create space-time cube” tool in ArcGIS, the data was first structured into Network Common Data Form (NetCDF) data cube (Figure 3). NetCDF is a file format that stores multidimensional scientific data (variables) so that they can be displayed through a dimension, such as time that is displayed in ArcGIS by making a layer from the NetCDF file (ArcGIS, 2016). The “create space-time cube” tool creates the NetCDF data cube by taking the time stamped point features and aggregating them into space-time bins. The structure created is a three-dimensional cube made up of bins that each represent a fixed position in space (x, y) and in time (t). Spatial extent of the cube is determined by the rows and column with time-steps determining the temporal extent. A space-time cube was created using each of the data layers representing a category of manatee mortality as the input feature.

All points within the same time-step interval (temporal component) and a distance interval (spatial component) were aggregated in a bin. This bin represents a specific geographic location for a specific period of time or time-step interval. The time-step is the “time slice” or specific time range that the model will aggregate together into a bin (ArcGIS, 2016). For this analysis, the time-step interval was set to a two-year interval with the time-step alignment set to END_TIME. Time-steps align to the last time event and then aggregated back in time in two-year increments, representing a “time slice” (Figure 4.A.). These “time slices” represent all the geographic data locations during a specific period of time (Figure 4.A.). A distance interval was set at 1000 m based on experience-based recommendation from FWC biologists. All the data points that fall within this 1000 m distance interval were aggregated into a bin, with (x, y) fixed location in space (Figure 4.B.). The generated space-time cube was then analyzed using the emerging hotspot analysis tool.
Figure 4: Space-Time Cube

(A) Each time slice represents a time (t) increment or time-step interval. These time-steps in sequential order create a bin time series.

(B) The (x, y) of each bin is the geographic location of each bin.

2.5: Emerging Hotspot Analysis

The “emerging hotspot analysis” tool was used to identify statistically significant trends in data such as new, intensifying, diminishing, and sporadic hot/coldspots. This analysis was run separately on the following categories of manatee mortality: watercraft collision, perinatal, cold stress, and natural other (including red tide). Based on an error message from the tool, the flood gate/canal lock category of manatee mortality had an insufficient range of data points to create a space-time cube to run in the emerging hotspot analysis tool, thus it was not included in this analysis. Using the space-time NetCDF cube created in the “create space time cube” as the input, the neighborhood distance and neighborhood time step parameter values were used to calculate the Getis-Ord Gi* or Gi* statistic (hotspot analysis) for each of the features or bins relative to its neighboring bins in the space time cube to calculate spatial trends in data, i.e. location and intensity of spatial clustering.

For every manatee mortality data point, an attribute value of one was assigned, indicating one mortality occurred at that location and date. Based on the input parameters, the space-time cube took these attributes values and aggregated all points with a distance interval of 1000 m and a time-step interval of two-years to create a bin. The sum of all the aggregated data attribute values included in the bin is the attribute value for that bin (ArcGIS, 2016). This tool uses the Gi* statistic is a measure the degree of association between the attribute value for each bin ($x_j$) within the space-time cube to the spatial weight or relationship with the attribute values of its neighboring bins ($w_{ij}$) (ArcGIS, 2016; Getis and Ord, 1992). With statistically significant high (or low) attribute values being surrounded by other bins with high (or low) attribute values. It then compares the attribute value for a bin and its neighbors to the mean attribute value of all bins (Figure 5). The Gi* statistic returned for each bin in the dataset is a z-score or standard deviation (ArcGIS, 2016).
Figure 5: Getis-Ord Gi* Equation – For the Gi* statistic equation “feature” refers to bins as it is used in this ArcGIS tool. In this statistic, \( x_j \) is the attribute value for bin \( j \). The spatial weight or relationship between bins \( i \) and \( j \) is \( w_{i,j} \), with the total number of bins equal to \( n \). (Source: http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm)

The z-score is compared to the expected value or null hypothesis of zero, indicating no spatial clustering. If the z-score is different than expected, the result is statistically significant. Statistically significant positive z-scores with a larger value indicates more intense clustering of high values or hotspot. Statistically significant negative z-scores with a smaller value indicates more intense clustering of low values or coldspot. The p-value represents the probability that the observed spatial pattern was created by a random process. A low p-value indicates a low probability that the observed pattern is the result of random processes.

After the Gi* statistic has been computed, hotspot/coldspot trends were analyzed using the Mann-Kendall trend test to detect temporal trends at each spatial location with data against time (Mann, 1945; Kendall and Gibbons, 1990). The Mann-Kendall trend test evaluates data as an ordered time series that seeks correlations between the Getis-Ord Gi value and time for each spatial location by calculating the associated trend z-score and
p-value for each location with data (ArcGIS, 2016). It compares the bin count or value for the first period with the bin value for the second. A result of +1 if the first value is smaller than the second, a result of zero if the two values are tied, and -1 if the first value is larger than second. These results are compared to the expected sum, which is zero indicating no trend in values over time, to determine if the difference is statistically significant. The sign of the z-score indicates if the trend in bin values increases (positive z-score) or decreases (negative z-score). Statistically significant trends have a small p-value.

Using the calculated hotspot z-score and p-value for each bin and the trend z-score and p-value, the emerging hotspot analysis tool classifies each location into one of 17 categories (Zhu and Newman, 2016) (Table 1).
# Table 1: Emerging hotspot analysis category definitions

<table>
<thead>
<tr>
<th>Category #</th>
<th>Pattern Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Pattern Detected</td>
<td>Does not fall into any of the hot or cold spot patterns defined below.</td>
</tr>
<tr>
<td>1</td>
<td>New Hotspot</td>
<td>A location that is a statistically significant hot spot for the final time step and has never been a statistically significant hot spot before.</td>
</tr>
<tr>
<td>2</td>
<td>Consecutive Hotspot</td>
<td>A location with a single uninterrupted run of statistically significant hot spot bins in the final time-step intervals. The location has never been a statistically significant hot spot prior to the final hot spot run and less than ninety percent of all bins are statistically significant hot spots.</td>
</tr>
<tr>
<td>3</td>
<td>Intensifying Hotspot</td>
<td>A location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant.</td>
</tr>
<tr>
<td>4</td>
<td>Persistent Hotspot</td>
<td>A location that has been a statistically significant hot spot for ninety percent of the time-step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over time.</td>
</tr>
<tr>
<td>5</td>
<td>Diminishing Hotspot</td>
<td>A location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering in each time step is decreasing overall and that decrease is statistically significant.</td>
</tr>
<tr>
<td>6</td>
<td>Sporadic Hotspot</td>
<td>A location that is an on-again then off-again hot spot. Less than ninety percent of the time-step intervals have been statistically significant hot spots and none of the time-step intervals have been statistically significant cold spots.</td>
</tr>
<tr>
<td>7</td>
<td>Oscillating Hotspot</td>
<td>A statistically significant hot spot for the final time-step interval that has a history of also being a statistically significant cold spot during a prior time step. Less than ninety percent of the time-step intervals have been statistically significant hot spots.</td>
</tr>
<tr>
<td>8</td>
<td>Historical Hotspot</td>
<td>The most recent time period is not hot, but at least ninety percent of the time-step intervals have been statistically significant hot spots.</td>
</tr>
<tr>
<td>9</td>
<td>New Coldspot</td>
<td>A location that is a statistically significant cold spot for the final time step and has never been a statistically significant cold spot before.</td>
</tr>
<tr>
<td>10</td>
<td>Consecutive Coldspot</td>
<td>A location with a single uninterrupted run of statistically significant cold spot bins in the final time-step intervals. The location has never been a statistically significant cold spot prior to the final cold spot run and less than ninety percent of all bins are statistically significant cold spots.</td>
</tr>
<tr>
<td>11</td>
<td>Intensifying Coldspot</td>
<td>A location that has been a statistically significant cold spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is increasing overall and that increase is statistically significant.</td>
</tr>
<tr>
<td>12</td>
<td>Persistent Coldspot</td>
<td>A location that has been a statistically significant cold spot for ninety percent of the time-step intervals with no discernible trend, indicating an increase or decrease in the intensity of clustering of counts over time.</td>
</tr>
<tr>
<td>13</td>
<td>Diminishing Coldspot</td>
<td>A location that has been a statistically significant cold spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is decreasing overall and that decrease is statistically significant.</td>
</tr>
<tr>
<td>14</td>
<td>Sporadic Coldspot</td>
<td>A location that is an on-again then off-again cold spot. Less than ninety percent of the time-step intervals have been statistically significant cold spots and none of the time-step intervals have been statistically significant hot spots.</td>
</tr>
<tr>
<td>15</td>
<td>Oscillating Coldspot</td>
<td>A statistically significant cold spot for the final time-step interval that has a history of also being a statistically significant hot spot during a prior time step. Less than ninety percent of the time-step intervals have been statistically significant cold spots.</td>
</tr>
<tr>
<td>16</td>
<td>Historical Coldspot</td>
<td>The most recent time period is not cold, but at least ninety percent of the time-step intervals have been statistically significant cold spots.</td>
</tr>
</tbody>
</table>
Section 3: Results

The Emerging Hotspot Analysis was run on four categories of manatee mortality: watercraft-related, perinatal, cold-stressed, and other natural (including red tide). Based on FWC data spanning between 1974 and 2012 used in this analysis, watercraft collision mortality (22.5%) accounted for the highest percentage of manatee mortalities in Florida; followed by perinatal (20.1%), other natural (13.5%), and cold stressed (9.8%) (Figure 6). Across the four categories, the analysis identified five hotspot pattern categories; no pattern detected, new hotspot, consecutive hotspot, sporadic hotspot, and oscillating hotspot (Table 2). Out of the five detected hotspot pattern categories, the areas where consecutive or new hotspot categories were identified are of particular interest to wildlife managers as they indicate areas where emerging hotspot patterns are occurring. Each time-step interval was set to two-years, beginning in 2012, then aggregated back in time in two-year increments, with the total number of time-step intervals varying for each category of manatee mortality included in the analysis.

![Figure 6: Category percentage of total manatee mortalities](image)

No pattern detected indicates that the location was not classified into any of the defined hotspot or coldspot patterns (Table 2). This means there was no statistically significant spatial-temporal pattern detected for these bins. A sporadic hotspot indicates a location that is an intermittent hotspot where less than 90% of the two-year, time-step
intervals have been statistically significant hotspots with no coldspots (Table 2). This means that these locations are sometimes a hotspot. An oscillating hotspot indicates a location that includes time-steps as both hotspots and a coldspots, with the final time-step being a statistically significant hotspot during the final time-step and less than 90% of the two-year, time-step intervals being statistically significant hotspots (Table 2). This indicates that these locations are sometimes a hotspot and sometimes a coldspot. Sporadic and oscillating hotspots signify areas are sometimes hotspots of mortality but what this pattern means cannot be ascertained without further research into events occurring in these locations.

A consecutive hotspot is a location with a single uninterrupted run of statistically significant hotspot bins in the final two-year, time-step interval that has never been a statistically significant hotspot and with less than 90% of all bins being significant hotspots (Table 2). To be classified into this category there has to be a consecutive and continuous run of multiple two-year intervals that occur at the end of the time series. This indicates that these areas have relatively recently become hotspots of manatee mortality. There were six areas where consecutive hotspots were detected among the four categories of manatee mortality analyzed (Figure 7).

A new hotspot is a location where there is a statistically significant hotspot for the last time-step only and has never been statistically significant hotspot before (Table 2). A time-step of two-years was used when aggregating the data into the space-time cube, which created time-step intervals or time slices. A new hotspot indicates that in the final two-year interval, 2011-2012, there existed statistically significant hotspots of new manatee mortality. There were fourteen areas where new hotspots were detected among the four categories of manatee mortality analyzed (Figure 11).

Table 2: Hotspot category patterns detected

<table>
<thead>
<tr>
<th>Category #</th>
<th>Pattern Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Pattern Detected</td>
<td>Does not fall into any of the hotspot patterns defined below.</td>
</tr>
<tr>
<td>1</td>
<td>New Hotspot</td>
<td>The most recent time-step interval is hot for the first time</td>
</tr>
<tr>
<td>2</td>
<td>Consecutive Hotspot</td>
<td>A single, uninterrupted run of hot time-step intervals, comprised of less than 90% of all time-step intervals.</td>
</tr>
<tr>
<td>6</td>
<td>Sporadic Hotspot</td>
<td>Some of the time-step intervals are hot.</td>
</tr>
<tr>
<td>7</td>
<td>Oscillating Hotspot</td>
<td>Some of the time-step intervals are hot, some are cold.</td>
</tr>
</tbody>
</table>
Table 3: Number and percentage of total emerging hotspot category bins detected

<table>
<thead>
<tr>
<th>Pattern Name</th>
<th>Watercraft</th>
<th>Watercraft %</th>
<th>Watercraft</th>
<th>Cold Stress</th>
<th>Cold Stress %</th>
<th>Natural</th>
<th>Natural %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pattern Detected</td>
<td>595</td>
<td>41.2</td>
<td>574</td>
<td>52.7</td>
<td>30</td>
<td>4.3</td>
<td>533</td>
</tr>
<tr>
<td>New Hotspot</td>
<td>27</td>
<td>1.9</td>
<td>124</td>
<td>11.4</td>
<td>83</td>
<td>11.9</td>
<td>30</td>
</tr>
<tr>
<td>Consecutive Hotspot</td>
<td>3</td>
<td>0.2</td>
<td>0</td>
<td>82</td>
<td>11.8</td>
<td>7</td>
<td>0.8</td>
</tr>
<tr>
<td>Sporadic Hotspot</td>
<td>27</td>
<td>1.9</td>
<td>0</td>
<td>7</td>
<td>1.0</td>
<td>13</td>
<td>1.4</td>
</tr>
<tr>
<td>Oscillating Hotspot</td>
<td>793</td>
<td>54.9</td>
<td>392</td>
<td>36.0</td>
<td>495</td>
<td>71.0</td>
<td>336</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1445</td>
<td></td>
<td>1090</td>
<td></td>
<td>697</td>
<td></td>
<td>919</td>
</tr>
</tbody>
</table>

Figure 7: New/consecutive hotspot clusters of manatee mortality

(A), (B), (C), & (D) Highlight new (red), consecutive (blue), and mixed new/consecutive (green) hotspot clusters for each category of manatee mortality
3.1: Watercraft Collision Manatee Mortality Data

Watercraft collision mortalities accounted for 22.5% of the total manatee mortalities in Florida between 1974 and 2012 (Figure 6). For watercraft mortalities, the Emerging Hotspot analysis created 1445 bins (Table 3). The bins were classified into one of five categories based on the pattern detected. No pattern was detected for 41.2% of the bins. The remaining 58.8% of bins were categorized as a new hotspot (1.9%), consecutive hotspot (0.2%), sporadic hotspot (1.9%), or oscillating hotspot (54.9%). These hotspot categories were grouped into twelve clusters along the west and east coasts of Florida.

Eight oscillating hotspot clusters were found in Tampa Bay and on the coasts of Citrus, Manatee/Sarasota, Charlotte/Lee, Indian River/St. Lucie/Martin/Palm Beach, Brevard, Volusia, and Duval counties (Figures 8, 9, 10, 11, 12, 13, 14, & 15). One mixed consecutive/sporadic hotspot cluster located on the coast of Hernando and Pasco County, near New Port Richey (Figure 16). One mixed new/sporadic located in the keys of Monroe County, with a single new hotspot near the top of Key Largo, and a cluster near Duck Key (Figure 17). One mixed oscillating/new hotspot cluster in Indian River County (Figure 18). One new hotspot cluster located near Fernandina Beach in Nassau County (Figure 19).
Figure 8: Watercraft collision manatee mortality hotspot map – oscillating (1 of 8)

Oscillating hotspot cluster identified along the coast of Citrus County, FL.

Figure 9: Watercraft collision manatee mortality hotspot map – oscillating (2 of 8)

Oscillating hotspot cluster identified in Tampa Bay, which includes parts of Pinellas, Hillsbough, and Manatee Counties, FL.
**Figure 10:** Watercraft collision manatee mortality hotspot map – oscillating (3 of 8)

Oscillating hotspot cluster identified on the coast of Manatee and Sarasota County, FL.

**Figure 11:** Watercraft collision manatee mortality hotspot map – oscillating (4 of 8)

Oscillating hotspot cluster identified on the coast and inland bays of Charlotte and Lee County, FL.
**Figure 12:** Watercraft collision manatee mortality hotspot map – oscillating (5 of 8)

Oscillating hotspot cluster identified that span the coasts of Indian River, St. Lucie, Martin, and Palm Beach County, FL.

**Figure 13:** Watercraft collision manatee mortality hotspot map – oscillating (6 of 8)

Oscillating hotspot cluster identified along coast of Brevard County, FL.
**Figure 14:** Watercraft collision manatee mortality hotspot map – oscillating (7 of 8)

Oscillating hotspot cluster identified along the coast of Volusia County, FL.

**Figure 15:** Watercraft collision manatee mortality hotspot map – oscillating (8 of 8)

Oscillating hotspot cluster identified in Duval County, FL.
**Figure 16**: Watercraft collision manatee mortality hotspot map – consecutive/sporadic

Mixed consecutive/sporadic hotspot clusters identified on the coast of Hernando and Pasco County, FL.

**Figure 17**: Watercraft collision manatee mortality hotspot map – new/sporadic

Mixed new/sporadic hotspot cluster identified in the keys of Monroe County, FL.
Figure 18: Watercraft collision manatee mortality hotspot map – oscillating/new

Oscillating hotspot mixed with new hotspot clusters identified in Indian River County, FL

Figure 19: Watercraft collision manatee mortality hotspot map – new

New hotspot cluster identified in Nassau County near Fernandina Beach in Nassau County, FL
3.2: Perinatal Manatee Mortality Data

Perinatal mortalities accounted for 20.1% of the total manatee mortalities in Florida between 1974 and 2012 (Figure 6). For perinatal manatee mortalities, the Emerging Hotspot analysis created 1090 bins (Table 3). The bins were classified into one of three categories based on the pattern detected. No pattern was detected for 52.7% of the bins. The remaining 47.3% of bins were categorized as new hotspot (11.4%) and oscillating hotspot (36.0%). These hotspot categories were grouped into four clusters along the west and east coasts of Florida.

One new hotspot cluster of perinatal mortality was detected around Apalachee Bay (Figure 20). Two mixed new/oscillating hotspot clusters located on the coast and inland bays of Charlotte/Lee and in coastal St. Lucie/Martin counties (Figure 21 & 22). One oscillating hotspot cluster located along the coast of Brevard County (Figure 23).
Figure 20: Perinatal manatee mortality hotspot map – new

New hotspot cluster identified near Apalachee Bay located in Wakulla County, FL

Figure 21: Perinatal manatee mortality hotspot map – new/oscillating (1 of 1)

Mostly new hotspot cluster mixed with oscillating hotspots identified on the coast and inland bays of Charlotte and Lee County, FL
Figure 22: Perinatal manatee mortality hotspot map – new/oscillating (2 of 2)

Mixed new and oscillating hotspot cluster identified in coastal St. Lucie and Martin County, FL

Figure 23: Perinatal manatee mortality hotspot map – oscillating

Oscillating hotspot cluster running along coast of Brevard County, FL
3.3: Cold Stress Manatee Mortality Data

Cold stress mortality accounted for 9.8% of the total manatee mortalities in Florida between 1986 and 2012 (Figure 6). For cold stress manatee mortalities, the Emerging Hotspot analysis created 697 bins (Table 3). The bins were classified into one of five categories based on the pattern detected. No pattern was detected for 4.3% of the bins. The remaining 95.7% of bins were categorized as new hotspot (11.9%), consecutive hotspot (11.8%), sporadic hotspot (1.0%), and oscillating hotspot (71.0%). These hotspot categories were grouped into twelve clusters along the west and east coasts of Florida.

Three new hotspot clusters were detected in Levy County, St. Johns/Flagler County, and near Jacksonville in Duval County (Figure 24 & 25). One oscillating/new hotspot cluster was found along coastal St. Johns and Flagler counties (Figure 26). Three consecutive hotspot clusters are located in the Florida Keys and near Everglades National Park in Monroe County, and the coasts of Palm Beach/Broward/Miami-Dade (Figure 27, 28, &29). Two mixed consecutive/oscillating hotspot clusters were located in Tampa Bay and along the coasts of Palm Beach/Broward/Miami-Dade counties (Figure 30 & 31). Five oscillating hotspot clusters spanning Charlotte/Lee, Lee/Collier, Indian River/St. Lucie/Martin, Brevard/Indian River, and Volusia/Brevard counties (Figure 32, 33, 34, 35, & 36).
Figure 24: Cold stress manatee mortality hotspot map – new (1 of 2)

New hotspot cluster identified in coastal Levy County, FL

Figure 25: Cold stress manatee mortality hotspot map – new (2 of 2)

New hotspot cluster near Jacksonville in Duval County, FL
Figure 26: Cold stress manatee mortality hotspot map – new/oscillating

Mixed new and oscillating hotspot cluster identified along the coast of St. Johns and Flagler Counties, FL.

Figure 27: Cold stress manatee mortality hotspot map – consecutive (1 of 3)

Consecutive hotspot cluster identified near Everglades National Park in Monroe County, FL.
Figure 28: Cold stress manatee mortality hotspot map – consecutive (2 of 3)

Consecutive hotspot cluster identified in the keys of Monroe County, FL.

Figure 28: Cold stress manatee mortality hotspot map – consecutive (3 of 3)

Consecutive hotspot cluster identified along the coasts of Palm Beach, Broward, and Miami-Dade Counties, FL.
Figure 29: Cold stress manatee mortality hotspot maps – consecutive/oscillating (1 of 2)

Mixed consecutive and oscillating hotspot clusters identified in Tampa Bay, which includes parts of Pinellas, Hillsborough, and Manatee Counties, FL

Figure 30: Cold stress manatee mortality hotspot map – consecutive/oscillating (2 of 2)

Mixed consecutive and oscillating hotspot clusters identified spanning the coasts of Palm Beach, Broward, and Miami Dade Counties, FL
Figure 31: Cold stress manatee mortality hotspot map – oscillating (1 of 5)
Oscillating hotspot cluster identified in coastal Charlotte and Lee County, FL

Figure 32: Cold stress manatee mortality hotspot map – oscillating (2 of 5)
Oscillating hotspot cluster in coastal Lee and Collier County, FL
**Figure 33:** Cold stress manatee mortality hotspot map – oscillating (3 of 5)
Oscillating hotspot cluster identified in coastal Indian River, St. Lucie, and Martin Counties, FL

**Figure 34:** Cold stress manatee mortality hotspot map – oscillating (4 of 5)
Oscillating hotspot cluster identified in coastal Brevard and Indian River Counties, FL.
**Figure 35**: Cold stress manatee mortality hotspot map – oscillating (5 of 5)

Oscillating hotspot cluster identified in coastal Volusia and Brevard County, FL
3.4: Other Natural (includes Red Tide) Manatee Mortality Data

Other natural (includes red tide) mortalities accounted for 13.5% of the total manatee mortalities in Florida between 1974 and 2012 (Figure 6). For other natural (includes red tide) manatee mortalities, the Emerging Hotspot analysis created 919 bins (Table 3). The bins were classified into one of five categories based on the pattern detected. No pattern was detected for 58.0% of the bins. The remaining 42.0% of bins were categorized as new hotspot (3.3%), consecutive hotspot (0.8%), sporadic hotspot (1.4%), and oscillating hotspot (36.6%).

These hotspot categories were grouped into six clusters along the west and east coasts of Florida. New hotspot clusters were detected near Apalachee Bay in Wakulla County, Suwanee River in Dixie County, and in Volusia/Seminole counties (Figure 37, 38, & 39). One new/oscillating hotspot cluster located in Tampa Bay, which includes parts of Pinellas, Hillsbough, and Manatee Counties (Figure 40). One oscillating hotspot cluster located inland and coastal areas of Charlotte and Lee County (Figure 41). One mixed new/consecutive/sporadic hotspot cluster detected in Citrus County (Figure 42).
**Figure 36:** Natural other (includes red tide) manatee mortality hotspot map – new (1 of 3)

New hotspot cluster identified near Apalachee Bay in Wakulla County, FL

**Figure 37:** Natural other (includes red tide) manatee mortality hotspot map – new (2 of 3)

New hotspot cluster identified near Suwanee River in Dixie County, FL.
Figure 38: Natural other (includes red tide) manatee mortality hotspot map – new (3 of 3)

New hotspot cluster identified inland, in Volusia and Seminole Counties, FL.

Figure 39: Natural other (includes red tide) manatee mortality hotspot map – new/oscillating

New and oscillating hotspot cluster identified in Tampa Bay, which includes parts of Pinellas, Hillsborough, and Manatee Counties, FL.
Figure 40: Natural other (includes red tide) manatee mortality hotspot map – oscillating

Oscillating hotspot cluster located inland and coastal areas of Charlotte and Lee County, FL

Figure 41: Natural other (includes red tide) manatee mortality hotspot map – mixed

A cluster of consecutive hotspots, a cluster of sporadic hotspots, and one new hotspot located in coastal Citrus County, FL
Section 4: Discussion

The largest disadvantage of using manatee carcass locations to gain further insight concerning trends in mortality is that the animal may not always succumb at the exact location that the carcass is recovered. Manatee carcasses are subject to move with currents, tides, and wind forces acting on them, and may move in any direction. In most cases, where a manatee’s cause of mortality can be determined, it can be speculated that the carcass is in an early state of decomposition, and thus recovered within a shorter amount of time. Carcasses in a later state of decomposition tend to yield less information about pathological findings during necropsy. With this considered, the trends found in this study are subject to further investigation. As this study used a 1000 m distance interval to group and break down trends in mortality, it could be hypothesized that manatee carcasses were also picked up within a 1000 m radius, allowing for a margin of error in the data, but still assuming similar results for the patterns detected by this study.

Out of the five detected hotspot pattern categories, the areas where consecutive or new hotspot categories were identified are of particular interest as they indicate areas that relatively recently become hotspots of manatee mortality by being identified as statistically significant hotspots. A hotspot is statistically significant when the probability that the clustering of high values (manatee mortality) is caused by something other than random processes. Consecutive hotspots are locations where there were statistically significant hotspots detected continuously in multiple, two-year, time-step intervals leading up to the final time-step in the data series. A new hotspot is different from a consecutive hotspot in that at these locations only for the final time-step (last two-years of data series) was there a statistically significant hotspot detected. For new hotspots, the final time-step would span the years 2011 to 2012 indicating that there were statistically significant new manatee mortalities during that time interval.

For watercraft-related mortality, three new and one consecutive hotspot clusters were detected (Figure 7.A.). Based on 2010 Census data, these hotspot clusters overlap areas of higher population density, ranging from 200 to 77,214.4 people per square mile (US Census Bureau, 2017) (Figure 43). This pattern was expected as coastal areas with a higher population density could possibly have higher rates of recreational boating activity relative to areas with lower population density. Ackerman et al. (1995) established a
direct correlation between the number of watercraft-related manatee mortalities and the total number of commercial and recreational watercraft registered in the state of Florida. Florida already ranks number one in the nation for recreational boating registrations and will likely increase as Florida’s population grows (USCG, 2016). The U.S. Census Bureau estimates that Florida’s human population increased 9.6% by 2016 (U.S. Census Bureau, Quick Facts). As the population increases in Florida, the probability for negative interactions between manatees and watercraft may increase due to greater usage of the waterways by recreational boaters. Interestingly, the areas where new and consecutive hotspots were detected overlapped areas identified by Martin et al. (2015) as having lower predicted manatee abundance (Figure 2). This could be due to increased number of watercraft using those areas or possibly changes in manatee protection and speed zones.

![Population Density by Census Tract](image)

**Figure 42:** Florida population density with watercraft-related hotspot clusters highlighted. 2010 Florida population density by census tract with watercraft-related new (red) and consecutive (blue) mortality hotspot clusters highlighted. (Source: U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau)

There were three new hotspot clusters of perinatal mortality detected around Apalachee Bay, Cape Coral, and Port St. Lucie (Figure 7.B.). Since these are usually natural causes of mortality, it was expected that there would be no significant hotspots detected by the emerging hotspot analysis. This unexpected emerging pattern may be the
result of a disease in the area or an increased mortality of adult female manatees that resulted in orphaned manatees. Manatee calves typically stay with their mothers for up to two years and may be unable to survive on their own if they lose their mother (Bonde, 2009).

During cold weather where temperatures reach 20-22 °C, manatees are vulnerable to hypothermia if they cannot reach a warm water refuge. The emerging hotspot analysis identified several clusters of consecutive and new hotspots of cold stress related manatee mortalities (Figure 7.C.). While a natural phenomenon, cold stress related mortalities should have a temporal pattern that correlates to known cold weather events documented by FWC. These hotspots may correlate with two relatively recent cold-related mortality events recorded by FWC during the winters of 2008-2009 (429 mortalities) and 2009-2010 (503 mortalities) (FWC, 2014d). Manatees are dependent on warm water refuges to survive cold winter months and according to Laist et al. (2013) show a strong fidelity to these refuges.

These clusters of consecutive and new hotspots (Figure 7.C.) overlap areas of known manatee warm water refuges (Figure 3). This emerging hotspot pattern may be due to the manatee’s inability to reach these refuges in time, or the deterioration of those sites, habitat degradation, food reduction, human interaction, or increase in water salinity (Sattelberger et al., 2017). These hotspot clusters also overlap areas of higher population density (Figure 44). As previously mentioned, Florida’s population is growing, which leads to increased commercial and residential development statewide. Increased development may block or hinder manatee’s access to these sites, thereby increasing their risks for cold exposure (Laist et al., 2013).
Figure 43: Florida population density with cold-stress hotspot clusters highlighted. 2010 Florida Population Density by Census Tract with cold stress-related new (red) and consecutive (blue) mortality hotspot clusters highlighted. (Source: U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau)

For other natural mortalities, including red tide, several clusters of consecutive and new hotspots were detected around Apalachee Bay, Suwannee River, coastal Citrus County, Tampa Bay, and above Orlando (Figure 7.D.). As a natural cause of mortality, finding several new and one new/consecutive hotspot clusters of manatee mortality was not expected. Two of the areas where hotspot clusters were found, Tampa Bay and area above Brevard, overlapped areas with higher predicted manatee abundance as estimated by Martin et al. (2015) (Figure 45). It is interesting that areas with higher number of manatees overlapped areas with increased mortality due to a natural event such as red tide or disease. This could suggest there were specific events that could be correlated to these hotspots such as the manatee red tide mortality events that occurred in 2002-2003, 2005, 2007, 2013-2014, and 2016.
Figure 44: Distribution map of manatees in Florida with new other natural hotspot clusters highlighted

Distribution map of manatees in Florida with new other natural hotspot clusters in Tampa Bay area and Brevard County circled in red. Predicted abundance values are reported in each plot; colors indicate the abundance level per plot (from 0 to >20 manatees). (Source: modified from Martin et al., 2015)
**Conclusion**

Using existing manatee mortality data collected by FWC, an emerging hotspot analysis was run to identify significant spatial clusters of high values or “hotspots” of manatee mortality and the temporal patterns of these hotspots. In the manatee mortality categories included in the analysis, several consecutive and new hotspot patterns were detected. These patterns indicate emerging hotspot patterns and areas to examine future research efforts by wildlife managers.

In areas identified as consecutive or new hotspots of watercraft-related mortality, these mortalities may be mitigated through positive management of anthropogenic means of mortality such as new manatee speed zones and/or protection areas. There is little research on the relationship between coastal population density and the incidence of recreational boating activity. Further research is necessary, as areas with higher population density could indicate higher boating activity, which could correlate to increased manatee watercraft mortalities.

For natural causes of manatee mortality, such as cold stress and red tide, significant new hotspots were detected in Tampa Bay that was identified by Martin et al. (2015) as having a higher estimated manatee abundance (Figure 2). Areas with higher manatee abundance may correlate to hotspot patterns of natural causes of manatee mortality warranting future research. Some of the cold stress mortalities may possibly be the result of hindered access to warm water refuges (Laist et al., 2013). Laist et al. (2013) compared the carcass recovery location for years 1999-2011 with the distribution of known warm-water refuges and determined that greater protection against cold-stress was provided by springs. As power plant outfalls shut down, protection of natural springs may be the best measure to ensure manatees continue to have access to warm-water refuges during cold weather events.

These emerging hotspots of manatee mortality highlight problem areas where wildlife researchers can focus future research efforts into determining the causes of these emerging patterns. Interventions such as speed zones, manatee protection areas, and measures to protect warm water refuges may help mitigate these anthropogenic and natural causes of manatee mortality.
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