7-28-2014

# Loggerhead Sea Turtle (Caretta caretta) Hatchling Disorientation in Broward County, Florida

Allison Durland Donahou
*Nova Southeastern University Oceanographic Center*, ad1129@nova.edu

NOVA SOUTHEASTERN UNIVERSITY OCEANOGRAPHIC CENTER

# LOGGERHEAD SEA TURTLE (*CARETTA CARETTA*) HATCHLING DISORIENTATION IN BROWARD COUNTY, FLORIDA

By

Allison Durland Donahou

Submitted to the Faculty of
Nova Southeastern University Oceanographic Center
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology and Coastal Zone Management

Nova Southeastern University

July 28, 2014

**TABLE OF CONTENTS**

**SUMMARY OF TABLES AND FIGURES**

**ABSTRACT**

Hatchling disorientation after emergence is a major factor impacting sea turtle populations. This study utilized data from over 1,200 Florida Fish and Wildlife Conservation Commission (FWC) Marine Turtle Disorientation Report forms from years 2006 to 2011 to assess changes in the severity and locations of disorientation events and the impact of municipal beach lighting ordinances. While the FWC forms were completed for all sea turtle species observed, this study focused only on loggerhead sea turtles (*Caretta caretta*). A Disorientation Severity Index (DSI) was derived from the number of hatchlings and the direction of their tracks leaving the nests to evaluate the changes in disorientation over six years in Broward County. The FWC forms provide a much larger database for the analysis of hatchling disorientation patterns and trends than can be derived from the more precise, but labor intensive, Hatchling Orientation Index (HOI) survey method of Witherington et al. (1996). This research differs from prior work by focusing on the information provided in the FWC Marine Turtle Disorientation Report forms; using each individual disorientation to assess changes in the severity of hatchling disorientations over time. Prior work has not used the FWC forms for analysis. Significant differences were found for average DSI between years and locations. Overall, DSI decreased significantly from 2006 to 2011 in Hillsboro Beach, Pompano Beach, Lauderdale-by-the-Sea, Fort Lauderdale, and Hollywood. This might be due to increased compliance with lighting ordinances. In addition, disorientation hotspots were identified and the DSI in these hotspots decreased significantly in central and south Fort Lauderdale, Pompano Beach, and Lauderdale-by-the-Sea. Hotspots were visually identified as R-Zone ranges with higher numbers of disorientations than in other ranges (Fig. 6). Artificial beach illumination is very prevalent in Broward County. However, there was no significant relationship between the number of types of lights that were recorded on the FWC forms and DSI. Disorientations seemed to be clustered within hotspots with known lighting issues. Management strategies should use these analyses to reassess loggerhead recovery plans to reduce disorientation hotspots and increase hatchling recruitment.

**KEYWORDS:** Beachfront lighting, urban sky-glow, ordinances, compliance, R-Zone

## INTRODUCTION

Loggerhead sea turtles (*Caretta caretta*) are globally distributed in temperate and tropical seas. In the Atlantic Ocean, they nest heavily on the southeast coast of the United States, especially on the east coast of Florida (Johnson et al. 1996). Loggerheads are a threatened species and their nesting habitat is essential for their survival (Tomillo et al. 2008). Many factors threaten loggerhead nesting beaches, including coastal squeeze due to development and tourism (Mazaris et al. 2009; Yasué and Dearden 2006). Coastal squeeze is the inability of naturally shifting beaches to shift landward because of coastal development. Beaches are naturally eroded and, in the absence of coastal development, the eroded sand is deposited on the landward side of the beach, essentially shifting the beach. However, this does not occur where there is coastal development and it reduces the amount of beach that is available for sea turtles to utilize for nesting. In 2006, annual counts of loggerhead nests in Florida decreased (Witherington et al. 2009). Since then nesting has shown as increasing trend (Florida Fish and Wildlife Conservation Commission 2013b).

Sea turtle nesting is a sensitive procedure. Female sea turtles can be frightened easily during the nesting process, especially by human disturbance and lights (Johnson et al. 1996; Mazor et al. 2013). Sea turtle nest distribution is negatively related to nighttime ambient light intensities (Mazor et al. 2013). Every two to five years, female sea turtles migrate to their natal beaches to nest (Hart et al. 2010; Lamont 2007). During this process, they crawl several meters onto the beach until they find a suitable nesting site, then they excavate an incubation chamber, lay their eggs, cover the eggs, and camouflage their nests with sand. This whole process can take several hours and is very energy consuming (Fossette et al. 2012). Thus, it is essential that the female sea turtle is not disturbed during this process, as she could return to the ocean without depositing her eggs (Johnson et al. 1996). This is termed a false crawl and they historically occur approximately every other nesting attempt with or without anthropogenic disturbance (Weishampel et al. 2003). Environmental conditions need to be ideal in order for optimal loggerhead survival, especially temperature as it can alter the sex ratio of hatchlings and affects the timing and location of nesting (Mazaris et al. 2012; Pike 2013).

One of the most important aspects of sea turtle survival is the hatchling emergence success; the percent of hatchlings that escape from the nest. Sea-finding by hatchlings is equally as important. Emergence success and hatchling sea-finding are dependent on many factors, some of which are greatly influenced by anthropogenic effects on sea turtle nesting habitat. These can include trampling, poaching, human-made barriers, and the amount of artificial light that reaches the beach (Rizakalla and Savage 2011; Witherington 1992; Sella et al. 2006). Hatchling survival is also negatively affected by natural factors, such as predation by ghost crabs (subfamily Ocypodinae), raccoons (*Procyon lotor*), and various other predatory seabirds and fishes (Peterson et al. 2013; Stewart and Wyneken 2004). All of these negative factors result in an estimated 0.1 to 0.01% hatchling survival rate to maturity (Stewart and Wyneken 2004).

Hatchlings emerge from the nest after 45-75 days of incubation and attempt to crawl to the ocean (Salmon 2006). There are several environmental cues that hatchlings use to orient their crawls seaward. Several studies have suggested that hatchlings use the Earth's magnetic field for seaward orientation (Irwin and Lohmann 2003; Lohmann 1991). Others suggest the use of visual cues, such as movement away from large objects on the horizon and positive phototaxis (Sella et al. 2006; Avens and Lohmann 2003). Due to their presence on the horizon, seawalls and other artificial structures can disorient hatchlings during their seaward crawl (Sella et al. 2006).

Artificial light is especially harmful, as sea turtle hatchlings move towards the brightest part of the horizon. Hatchlings move towards the brightest horizon because the ocean reflects ambient light and is usually the brightest horizon in the absence of artificial light (Bolten and Witherington 2003, 45). In areas where there is little to no anthropogenic influence, hatchlings move directly towards the ocean, which is usually the brightest horizon. However, in urban areas hatchlings tend to move away from the ocean due to the large urban glow or individual lights (Sella et al. 2006). Studies have analyzed sea turtle sensitivity to varying light wavelengths and intensities in order to predict the effects different urban lights have on hatchling orientation (Horch et al. 2008; Witherington and Bjorndal 1991). These studies found that long wavelength light (reds and yellows) is not detrimental to sea turtle orientation because sea turtles are not as sensitive to this light as they are to shorter wavelength light (Horch et al. 2008; Witherington and Bjorndal 1991). City sky-glow has been found to cause hatchlings to disorient (Rusenko et al. 2005). According to Hölker et al. (2010), global light pollution is increasing by six percent annually, which includes increases in density in urban areas and expansion in rural areas.

It is important to monitor both direct and indirect light pollution as both have major indirect effects on hatchling survivorship (Kamrowski et al. 2012). Some studies have analyzed the varying effects of indirect and direct light pollution and have found that disorientation depends on a variety of factors acting in combination with the light sources (Chalkias et al. 2006). One study found that the combination of artificial light and low silhouettes, due to the absence of beach dunes, disrupted crawls (Tuxbury and Salmon 2005). In addition, low frequency wavelength filtered streetlights still attract sea turtle hatchlings and are not a great management strategy (Sella et al. 2006). Streetlights imbedded in the roadways have been suggested for reducing the impact of elevated artificial streetlights on hatchlings and have been put into effect in some areas (Bertolotti and Salmon 2005). However, on overcast nights with little moonlight, these lights still can contribute to urban glow. According to Witherington and Martin (2000), if a light source can be seen by the human eye from the beach then that light source is bright enough to cause disorientation in sea turtles.

Unfortunately, a new emerging technology might ultimately pose a larger threat to sea turtle hatchlings. White light emitting diodes (LEDs) are rapidly replacing traditional incandescent streetlights and are a more intense light than incandescent lights (Gaston et al. 2012). These lights use less energy than incandescent bulbs and last longer ultimately saving the user money. While these new lights are a problem if white LEDs are used, there are alternatives. LEDs are available in a wide variety of colors, including shades of red and yellow. If tuned to the proper wavelength frequency, LEDs could be a turtle-friendly alternative to incandescent lights by minimizing sea turtle hatchling disorientations caused by light pollution. Hatchlings possess many traits which allow them to correctly orient themselves while in the ocean; however, these same hatchlings have a much harder time making it to the water in the presence of artificial lighting

(Avens et al. 2003; Chalkis et al. 2006). In 2000, Broward County instituted a Beach Lighting Management Plan (BLMP) requiring all municipalities to enact a lighting ordinance. As of 2011, all coastal municipalities in Broward County had lighting ordinances in effect (FWC 2013a). However, disorientation of hatchlings is still a major issue in Broward County and there is a need to increase efforts to reduce the occurrence of disorientations (Burney and Wright 2012).

Since 1978, the Broward County Sea Turtle Conservation Program (BCSTCP) has monitored sea turtle nesting on the beaches of Broward County (Burney and Wright 2012). The purposes of this conservation program are:

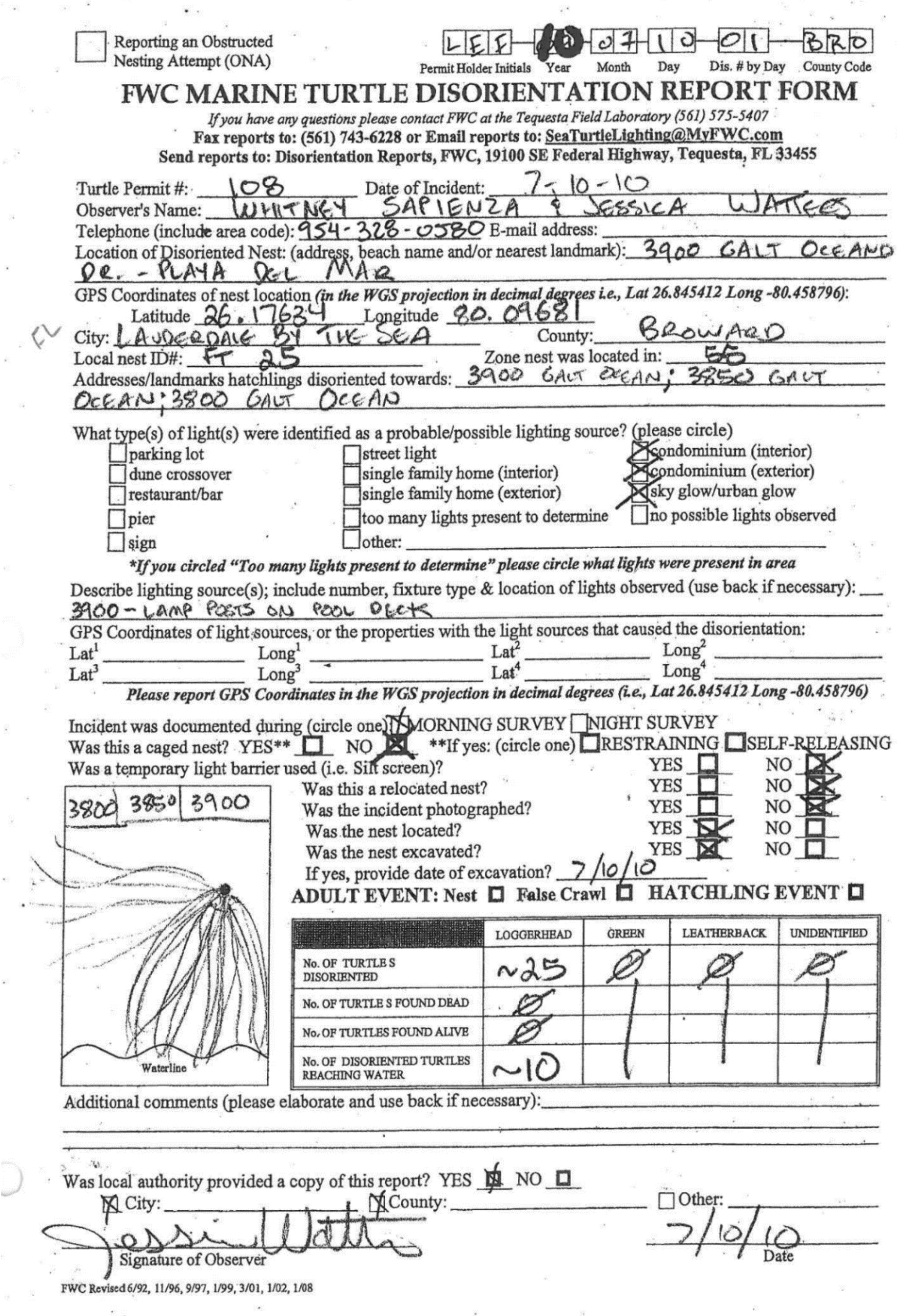
- to maximize hatchling survival;
- to accurately survey sea turtle nesting patterns, to document historical trends and assess natural and anthropogenic factors affecting nesting patterns and densities;
- to assess the success of sea turtle recruitment in terms of nesting success, hatching success, and total live hatchling production; and
- to inform and educate the public about sea turtles and their conservation.

The program managers organize daily beach surveys from March through September, during which workers recorded environmental conditions and other factors that may influence sea turtle nesting or hatching behavior, including the number of types of light sources near the nest.

When hatchling disorientation events are observed, the workers recorded information for the preparation of FWC Marine Turtle Disorientation Report Forms (Fig. 1), which included the estimated number of disoriented hatchlings (from observing the crawl tracks) and a sketch of the event indicating the direction of the tracks relative to the ocean. Both disorientations, events where the hatchling crawls in many directions and may still reach the ocean, and misorientations, events where the hatchling only moves away from the ocean, were recorded on the FWC forms (Tuxbury and Salmon 2005). In this thesis, disorientation refers to both disorientations and misorientations. Each FWC form includes the Department of Natural Resources Monument Zone (“R-Zone”) and municipality in which the disorientation occurred. R-Zones range from R1 to R128 numbered from north to south (Fig. 2). The municipalities, north to south, include Deerfield Beach (R1-R6), Hillsboro Beach (R7-R24), Pompano Beach (R25-R40), Lauderdale-by-the-Sea (R41-R53), Fort Lauderdale (R54-R85), Dania Beach (R98-R100), Hollywood (R101-R124), and Hallandale (R125-R128). R-Zones R86-R97 are within John U. Lloyd Beach State Park, managed by the Florida Park Service, and are not included in this study.

Specific areas of artificial lighting interest are within the selected R-Zones of this study. These areas include the Yankee Clipper Hotel (R80), which had extremely bright lights illuminating the beach, at least until 2008. An area where Highway A1A runs parallel to the beach, the Fort Lauderdale Strip (R64-R80), also contributes to increased beach illumination. In addition, North Beach Park/Hollywood Broadwalk (R100-R102) and the Pompano Pier (R33) were areas of high lighting. Probably the most detrimental light sources to hatchlings were at the Point of the Americas (R83) and the adjacent properties, which comprise a large condominium complex located near the entrance to Port Everglades. These light problem areas were highlighted in the analysis of disorientation hotspot areas within this study.

The purpose of this study was to use the data collected from BCSTCP to measure and analyze hatchling disorientation reports and look for temporal or spatial trends or patterns in order to assess the effectiveness of municipal coastal lighting ordinances and enforcement.



Reporting an Obstructed Nesting Attempt (ONA)

L E F | 10 | 07 | 10 | 01 | BRO

Permit Holder Initials | Year | Month | Day | Dis. # by Day | County Code

**FWC MARINE TURTLE DISORIENTATION REPORT FORM**

*If you have any questions please contact FWC at the Tequesta Field Laboratory (561) 575-5407*

**Fax reports to: (561) 743-6228 or Email reports to: SeaTurtleLighting@MyFWC.com**

**Send reports to: Disorientation Reports, FWC, 19100 SE Federal Highway, Tequesta, FL 33455**

Turtle Permit #: 108 Date of Incident: 7-10-10

Observer's Name: WHITNEY SAPIENZA & JESSICA WATERS

Telephone (include area code): 954-328-0580 E-mail address:

Location of Disoriented Nest: (address, beach name and/or nearest landmark): 3900 GALT OCEAN DR. - PLAYA DEL MAR

GPS Coordinates of nest location *(in the WGS projection in decimal degrees i.e., Lat 26.845412 Long -80.458796)*:

Latitude 26.17634 Longitude 80.09681

City: LAUDERDALE BY THE SEA County: BROWARD

Local nest ID#: FT 25 Zone nest was located in: 55

Addresses/landmarks hatchlings disoriented towards: 3900 GALT OCEAN; 3850 GALT OCEAN; 3800 GALT OCEAN

What type(s) of light(s) were identified as a probable/possible lighting source? (please circle)

- ☐ parking lot
- ☐ dune crossover
- ☐ restaurant/bar
- ☐ pier
- ☐ sign
- ☐ street light
- ☐ single family home (interior)
- ☐ single family home (exterior)
- ☐ too many lights present to determine
- ☐ other:
- ☒ condominium (interior)
- ☒ condominium (exterior)
- ☒ sky glow/urban glow
- ☐ no possible lights observed

***If you circled "Too many lights present to determine" please circle what lights were present in area***

Describe lighting source(s); include number, fixture type & location of lights observed (use back if necessary): 3900 - LAMP POSTS ON POOL DECKS

GPS Coordinates of light sources, or the properties with the light sources that caused the disorientation:

Lat¹ ____ Long¹ ____ Lat² ____ Long² ____

Lat³ ____ Long³ ____ Lat⁴ ____ Long⁴ ____

***Please report GPS Coordinates in the WGS projection in decimal degrees (i.e., Lat 26.845412 Long -80.458796)***

Incident was documented during (circle one) ☒ MORNING SURVEY ☐ NIGHT SURVEY

Was this a caged nest? YES** ☐ NO ☒ **If yes: (circle one) ☐ RESTRAINING ☐ SELF-RELEASING

Was a temporary light barrier used (i.e. Silt screen)? YES ☐ NO ☒

Was this a relocated nest? YES ☐ NO ☒

Was the incident photographed? YES ☐ NO ☒

Was the nest located? YES ☒ NO ☐

Was the nest excavated? YES ☒ NO ☐

If yes, provide date of excavation? 7/10/10

3800 3850 3900

Waterline

**ADULT EVENT: Nest ☐ False Crawl ☐ HATCHLING EVENT ☐**

| | LOGGERHEAD | GREEN | LEATHERBACK | UNIDENTIFIED |
|---|---|---|---|---|
| No. OF TURTLES DISORIENTED | ~25 | Ø | Ø | Ø |
| No. OF TURTLES FOUND DEAD | Ø | \| | \| | \| |
| No. OF TURTLES FOUND ALIVE | Ø | \| | \| | \| |
| No. OF DISORIENTED TURTLES REACHING WATER | ~10 | \| | \| | \| |

Additional comments (please elaborate and use back if necessary):

Was local authority provided a copy of this report? YES ☒ NO ☐

☒ City: ☒ County: ☐ Other:

Jessica Waters 7/10/10

Signature of Observer Date

FWC Revised 6/92, 11/96, 9/97, 1/99, 3/01, 1/02, 1/08

Figure 1. Example of a FWC Marine Turtle Hatchling Incident Report form.


Figure 2. The Department of Natural Resources Monument Zones ("R-Zones") ranging from R1 to R128 north to south.

## PROBLEM

Light pollution negatively affects the population of sea turtles by disorienting sea turtle hatchlings as they attempt to crawl to the ocean. Additional effort is needed to empower management agencies to more completely enforce lighting ordinances in coastal areas throughout Broward County. BCSTCP data analyzed from years 2006 through 2011 was used to determine if the severity of hatchling disorientation events changed temporally and to assess the impact of lighting ordinance enforcement.

## HYPOTHESES

$H_{a1}$: There was an increase over time in the average disorientation severity index between 2006 and 2011 countywide and at known disorientation trouble spots, especially at Lauderdale-by-the-Sea and Point of the Americas.

$H_{o1}$: There has been no change over time in the average disorientation severity index between 2006 and 2011 countywide or at known disorientation trouble spots, such as Lauderdale-by-the-Sea and Point of the Americas.

$H_{a2}$: There was a positive correlation between the number of types of light sources and the severity of hatchling disorientation.

$H_{o2}$: There has been no relationship between the number of types of light sources and the severity of hatchling disorientation.

## METHODS

During the daily BCSTCP beach surveys from 2006 through 2011, BCSTCP workers recorded hatchling disorientation data and noted the types of different artificial light sources. BCSTCP workers made sketches of the direction of observed hatchling tracks relative to the ocean and estimated the total number of hatchlings.

An existing disorientation severity method (Hatchling Orientation Index) developed from Witherington et al. (1996) was considered, which uses the magnetic bearing of hatchling crawl directions and their angles relative to the ocean to calculate the severity of disorientation. This method is labor intensive and it was not possible for a single worker to collect the large quantities of the type of data needed for this study (Wilson 2009). The FWC forms (Fig. 1) provided access to a larger quantity of less detailed data, using less personnel time, totaling over 1,200 reports.

Since the disorientation data from the FWC forms was not suitable for analysis by the Witherington et al. (1996) method, a simple empirical Disorientation Severity Index (DSI) was developed. The directional severity was estimated by analyzing the sketch of the hatchling crawls from the FWC forms and assigning numbers one through three based on the direction of the majority of the crawls. All of the FWC forms were not completed by the same BCSTCP worker, thus the sketches of the crawls varied. This could have confounded the results of this analysis; however, the disorientation index system was designed to offset this potential bias. If most of the hatchlings crawled to the water then a severity index of “1” was assigned (Fig. 3a), and if all the hatchlings crawled away from the water, then the disorientation was assigned a “3” for high severity (Fig. 3c), while intermediate cases were assigned a severity of “2” (Fig. 3b). A severity index of three would be mostly misorientations, while a severity index of two would be disorientations. The number of disoriented hatchlings from each report was assigned to one of eleven groups as shown in Table 1.

a. b. c.

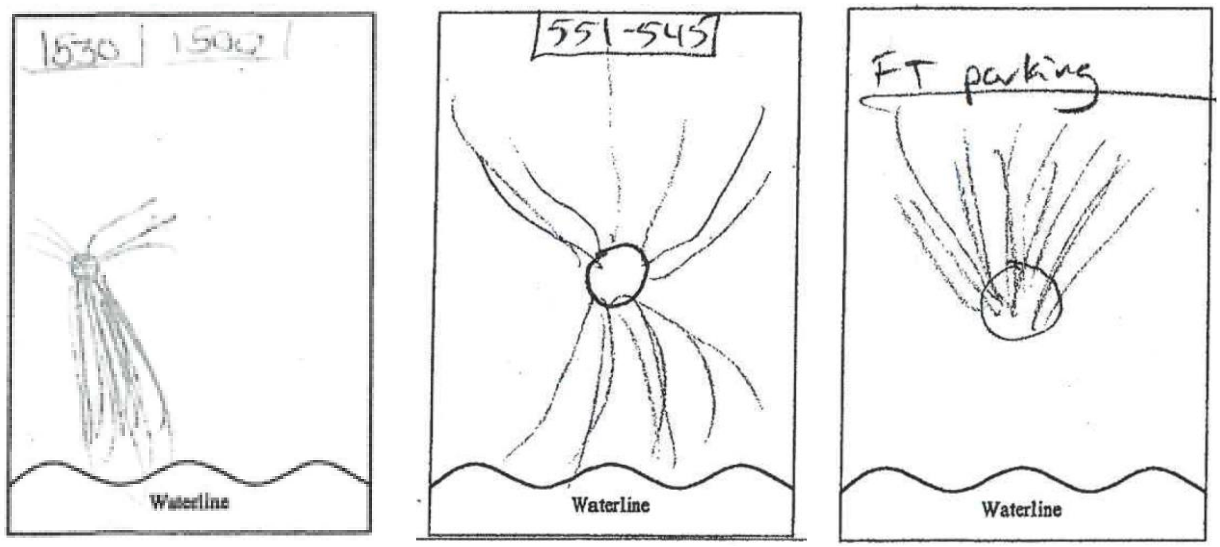



Figure 3. Example of a FWC Marine Turtle Hatchling Incident Report form with moderate (a), intermediate (b), and severe (c) disorientation.

| Table 1: Hatchling Index Group Number | |
|---|---|
| Number of Disoriented Hatchlings | Hatchling Index Group Number |
| 1-10 | 1 |
| 11-20 | 2 |
| 21-30 | 3 |
| 31-40 | 4 |
| 41-50 | 5 |
| 51-60 | 6 |
| 61-70 | 7 |
| 71-80 | 8 |
| 81-90 | 9 |
| 91-100 | 10 |
| 101+ | 11 |

The DSI was determined by multiplying the hatchling index group number by the directional severity number. For example, if fifteen hatchlings all crawled away from the water, the incident would be given a hatchling index group number of two and a severity of three, resulting in a DSI score of six. The DSI can range from 1-33 under this scoring framework.

In addition, the number of light source types was reported on the FWC forms and was enumerated based on the BCSTCP worker observations, with a maximum of eleven. The number of different types of lights, such as "street light" and "parking lot", rather than the total number of light sources is reported on the FWC forms. There are eleven categories of types of lights which a BCSTCP worker could choose from on these forms (Fig. 1). In the analysis, the number of categories chosen was the light index and was analyzed to determine if there was any correlation between the number of types of light sources and the DSI. For example, if a BCSTCP worker chose "street light", "parking lot", and "pier" then the number of types of lights would be three. However, if the category "too many lights present to determine" was chosen then the disorientation was automatically assigned a light index of eleven.

Annual DSI averages were calculated countywide and for each municipality to look for significant annual temporal trends with regression and correlation analysis. DSI changes over time were evaluated and disorientation trouble spots were identified from the clustering of incidents in certain areas. Distributions of severe disorientation events, where most hatchlings crawled away from the ocean (Fig. 3c), were analyzed to highlight areas with more severe disorientation problems. In addition, changes in DSI values between years for each of the 128 R-Zones of Broward County were evaluated using correlation and ANOVA analyses. Wilcoxon/Kruskal-Wallis ANOVA tests were run to compare the individual DSI values within each municipality between years, the individual DSI between R-Zones within each year, and the disorientation severity by number of light source types within each year. A Tukey-Kramer HSD test was used to identify where the significance was for each of these tests. Significance was assessed at $P=0.05$. Relationships between annual trends in DSI and number of types of light sources recorded on the FWC reports were visually assessed.

## RESULTS

*Yearly DSI Trends by Municipality*

The average DSI per year decreased from 2006 to 2010 with a slight increase in 2011 (Fig. 4). ANOVA testing indicated a significant difference in the average DSI per year (P=0.0456, N=1142). The year 2010 was significantly lower than all years except 2011. Average DSI in 2011 was also significantly lower than in 2006 and 2007. The municipalities with the highest and lowest average DSIs varied by year (Table 2). Hillsboro Beach and Dania Beach had (or tied for) the lowest and highest values, respectively, in four of the six years. Figure 5 shows that there were overall downward yearly average DSI trends in all but one of the municipalities (Dania Beach, Fig. 5f). These declines were statistically significant in four of the five municipalities which had data for all six years (Fig. 5b,c,d,e). To confirm the yearly trends, linear regressions were also run using all of the individual DSI values available for each municpality per year (Table 3). The significant relationships cited above were all significant using the individual DSI values. The slope of the relationships in Hollywood and Hallandale were significant with the regressions using the raw data (individual DSI), but these are not considered reliable due to the smaller number of DSI reports from these areas (Table 3). The majority of the average DSIs by year was less than fifteen, except in Deerfield Beach (Fig. 5a) and Dania Beach (Fig. 5f).

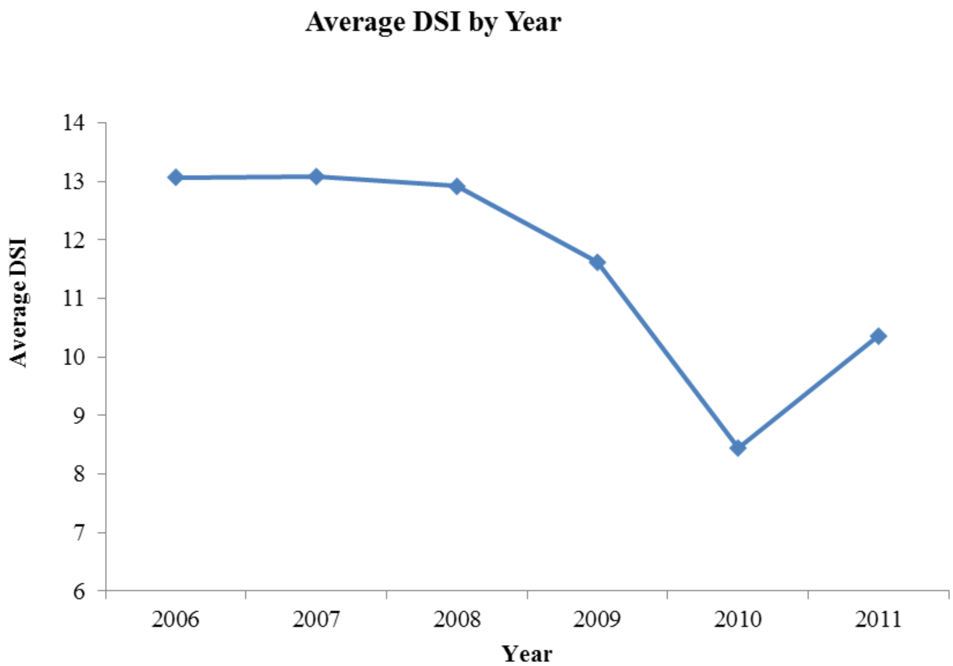
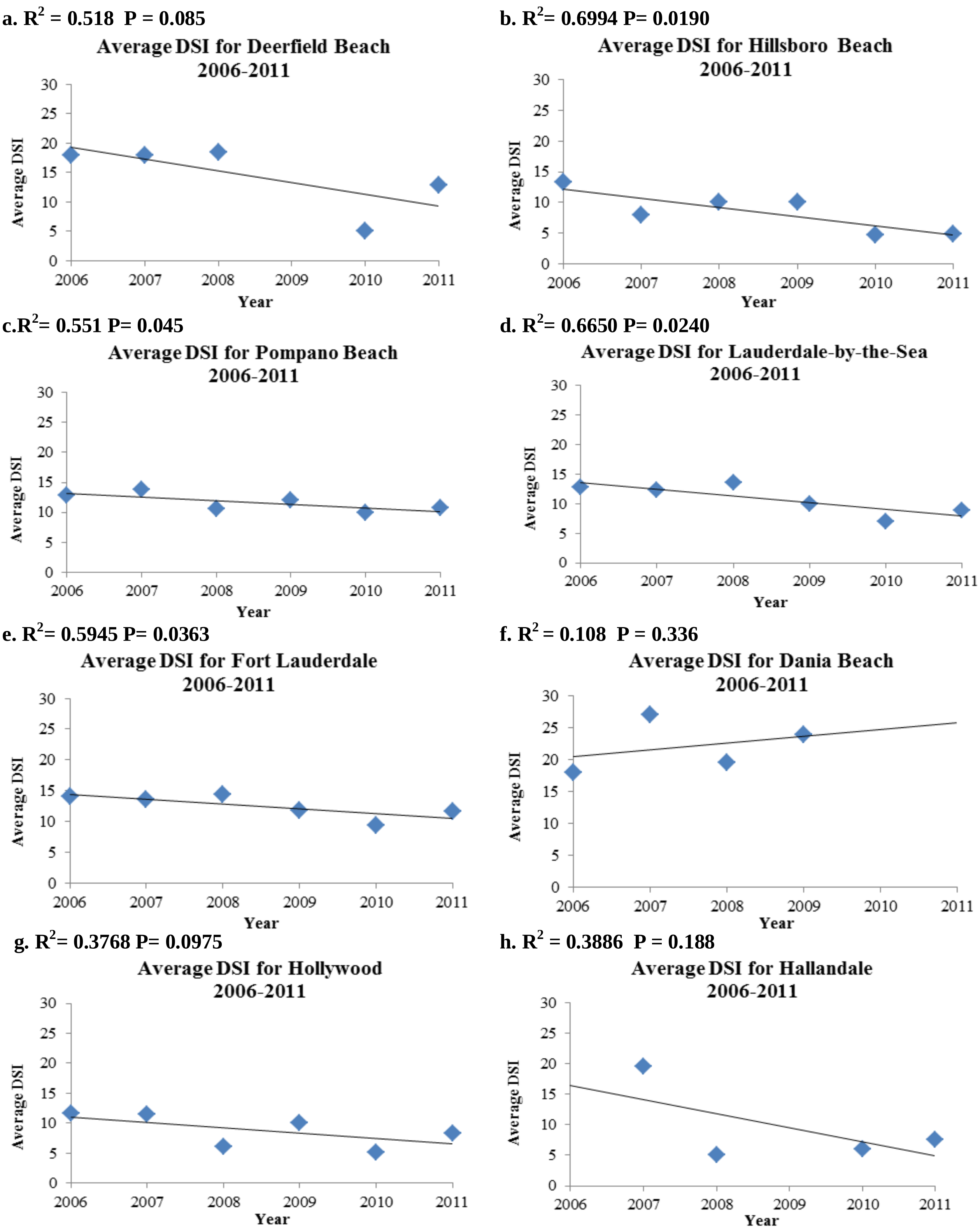



Figure 4. Average disorientation severity index (DSI) by year from 2006 to 2011.

Table 2: Locations and values of the maximum and minimum average DSI scores in Broward County from 2006 through 2011.

| Year | Minimum Average DSI | | Maximum Average DSI | |
|---|---|---|---|---|
| 2006 | 11.7 | Hollywood | 18.0 | Dania Beach, Deerfield Beach |
| 2007 | 8.0 | Hillsboro Beach | 27.0 | Dania Beach |
| 2008 | 5.0 | Hallandale | 19.5 | Dania Beach |
| 2009 | 10.0 | Hillsboro Beach, Lauderdale-by-the-Sea, Hollywood | 24.0 | Dania Beach |
| 2010 | 4.7 | Hillsboro Beach | 10.0 | Pompano Beach |
| 2011 | 4.9 | Hillsboro Beach | 12.8 | Deerfield Beach |




Figures 5a-h. Average disorientation severity index trends for each municipality from 2006 to 2011.

| Table 3: Summary of yearly DSI trends in Broward County municipalities by linear regression using yearly average DSI and all individual DSI scores for each year. (*, $P < 0.05$) Lauderdale-by-the-Sea (LBTS) | | | | | | |
|---|---|---|---|---|---|---|
| Municipality | Yearly Average DSI | | | All Individual DSI Scores | | |
| | $R^2$ | N | P | $R^2$ | N | P |
| Deerfield Beach | 0.5184 | 5 | 0.0851 | 0.1234 | 13 | 0.8203 |
| Hillsboro Beach | 0.6994 | 6 | 0.0190* | 0.1921 | 36 | 0.0075* |
| Pompano Beach | 0.5551 | 6 | 0.0446* | 0.0213 | 321 | 0.0088* |
| LBTS | 0.6650 | 6 | 0.0240* | 0.0342 | 338 | 0.0006* |
| Fort Lauderdale | 0.5945 | 6 | 0.0363* | 0.0233 | 367 | 0.0033* |
| Dania Beach | 0.1077 | 4 | 0.3359 | 0.0200 | 5 | 0.8203 |
| Hollywood | 0.3768 | 6 | 0.0975 | 0.0940 | 50 | 0.0303* |
| Hallandale | 0.3886 | 4 | 0.1883 | 0.3977 | 13 | 0.0208* |

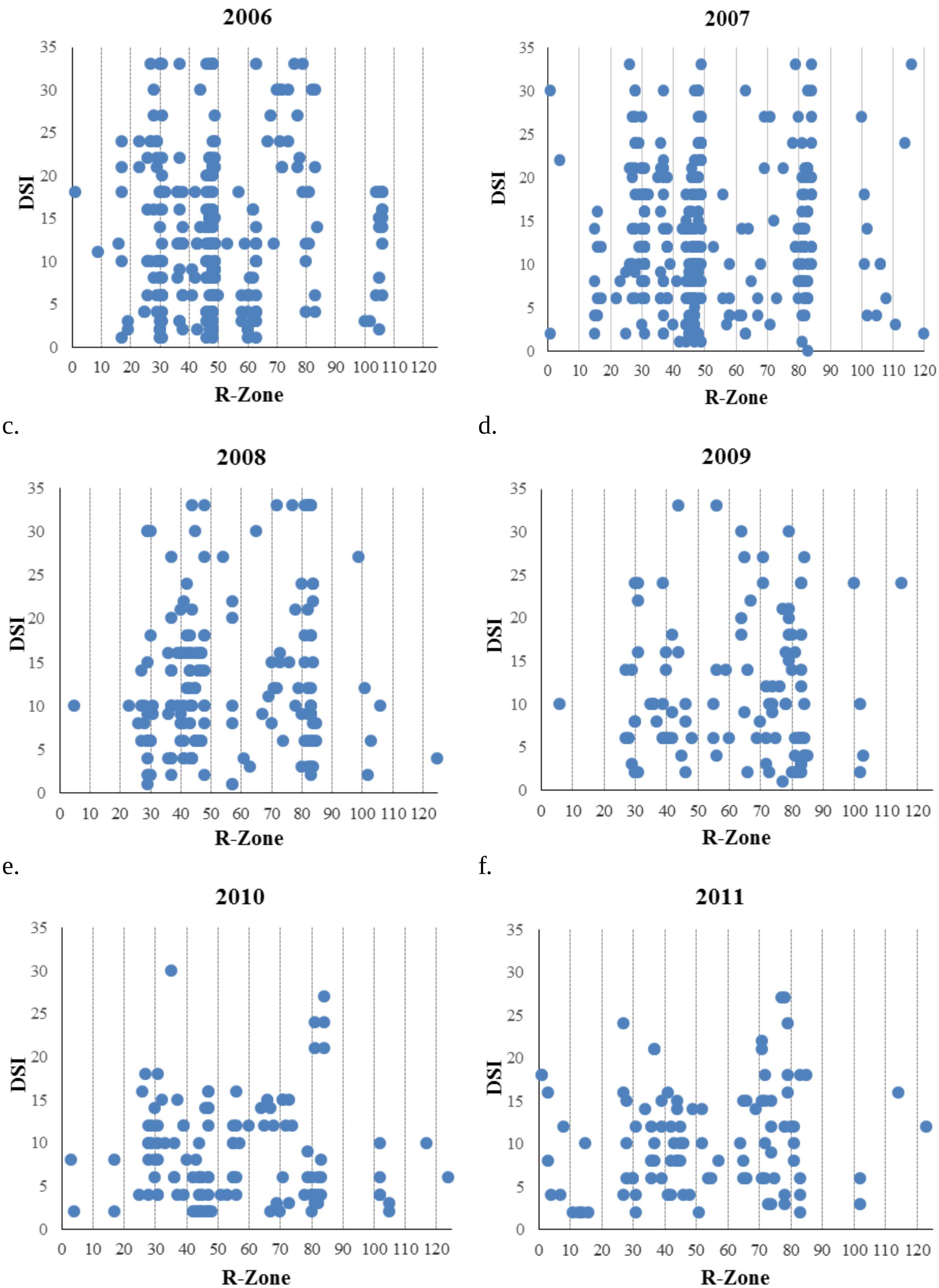
*Hotspots*

Figures 6a-f show distinct horizontal groupings in the distributions of individual DSI values in the 128 R-Zones across Broward County. The intensity of these clusters decreased in the later years, becoming less distinct from 2006 to 2011 (Table 4). In 2006, there was a wide range in the magnitudes of the DSIs in all R-Zone clusters. There were no disorientation reports south of R-Zone 106, probably due to nest relocation by BCSTCP (Fig. 6a). In 2007, the R-Zones 70-85 grouping was more concentrated around R-Zones 78-85. Unlike the rest of the years, there were also several disorientations in R-Zones 120-128 (Fig. 6b). Overall, the groupings were less visible in 2008 than previous years. There was still a grouping from R-Zones 70-85 with the larger and more numerous DSIs in the R-Zone 78-85 range (Fig. 6c). The groupings virtually disappeared in 2009. However, there was still a small cluster of DSIs in R-Zones 77-85 (Fig. 6d). The DSI in 2010 and 2011 (Figs. 6e,f) had smaller, less distinct clusters and overall lower DSI scores. Eight disorientation hotspots identified from Figure 6 are summarized in Table 4 with estimates of their relative strengths for each year. General descriptions of the coastal development and the municipalities of the hotspots are given in Table 5.

| Table 4: Strength of the DSI by R-Zone clusters by year identified from Figure 6. Cluster was identified as strong if there was a large amount of data clustering in the R-Zone range and weak if there was very little or no clustering in the range. ("-", there were no data for the R-Zone range in that year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Disorientation Clusters by R-Zone | | | | | | | |
| | R26-31 | R36-41 | R43-49 | R55-63 | R64-69 | R70-85 | R100-111 | R114-127 |
| 2006 | Strong | Medium | Strong | Weak | Weak | Strong | Medium | - |
| 2007 | Strong | Medium | Strong | Weak | Weak | Strong | Medium | Medium |
| 2008 | Medium | Weak | Medium | Weak | Weak | Strong | Weak | Weak |
| 2009 | Weak | Weak | Weak | Weak | Weak | Medium | Weak | - |
| 2010 | Weak | Weak | Weak | Weak | Weak | Weak | Weak | Weak |
| 2011 | Weak | Weak | Weak | Weak | Weak | Weak | Weak | Weak |

| Table 5: The locations and descriptions of eight disorientation hotspots identified from Figure 6. | | | |
|---|---|---|---|
| Hotspot | R-Zone Range | Municipality | Description |
| 1 | 26-31 | Pompano Beach | Starts just south of Hillsboro inlet. Ends just north of Pompano Pier. Considerable high-rise development. |
| 2 | 36-41 | Pompano Beach, Lauderdale-by-the-Sea | Just south of Pompano Pier. Mixed low-rise and high-rise development. |
| 3 | 43-49 | Lauderdale-by-the-Sea | Just north of Commercial Boulevard Pier. Mixed low-rise and high-rise. |
| 4 | 55-63 | Fort Lauderdale | Very high-rise condos in north. Low-rise single family homes in south. Galt Ocean Mile. |
| 5 | 64-69 | Fort Lauderdale | A1A is right next to beach. Low-rise single family homes and state park. Fort Lauderdale Strip. |
| 6 | 70-85 | Fort Lauderdale | A1A is right next to beach. High-rise and heavily developed. Fort Lauderdale Strip. Point of the Americas. Yankee Clipper. |
| 7 | 100-111 | Hollywood | Low-rise housing and park. North Beach Park/Hollywood Broadwalk. |
| 8 | 114-127 | Hollywood, Hallandale | Mixed low-rise and high-rise. South of Broadwalk. |

a. b.



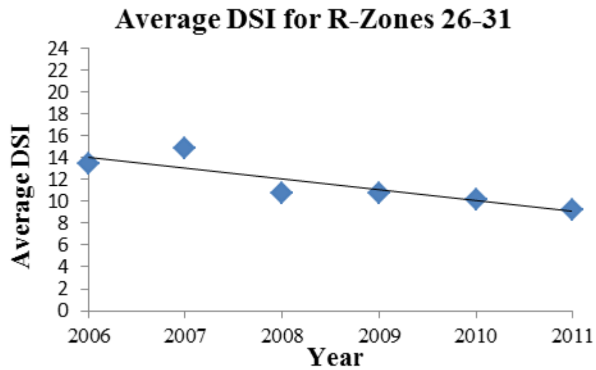

Figures 6a-f. Distribution of disorientation severity index by R-Zones for each year, 2006 to 2011.

Figure 7 shows significant declining trends in average yearly DSI in five of the eight disorientation hotspots. The yearly trends at hotspot numbers two and eight (Figs. 7b,h) had negative slopes that were not significantly less than zero and hotspot four (Fig. 7d) had a flat trend. The comparison of regression results using yearly averages and all individual values for each year (Table 6) shows that although the $R^2$ values for the latter analysis were much lower, due to the increased degrees of freedom, all trends with yearly averages were also significant using the individual values.

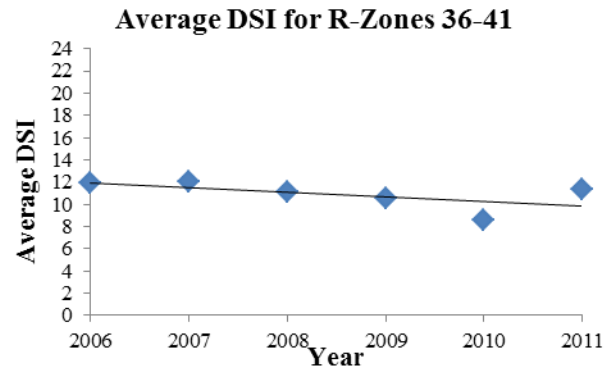
Table 6: Summary of yearly DSI trends at disorientation hotspots by linear regression using yearly average DSI and all individual DSI scores for each year. (* P < 0.05)

| Hotspot | Yearly Average DSI | | | All Individual DSI Scores | | |
|---|---|---|---|---|---|---|
| | $R^2$ | N | P | $R^2$ | N | P |
| 1) R26-31 | 0.7532 | 6 | 0.0125* | 0.0380 | 189 | 0.0036* |
| 2) R36-41 | 0.3565 | 6 | 0.1054 | 0.0094 | 114 | 0.1523 |
| 3) R43-49 | 0.5485 | 6 | 0.0461* | 0.0289 | 312 | 0.0013* |
| 4) R55-63 | 0.0028 | 6 | 0.4603 | 0.0097 | 73 | 0.2034 |
| 5) R64-69 | 0.5961 | 6 | 0.0360* | 0.0822 | 36 | 0.0450* |
| 6) R70-85 | 0.6758 | 6 | 0.0223* | 0.0796 | 251 | <0.0001* |
| 7) R100-111 | 0.8000 | 6 | 0.0081* | 0.1576 | 44 | 0.0038* |
| 8) R114-127 | 0.0100 | 5 | 0.4253 | 0.1198 | 21 | 0.0622 |

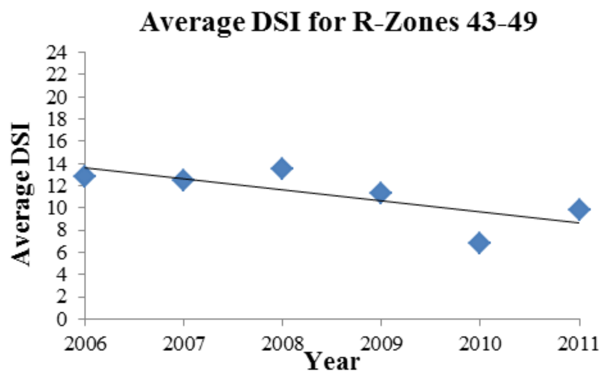
a. Hotspot 1: $R^2$= 0.7532 P= 0.0125



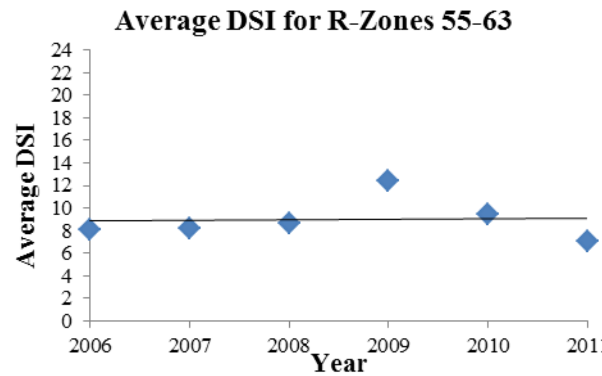

b. Hotspot 2: $R^2$= 0.3565 P= 0.1054



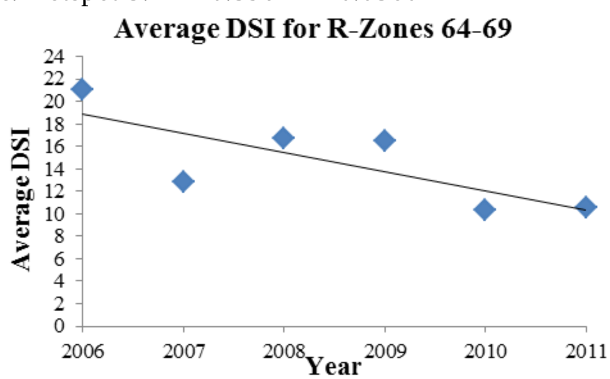

c. Hotspot 3: $R^2$= 0.5485 P= 0.0461



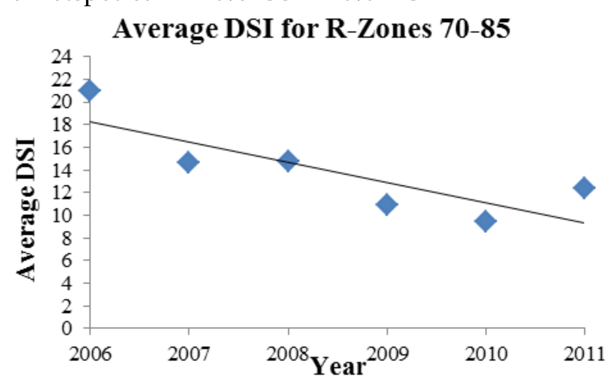

d. Hotspot 4: $R^2$= 0.0028 P= 0.4603



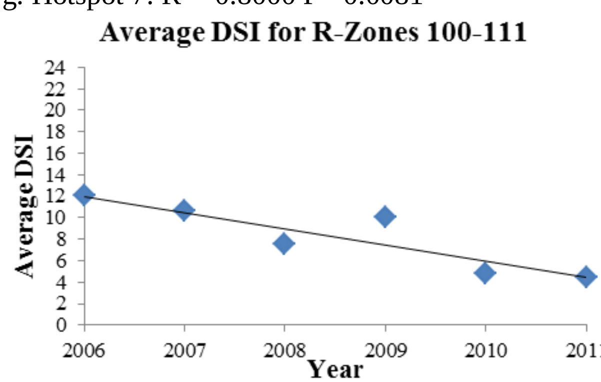

e. Hotspot 5: $R^2$= 0.5961 P= 0.0360



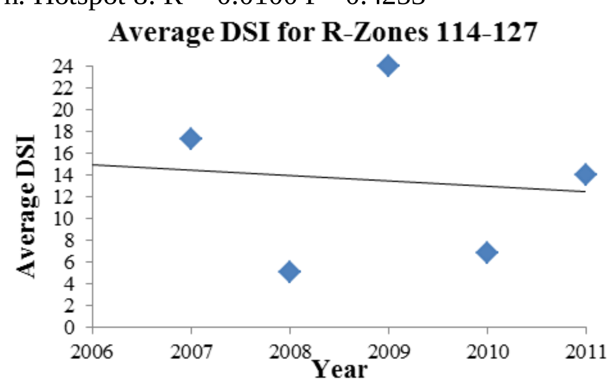

f. Hotspot 6: $R^2$= 0.6758 P= 0.0223




g. Hotspot 7: $R^2$= 0.8000 P= 0.0081



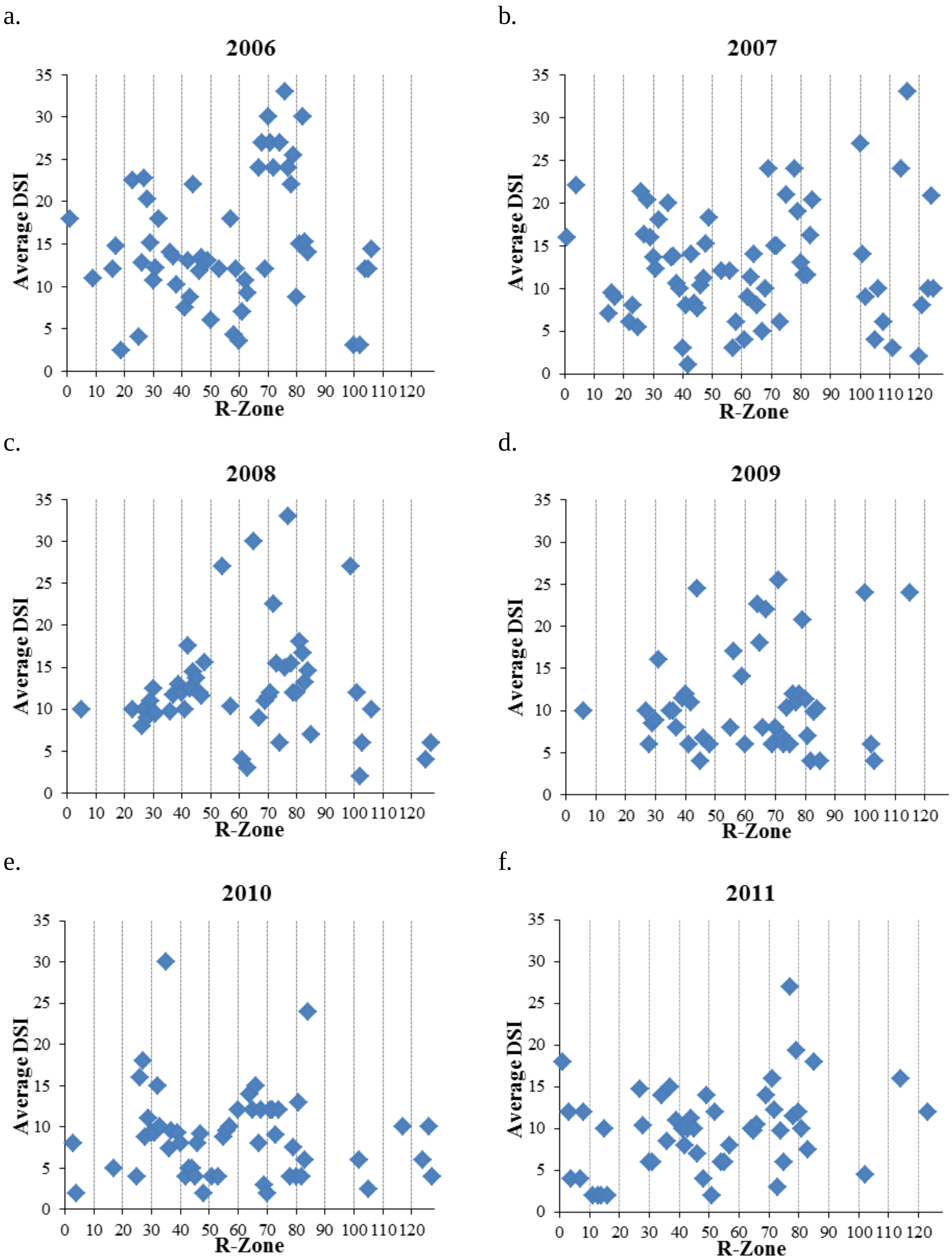

h. Hotspot 8: $R^2$= 0.0100 P= 0.4253




Figures 7a-h. Average disorientation severity index for each hotspot from 2006 to 2011.

*Average Zonal DSI*

The patterns of average DSI for each R-zone (Fig. 8) appear different than those of the individual DSI values (Fig. 6), because the wide range of DSI values in the hotspots resulted in intermediate averages. However, Figure 8 highlights the areas with consistently high DSI scores. In 2006, there was a grouping of average DSI values greater than twenty in R-Zones 67-82 (Fig. 8a), which overlapped hotspots five and six (Table 5) on the Fort Lauderdale Strip. There were fewer high values in this area in later years, but even 2010 and 2011 had one or two high values just north or south of R80. Elsewhere, there were several high average DSI scores between R-Zones 100-128 in 2007 (Fig. 8b), but this was not apparent in any other year. In the R20-R40 area (Figs. 7a,b) there were average DSI values greater than twenty during the first two years, which were not obvious in later years. In 2010 and 2011, only one or two R-Zones had average DSIs higher than twenty.



Figures 8a-f. Distribution of average disorientation severity index by R-Zone for each year, 2006 to 2011.

*Distribution of Severe Disorientations*

In an attempt to more clearly highlight areas with severe disorientation problems, the distributions of disorientation events with severity indices of three (Fig. 3c) were analyzed separately. The number of severe disorientation reports decreased markedly from 2006 to 2011 (Fig. 9). The percentage of severe disorientation events (Fig. 10) compared to the total number of reported events in each R-zone (Fig. 11) illustrates the zones with 100% severe disorientations. In 2006 (Fig. 10a), a cluster of zones between R67-R82 experienced 100% severe disorientations. There were several 100% severe disorientation zones in this area in all the other years. While there were other scattered instances of 100% severe disorientation, this did not occur consistently in other areas. Figure 11 also shows that the areas which experienced 100% severe disorientations also had relatively low numbers of total disorientation reports, but this was not always the case. In 2008, between R80-R81 there were a total of seven disorientation reports, all of which indicated severe disorientation. In R82, there were thirteen reports with eight severe disorientation events.

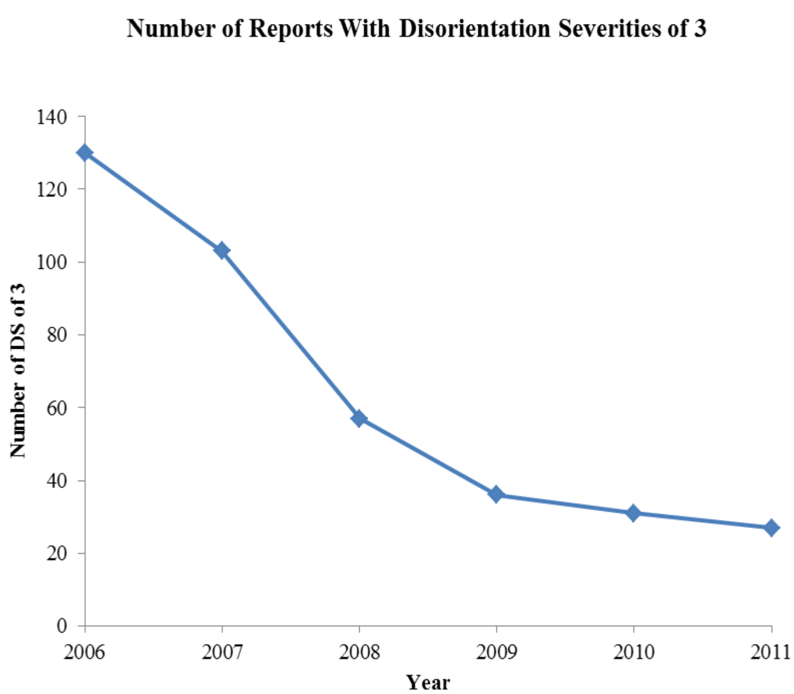
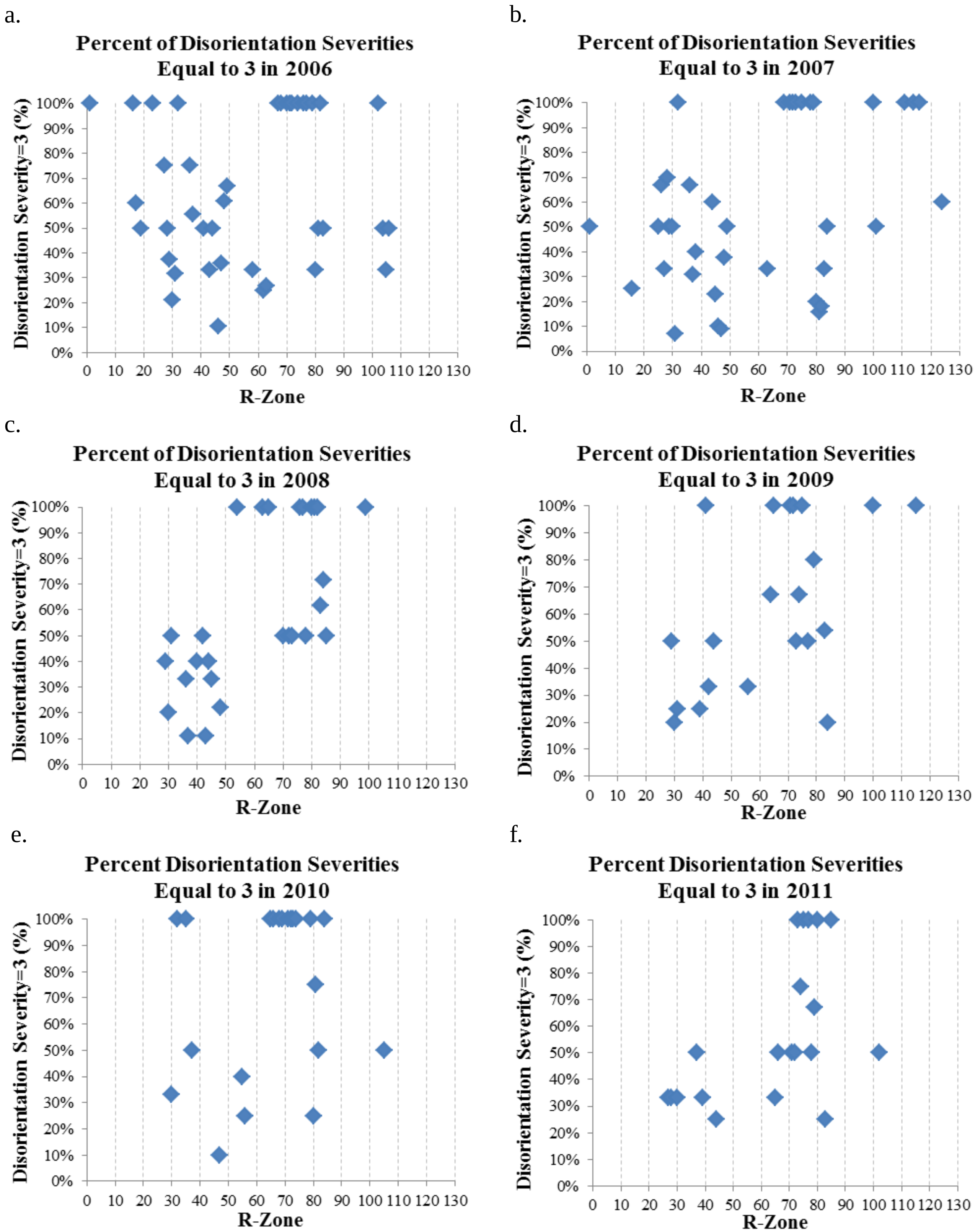



Figure 9. Number of reports with disorientation severities equal to three for years 2006 to 2011.




Figures 10a-f. Percent disorientation severities equal to three per R-Zone for years 2006 to 2011.

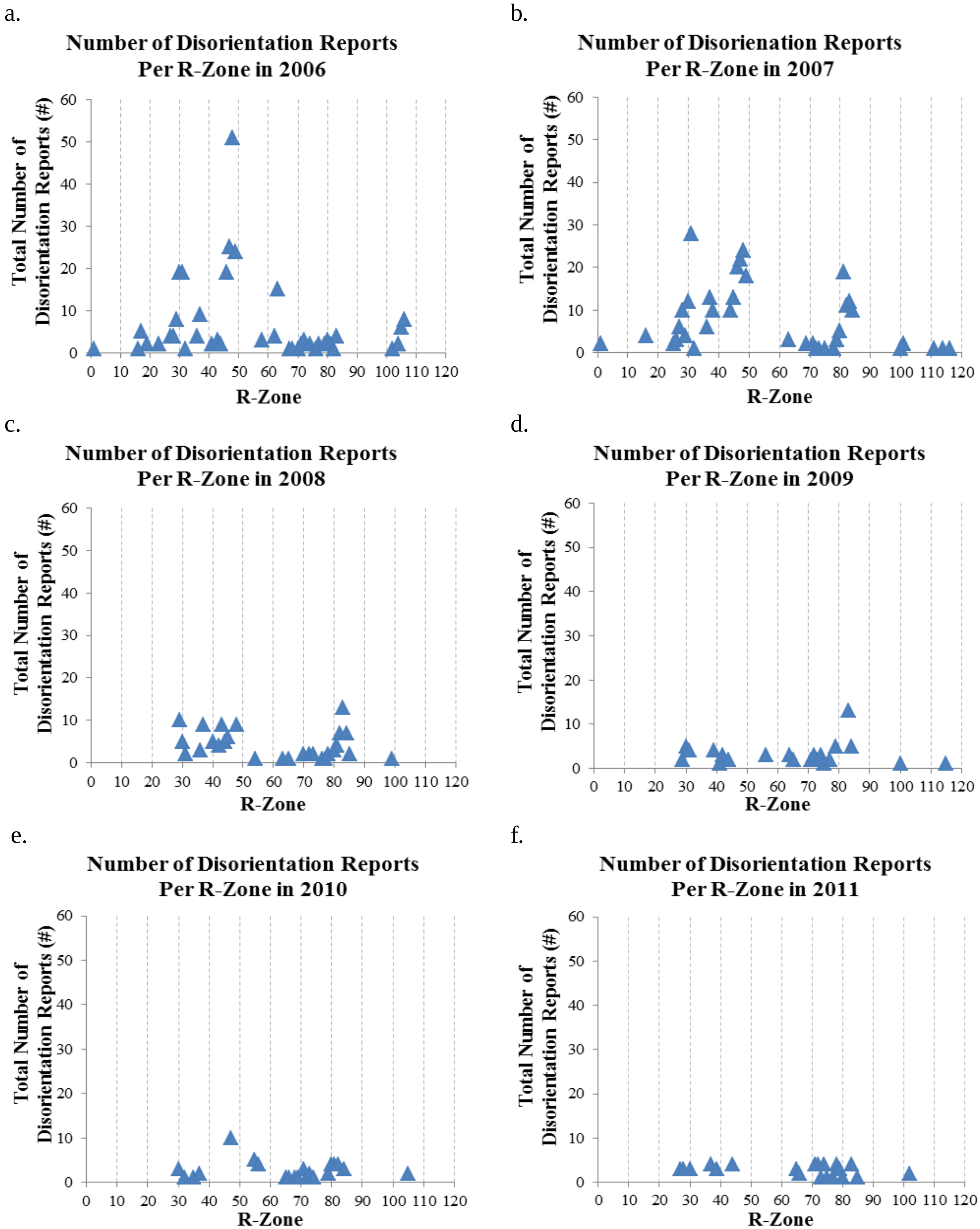


Figure 11a-f. Total number of disorientation reports per R-Zone for years 2006 to 2011.

*Number of Types of Light Sources*

The average number of types of light sources in coastal Broward County increased from 2006 to 2007 and has stayed relatively steady, around nine to ten light source types, with slight fluctuations between years (Fig. 12). There is a slight positive correlation between the average number of types of light sources and the year (R=0.6700). However, the relationship was not significant (P=0.1453). Figure 12 shows that the average number of light source types in the individual municipalities generally increased over the duration of this study. Lauderdale-by-the-Sea and Pompano Beach (Fig. 13d,e) showed patterns similar to the countywide pattern (Fig. 12), with large increases in 2007 followed by only minor fluctuations. The Hollywood pattern (Fig. 13c) was also similar, except for a decline from 2009 to 2011. Additionally, Fort Lauderdale (Fig. 13a) was also similar to the countywide pattern, but had a smooth increase until 2009. Unlike the other municipalities, the average number of types of light sources in Hillsboro Beach fluctuated widely, but this was due to the low number of disorientation reports filed from that area (Fig. 13b). Data from Deerfield Beach, Dania Beach, and Hallandale are not shown in Figure 13 because of the lack of data for some years and the low overall number of reports. Statistical comparisons of the average number of types of light sources between municipalities and years was hampered by the presence of the "too many lights present to determine" category on the FWC Marine Turtle Disorientation Report form (Fig. 1).

Comparison of the patterns of yearly average DSI (Fig. 5) and the average number of light source types showed no obvious relationships. Generally, average DSI decreased slightly over time, with almost linear declines in five of the eight locations. However, the average number of light source types generally increased initially and then showed minor fluctuations, with only Hollywood showing some evidence of a decline in the latter two years.

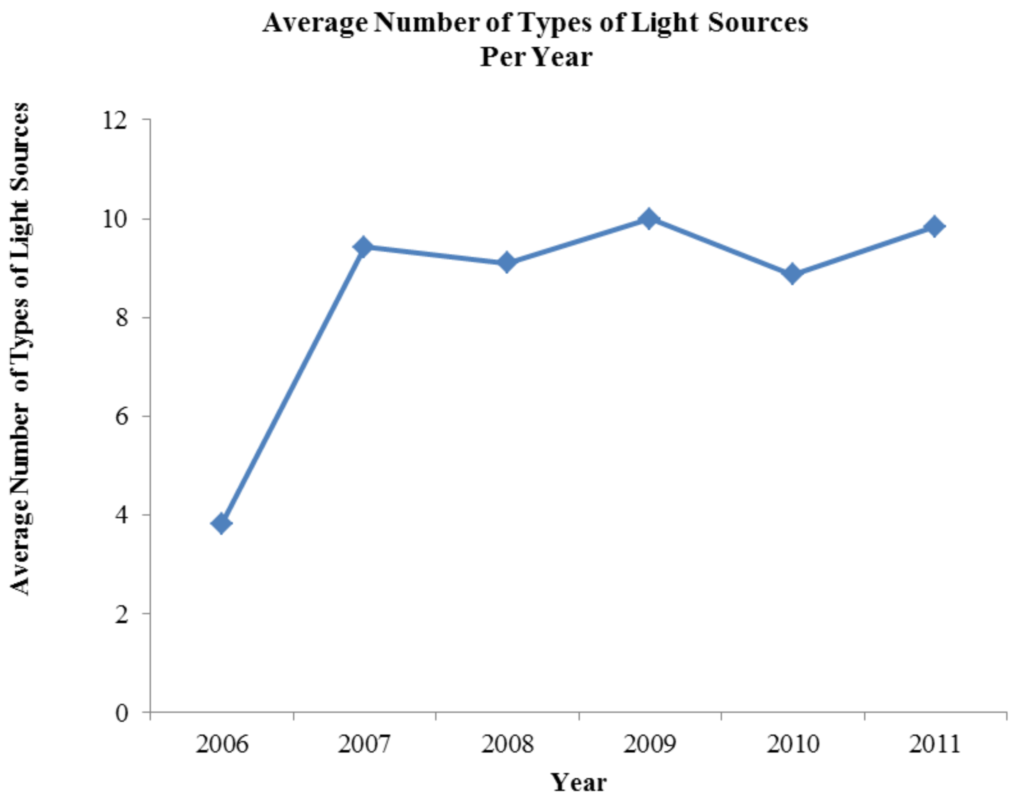
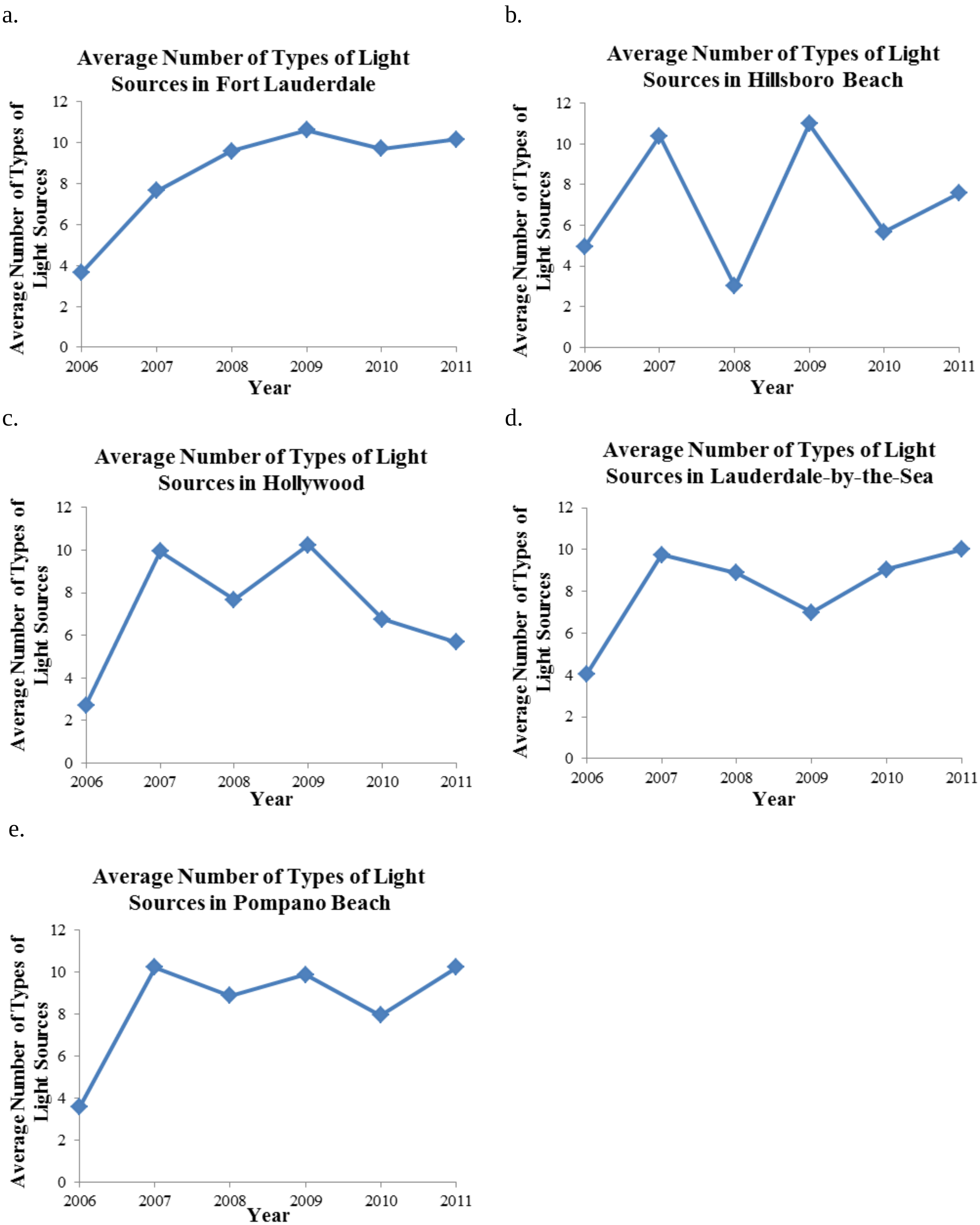



Figure 12. Average number of types of light sources per year for years 2006 to 2011.




Figures 13a-e. Average number of types of light sources per year for each municipality with incidences for all years 2006 through 2011.

## DISCUSSION

*Yearly DSI Trends by Municipality*

The average DSI per year showed a significant decline from 2006 to 2010 with a slight increase in 2011 (Fig. 4). In addition, there were some municipalities which had a significant trend in average and individual DSI values per year (Fig. 5, Table 3). This seems to indicate that the severity of hatchling disorientation events, combining both the degree of directional disorientation relative to the ocean and the number of hatchlings involved, may have decreased slightly throughout much of the county from 2006 to 2011. The low overall number of disorientation reports from Deerfield Beach, Dania Beach, and Hallandale and the lack of reports from these areas in some years make conclusions for these areas more difficult.

Disorientation events may be decreasing across Broward County. However, starting in 2007, a new conservation organization, Sea Turtle Oversight Protection (STOP), began monitoring nests to rescue disoriented hatchlings in Broward County. This organization received an FWC Marine Turtle Permit to monitor sea turtle nests in Broward County. This permit was in addition to the permits BCSTCP already had. STOP increased its monitoring activity in 2010 and 2011 and their work was probably responsible for the reduced numbers of disorientation reports that were filed by BCSTCP in the later years of this study. The number of disorientation reports filed for each R-Zone per year decreased from 2006 to 2011 (Fig. 11). This was the reason the focus of this study was on the average DSIs for the reports that were generated. STOP might have targeted nests that were more likely to disorient, so this may have been partially responsible for the decline in the number of severe disorientations (Fig. 9). However, data from a spreadsheet provided by STOP in 2011 showed that only 103 of 335 (31%) total disorientation events involved more than 50 hatchlings (events currently rated by FWC guidelines as “severe”), suggesting that STOP did not solely focus on nests that were more probable to severely disorient. The FWC severity scale is based on hatchling numbers alone and is not directly comparable with the DSI. Regardless, this does suggest that STOP handled nests with a wide range of disorientation severities; therefore, the sampling of the total number of disoriented nests used in this study may not have been skewed toward lower DSI values by the work of STOP. There was no area or R-Zone that exhibited a slower decline than the rest, so while STOP may have decreased the total number of reports it did not affect disorientation severity.

*Hotspots*

There were no significant countywide zonal trends in individual DSI (Fig. 6a-f), but the plots clearly identified zones that generated more disorientation reports. In 2006 and 2007 before intensive STOP activity, one strong hotspot (Table 4) was in the northern section of Pompano Beach (R26-31), an area with considerable high-rise condominium development. The nearby Pompano Pier (R33) may have had an influence on the disorientations in this hotspot as light glow can have a wide effect (Rusenko et al. 2005). Other intense clusters of reports originated from Lauderdale-by-the-Sea (R43-R49), also characterized by large well-lit condominiums but also with some low rise development, and from a section of southern Fort Lauderdale (R70-R85). The Fort Lauderdale Strip (R64-R80) extends into this area as well as the Yankee Clipper Hotel (R80) and the Point of the Americas (R83) high-rise condominiums that are located at the southern end. In addition, Port Everglades is south of R-Zone 85 and produces a large amount of urban glow. It is not surprising that the average DSI was high in this area. In 2007, the streetlights along Highway A1A were scheduled to be turned off or shielded. Additionally, the Yankee Clipper Hotel turned off its roof-top spotlight in 2008. Thus the reduction in average DSI from 2006 to 2009 might be a result of these light reductions (Fig. 7f).

These intense hotspots were very apparent in the early years but became less distinct after the STOP group began extensive night monitoring. Table 5 shows that the other identified hotspots were characterized by mixed development. Clearly, the high-rise versus low-rise nature of coastal development cannot identify disorientation hotspots. Urban sky-glow (Rusenko et al. 2005) can also cause disorientations and may be unrelated to the type of immediate coastal development.

Yearly DSI trends in the hotspots were generally negative and significant ($P < 0.05$) where sufficient data was available (Fig. 7, Table 6). This is similar to the trends in the municipalities, leading to the same conclusion: the overall severity of hatchling disorientations may have decreased slightly from 2006 to 2011. The only hotspot with data for each year that showed a flat trend was in a section of Fort Lauderdale, which included low-rise single family housing, and the Galt Ocean Mile (R53-R57), a high-rise condominium area.

*Average Zonal DSI*

Figure 8 identifies areas with high overall DSI levels, indicating disorientation trouble spots. In 2006, the cluster of points with DSI values greater than twenty in R67-R82, in and just south of the Fort Lauderdale Strip area, overlaps with hotspots five and six (Table 5) and more clearly highlights this area as a disorientation problem zone. This area is characterized by Highway A1A running directly adjacent to the beach in the south and central sections, by a beachfront park, and the Yankee Clipper Hotel in the south. Although DSI averages above twenty were present in this area in the later years (Fig. 8), they were never as apparent as in 2006. This may suggest that lighting reduction in later years along the Fort Lauderdale Strip may have been beneficial. The aforementioned reductions in lighting included the turning off and shielding of streetlights along Highway A1A and the turning off of the Yankee Clipper Hotel roof-top spotlight. The reduction in average DSI along the strip could also have been partially due to the work of the STOP group.

*Distribution of Severe Disorientations*

There were large changes over time in the number of severe disorientation reports (Fig. 9) and the distributions of the percentages of total disorientation reports from each R-Zone which showed severe disorientation (Fig. 10), defined as incidents where the majority of the hatchlings crawled away from the ocean (Fig. 3c). Since the decline in the total number of disorientation reports (Fig. 11) was probably due to STOP efforts, the focus of this analysis was on the percentage of severe incidents in order to track changes over time. In 2006 (Fig. 10a), there were ten R-zones between R67 and R82 that experienced 100% severe disorientations. This area was also characterized by high average DSI per zone, as discussed above. While there were only one or two disorientation reports from most of these zones (Fig. 11), the fact that most of the hatchlings crawled away from the ocean in all of these nests further highlights the Fort Lauderdale Strip as a high-disorientation area. Even though there was a decline in the number of 100% severe zones on the Fort Lauderdale Strip in later years, there continued to be incidents through 2011. Even with efforts to turn off or shield lights along the Fort Lauderdale Strip, light from storefronts and buildings as well as sky glow remain problematic. Elsewhere, in 2006 (Fig. 10a) there were 100% severe zones in Deerfield Beach (R1) and southern Hillsboro Beach (R16) into northern Pompano Beach (R32) but these were single nest incidents (Fig. 11). There was also a scattering of R-Zones with greater than 50% severe disorientations between R17 and R49. R-Zones with over 50% severe incidents in this area declined in 2007 (Fig. 10b), disappeared completely in 2008 (Fig. 10c), and were very low or nonexistent in the later years. There appears to have been improvement in the hatchling disorientation problem in the northern part of Broward County since 2006. The improvement became apparent in 2008, before the STOP group began extensive monitoring.

*Number of Types of Light Sources*

The average number of types of light sources countywide and per municipality increased from 2006 to 2011 (Fig. 12). Fort Lauderdale, Lauderdale-by-the-Sea, and Pompano Beach all have a pattern of increasing number of types of light sources from 2006 to 2011 with a plateau in 2011 (Figs. 13a,d,e). Hillsboro Beach and Hollywood have highly variable numbers of types of light sources each year (Figs. 12b-c), but this was due to the low number of reports from this area. Additionally, the subjectivity of each BCSTCP worker may have biased the actual number of types of light sources reported. Statistical analysis of these data was problematic because of the “too many lights present to determine” category on the FWC Marine Turtle Hatchling Incident Report Form (Fig. 1). The forms did not record the total number of light sources visible from the beach, but only the number of types of sources (streetlight, parking lot, etc.). While the number of types of lights can indicate the presence of light in an area, it is not suitable for statistical comparison to average DSI of an area. Visual comparison of the average yearly lighting patterns (Fig. 13) and average yearly DSI (Fig. 5) showed no apparent relationships. A similar study spatially and temporally analyzed light survey data from 2003 through 2008 and found that there were no significant countywide trends in the average number of individual light sources between years, except in 2003 (Wilson 2009).

Even though there may have been a slight reduction in the severity of disorientation events in Broward County from 2006 to 2011, there is still a beachfront lighting problem in Broward County. According to Anderson et al. (2013), the light levels in Broward County during 2011 and 2012 were lower from March to November than from December to February. However, hatchling disorientation is still occurring and it occurs more heavily in areas with lighting hotspots, such as Point of the Americas. While light intensity may be decreasing in Broward County, it is still not low enough to prevent sea turtle hatchling disorientation. Municipal coastal lighting ordinances have been in effect in Broward County since 2000. However, the ordinances typically only address the level of light reaching the beach. A progressive approach to lighting ordinances and ordinance enforcement is necessary for the further reduction in sea turtle hatchling disorientation. This would include the use of red/yellow LED lights in all streetlights and homes, as sea turtles are affected less by red/yellow spectrum light (Witherington and Bjorndal 1991). Not only would this allow for a lower level of light, but LEDs are also energy efficient and would save homeowners and municipalities money. While LED lights are initially more expensive than incandescent lights, they save the user money over time because they use less electricity and last longer. Additionally, the use of remote sensing as an enforcement technique would increase compliance and make it easier to enforce ordinances. Management could monitor light levels over a larger area using remote sensing. The subsequent enforcement would then be based on time stamped aerial imagery making it easier to prosecute offenders. Once potential offenders realize that management is monitoring their light use, they will be more inclined to comply with the ordinances. In endangered or threatened species recovery plans, it is necessary to take into consideration every threat to the species (Bolten et al. 2011). For sea turtle hatchlings this includes, among many factors, the type of light and the light intensity, including urban glow.

## CONCLUSION

The yearly average DSI declined from 2006 to 2011 in Broward County, as well as in Hillsboro Beach, Pompano Beach, Lauderdale-by-the-Sea, Fort Lauderdale, and Hollywood. These declines suggest that there has been a slow reduction in the severity of hatchling disorientation incidents possibly due to changes in beach lighting intensities, which may be due to compliance with lighting ordinances. In addition, there were significant hotspots of DSI, most notably in Pompano Beach, Lauderdale-by-the-Sea, and in central and south Fort Lauderdale. Since this study analyzed a sampling of the overall number of disorientation events, there is the possibility that our sample was skewed in the later years by the STOP group who monitored nests at night and interrupted disorientation events in progress to rescue the hatchlings. However, the distribution of severe events reported by STOP in 2011 suggests that their work may not have skewed our sample toward lower DSI averages by focusing on severely disoriented nests. In fact, this study shows some evidence of reductions in average DSI and in the percentages of severe disorientations in several areas before the STOP group became fully active. Additionally, there may be some bias in the crawl sketches and light source observations because the BCSTCP workers varied between each FWC report.

While there was no reliable relationship between the number of types of light sources and DSI, there were a large number of lights observed throughout Broward County. Disorientations seem to be location based and do not occur randomly throughout the county. Based on these results, efforts could be focused on the trouble areas. Remote sensing is a relatively new tool that could be used to measure lighting ordinance compliance (Anderson et al. 2013). It allows management the ability to quantify the amount of light emitted in an area at night (Mazor et al. 2013). More education and enforcement effort could be shifted to preventing disorientations in the hotspots identified in this study. There has been considerable progress in the hatchling disorientation problem (Sella et al. 2006) since the positive correlation of lights and hatchling disorientations was first reported. Regardless, efforts to reduce beachfront lighting must continue and intensify, because progress can easily be reversed. A beach can go from hatchling safe to deadly with the flip of a switch.

## LITERATURE CITED


Anderson SJ, Nuernberger S, Yamamoto KH, Sutton PC. 2013. Evaluating the compliance of sea turtle light ordinances in Florida using remote sensing. Geography Compass 7/12(2013): 867-878.

Avens L, Lohmann K. 2003. Use of multiple orientation cues by juvenile loggerhead sea turtles *Caretta caretta*. Journal of Experimental Biology 206: 4317-4325.

Avens L, Wang J, Johnsen S, Dukes P, Lohmann K. 2003. Responses of hatchling sea turtles to rotational displacements. Journal of Experimental Marine Biology and Ecology 288: 111-124.

Bertolotti L, Salmon M. 2005. Do embedded roadway lights protect sea turtles? Environmental Management 36(5): 702-710.

Bolten AB, Crowder LB, Dodd MG, MacPherson SL, Musick JA, Schroeder BA, Witherington BE, Long KJ, Snover ML. 2011. Quantifying multiple threats to endangered species: an example from loggerhead sea turtles. Frontiers in Ecology and the Environment 9(5): 295-301.

Bolten AB, Witherington BE. Loggerhead Sea Turtles. Washington, DC: Smithsonian Institution, 2003.

Burney C, Wright L. 2012. Technical Report 11-01: Sea Turtle Conservation Program Broward County, Florida. Broward County Board of County Commissioners.

Chalkias C, Petrakis M, Psiloglou B, Lianou M. 2006. Modelling of light pollution in suburban areas using remotely sensed imagery and GIS. Journal of Environmental Management 79(2006): 57-63.

Florida Fish and Wildlife Conservation Commission. 2013a. Sea turtle protection ordinances adopted by counties and municipalities. http://myfwc.com/conservation/you-conserve/lighting/ordinances.

Florida Fish and Wildlife Conservation Commission. 2013b. Trends in nesting by Florida loggerheads. http://myfwc.com/research/wildlife/sea-turtles/nesting/loggerhead-trends.

Fossette S, Schofield G, Lilley M, Gleiss A, Hays G. 2012. Acceleration data reveal the energy management strategy of a marine ectotherm during reproduction. Functional Ecology 26: 324-333.

Gaston KJ, Davies TW, Bennie J, Hopkins J. 2012. Reducing the ecological consequences of night-time light pollution: options and developments. Journal of Applied Ecology 49: 1256-1266.

Hart K, Zawada D, Fujisaki I, Lidz B. 2010. Inter-nesting habitat-use patterns of loggerhead sea turtles: enhancing satellite tracking with benthic mapping. Aquatic Biology 11: 77-90.

Hölker F, Wolter C, Perkin EK, Tockner K. 2010. Light pollution as a biodiversity threat. Trends in Ecology and Evolution 25(12): 681-682.

Horch KW, Gocke JP, Salmon M, Forward RB. 2008. Visual spectral sensitivity of hatchling loggerhead (Caretta caretta L.) and leatherback (Dermochelys coriacea L.) sea turtles, as determined by single-flash electroretinography. Marine and Freshwater Behaviour and Physiology, 41(2): 79-91.

Irwin W, Lohmann K. 2003. Magnet-induced disorientation in hatchling loggerhead sea turtles. Journal of Experimental Biology 206: 497-501.

Johnson S, Bjorndal K, Bolten A. 1996. Effects of Organized Turtle Watches on Loggerhead (*Caretta caretta*) Nesting Behavior and Hatchling Production in Florida. Conservation Biology 10(2): 570-577.

Kamrowski RL, Limpus C, Moloney J, Hamann M. 2012. Coastal light pollution and marine turtles: assessing the magnitude of the problem. Endangered Species Research 19: 85-98.

Lamont M, Carthy R. 2007. Response of Nesting Sea Turtles to Barrier Island Dynamics. Chelonian Conservation and Biology 6(2): 206-212.

Lohmann K. 1991. Magnetic orientation by hatchling loggerhead sea turtles (*Caretta caretta*). Journal of Experimental Biology 155: 37-49.

Mazaris AD, Kallimanis AS, Pantis JD, Hays GC. 2012. Phenological response of sea turtles to environmental variation across a species' northern range. Proceedings of the Royal Society B 280: 20122397.

Mazaris A, Matsinos G, Pantis J. 2009. Evaluating the impacts of coastal squeeze on sea turtle nesting. Ocean and Coastal Management 52(2009): 139-145.

Mazor T, Levin N, Possingham HP, Levy Y, Rocchini D, Richardson AJ, Kark S. 2013. Can satellite-based night lights be used for conservation? The case of nesting sea turtles in the Mediterranean. Biological Conservation 159(2013): 63-72.

Peterson CH, Fegley SR, Voss CM, Marschhauser SR, VanDusen BM. 2013. Conservation implications of density-dependent predation by ghost crabs on hatchling sea turtles running the gauntlet to the sea. Marine Biology 160(2013): 629-640.

Pike DA. 2013. Climate influences the global distribution of sea turtle nesting. Global Ecology and Biogeography 22: 555-566.

Rizakalla C, Savage A. 2011. Impact of Seawalls on Loggerhead Sea Turtle (*Caretta caretta*) Nesting and Hatching Success. Journal of Coastal Research 27(1): 166-173.

Rusenko KW, Mann JL, Albury R, Moriarty JE, Carter HL. 2005. Is the wavelength of city glow getting shorter? Parks with no beachfront lights record adult aversion and hatchling disorientations in 2004. Pp. 149 in H Kalb, AS Rohde, K Gayheart, and K Shanker, eds. Proceedings of the Twenty-Fifth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-582.

Salmon M. 2006. Protecting sea turtles from artificial night lighting at Florida's oceanic beaches. *Ecological consequences of artificial night lighting* (pp. 141-154). Washington, DC: Island Press.

Sea Turtle Oversight Protection. 2014. 2012 STOP hatchling rescue report map. seaturtleop.org

Sella K, Salmon M, Witherington B. 2006. Filtered streetlights attract hatchling marine turtles. Chelonian Conservation and Biology 5(2): 255-261.

Stewart K, Wyneken J. 2004. Predation risk to loggerhead hatchlings at a high-density nesting beach in southeast Florida. Bulletin of Marine Science 74(2): 325-335.

Tomillo P, Saba V, Piedra R, Paladino F, Spotila J. 2008. Effects of illegal harvest of eggs on the population decline of leatherback turtles in Las Baulas Marine National Park, Costa Rica. Conservation Biology 22(5): 1216–1224.

Tuxbury SM, Salmon M. 2005. Competitive interactions between artificial lighting and natural cues during seafinding by hatchling marine turtles. Biological Conservation 121 (2005): 311-316.

Weishampel, JF, DA Bagley, LM Ehrhart, BL Rodenbeck. 2003. Spatiotemporal patterns of annual sea turtle nesting behaviors along an East Central Florida beach. Biological Conservation 110 (2003): 295-303.

Wilson. c. 2009. An Analysis of the Policies and Conservation Techniques aimed at reducing the accidental deaths of Sea Turtle Hatchlings due to Light Pollution. Nova Southeastern University Oceanographic Center. Master's thesis.

Witherington B. 1992. Behavioral Responses of Nesting Sea Turtles to Artificial Lighting. Herpetologica 48 (1): 31-39.

Witherington BE, Bjorndal KA. 1991. Influences of wavelength and intensity on hatchling sea turtle phototaxis: implications for sea-finding behavior. Copeia 1991 (4): 1060-1069.

Witherington BE, Crady C, Bolen L. 1996. A "hatchling orientation index" for assessing orientation disruption from artificial lighting. Pp. 344-347 in J.A. Keinath, D.E. Bernard, J.A. Musick, and B.A. Bell, eds. Proceedings of the Fifteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-387.

Witherington B, Kubilis P, Brost B, Meylan A. 2009. Decreasing annual nest counts in a globally important loggerhead sea turtle population. Ecological Applications 19 (1): 30-54.

Witherington BE, Martin RE. 2000. Understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches. 2nd ed. rev. Florida Marine Research Institute Technical Report TR-2 73 p.

Yasué M, Dearden P. 2006. The potential impact of tourism development on habitat availability and productivity of Malaysian plovers, *Charadrius peronei*. Journal of Applied Ecology 43: 978–989.