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An Analysis of Policies and Conservation Techniques to Reduce the Accidental Deaths of Sea Turtle Hatchlings due to Light Pollution in Broward County, FL.

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An Analysis of Policies and Conservation Techniques to Reduce the Accidental Deaths of Sea Turtle Hatchlings due to Light Pollution in Broward County, FL.

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I. Abstract

Light pollution is any excessive or obtrusive man made light source which disrupts the natural environment. Hatchling marine turtles are adversely affected by light pollution and therefore unlit nesting beaches are essential habitats for all marine turtle species. In Broward County, the most significant conservation issue facing nesting and hatchling marine turtles is the amount of light pollution present on urban sea turtle nesting beaches. The reduction of hatchling mortality from light pollution is an ongoing conservation goal of the State of Florida, Broward County, and the Broward County Sea Turtle Conservation Project (BCSTCP). Conservation techniques and policies intended to reduce hatchling mortality due to light pollution in Broward County have included: mass nest relocation using restraining and self release hatcheries, limited individual relocation of nests, and lighting ordnances in coastal municipalities. Until the 2006 sea turtle nesting season the BCSTCP utilized a mass relocation scheme which removed nests from unsafe and well lighted beach areas to other hatching areas which were not as severely impacted by light pollution. In 2006 the use of hatcheries was phased out and only limited relocation continued. Along with limited relocation, municipalities were strongly encouraged to reduce light pollution.

Comparisons will be made based on the 2003-2008 nesting seasons determine which policies and conservation tools were the most effective at reducing hatchling mortality due to light pollution. This study tested the following hypotheses: (1) there has been no significant decrease in light pollution in Broward County, (2) there has been no significant decrease in disoriented hatchlings on Broward County beaches, (3) recent changes to relocation techniques have not improved hatchling production with in

Broward County. Results showed that the despite efforts by municipalities no overall reduction in light pollution has occurred. Initially hatchling disorientation events and the number of disoriented hatchlings increased after the policy change but have decreased during the most recent nesting season. Limited relocation yields a higher hatchling success rate then mass relocation. Although some improvements have been made light pollution control and reduction is still needed in order to reduce the accidental deaths of hatchlings due to disorientation.

II. Introduction

Light pollution is any excessive or obtrusive man made light source which disrupts the natural environment. Sources of light pollution include, but are not limited to, street lights, flood lights, spot lights, lighting used to illuminate houses and landscaping, lights from businesses, private residences and city sky glow. Photo-pollution is not a toxin, however it does degrades the quality of essential marine turtle habitats (Witherington & Martin 1996). Light pollution is a problem for many species but it posses a particular risk for nesting and hatchling marine turtles as it alters visual cues that the turtles use to find the ocean and can ultimately prevent them from reaching the ocean, which both adult and hatchling marine turtles must do in order to survive (Deem et al. 2007, Salmon et al., 1992, Witherington 1992).

Although marine turtles spend almost all their lives at sea, females must return to land to lay their eggs. Therefore nesting beaches are essential habitats for all marine turtle species. In Broward County, Florida, nesting beaches are highly developed and well lit. Experiments have shown that nesting females can be deterred by strongly illuminated nesting beaches, but some will still nest in well lit areas (Witherington 1992). Light pollution also can cause females to choose nest sites with suboptimal conditions, which can include nest crowding or depositing nests in locations which are prone to erosion and inundation (Foley, et al. 2006, Kikukawa et al. 1999, Witherington & Martin 1996). Also, lights from houses or business may not be on throughout the night. Females may deposit eggs in areas which appear safe at the time but actually have high levels of light pollution earlier in the night that will cause hatchling to disorient (Salmon et al. 1995a).

After a marine turtle has deposited her eggs, she must return to the ocean. Marine turtles use the ambient brightness of their surrounding to interpret the beach around them and find the ocean (Salmon et al. 1992, Van Rhijn, 1979). All marine turtle species orient themselves towards the ocean based on cues such as brightness and beach silhouette, but light is the guiding cue which a sea turtle will use to find the ocean. Artificial lights can disorient hatchling and adult marine turtles (Salmon et al. 1992, Tuxbury & Salmon. 2005, Witherington & Martin 1996). In some cases adult marine turtles have died after becoming disoriented and ensnared in beach furniture or crawling onto roads and being struck by vehicle. In Pongara National Park, Gabon, three adult leatherback turtles (*Dermochelys coriacea*) perished because of disorientation caused by light pollution (Deem et al. 2007).

Hatchling marine turtles are adversely affected by light pollution. Light pollution increases the instance of disorientation among sea turtle hatchlings (Adamany et al. 1997, Salmon 2003, Witherington & Martin 1996). Hatchling sea turtles emerge from their nests at night (Glen et al. 2005). Upon emergence, hatchlings are in a state of frenzy and will crawl for great distances towards what they interpret as the ocean. To a hatchling sea turtle, the brightest, flattest plane is the way to the ocean (Lorne & Salmon 2007, Salmon et al.1992). Like adult marine turtles, hatchling's sea finding ability is based on visual cues such as brightness, silhouette, as well as the wavelength of light emitted from a light source (Lohmann, et al. 1990, Oliver, et al. 1992, Tuxbury & Salmon 2005). Some studies have suggested that any delay in reaching the ocean may decrease a hatchling's fitness and ultimate ability to survive (Carswell 2001).

At night on an undeveloped beach the ocean direction is lighter and has a flatter profile than the landward direction. Beach front development alters the natural profile of the beach which in turn alters the visual cues used by marine turtles to find the ocean. Artificial lights provide marine turtles with false visual cues which can cause hatchlings to disorient towards the land. In Broward County, many artificial light sources are directly and indirectly visible from marine turtle nesting beaches. This light pollution cause hatchlings to orient away from the ocean and can lead to mortality from dehydration, overheating, exhaustion, or predation (Engeman, et al. 2002, Lohmann et al. 1990, Stewart & Wyneken 2004). If disoriented hatchlings are rescued and released in the sea, the effects of disorientation may decrease a hatchlings ability to correctly orient at sea (Lorne & Salmon 2007).

Currently there are many ways to reduce the presence of artificial light pollution on marine turtle nesting beaches. Adult and hatchling sea turtles are less attracted to longer wavelength lights in the red and yellow range (Witherington & Bjorndal 1991). Therefore lights filtered to these monochromatic wavelengths do not interrupt marine turtle's sea finding ability. Certain types of municipal light fixtures, such as acorn, posted carriage, or cobra head streetlights produce more light pollution then others. Turtle-safe types of lights fixtures can be used on and adjacent to nesting beaches and will reduce the amount light pollution present. Some turtle friendly lights include: low watt bulb which reduce brightness, long wavelength colors which are less attractive to marine turtles, lights with shields which prevent light from spreading beyond its intended area, installing low profile lights, and using curtains to block interior lights. Streetlights are harder to make turtle friendly, due to their brightness, height, and location (Ecological

Associates, Inc. 1998). Most streetlights can be seen from the beach above houses or dune vegetation. Filters, shields, and alternative fixtures are available for many streetlights (Bertolotti & Salmon 2005). Although filtered streetlights and some shields might not prevent all hatchling disorientations it is possible that shields and filtered bulbs may represent the best available technology (Sella et al. 2006).

Since 2000 there has been a sharp decline in marine turtle nesting in Broward County with slight rebound in 2008 (Burney & Wright 2008). In light of this decline, conservation of marine turtles on nesting beaches is more important than ever because decreased nesting may be offset by an increase in hatchling production (Antworth et al. 2006, Hays 2004, Troëng & Rankin 2004). In Broward County, the most significant conservation issue facing nesting marine turtles is the amount of light pollution present on urban sea turtle nesting beaches. During the 2006 and 2007 nesting seasons Broward County had the highest number of marine turtle disorientation events in the state (FFWCC 2007a).

Three species of marine turtles, the loggerhead sea turtle (*Carreta carreta*) the green sea turtle (*Chelonia mydas*), and the leatherback sea turtle, regularly nest on Broward County beaches and are adversely impacted by light pollution. Any human made light source visible from a marine turtle nesting beach can be a source of light pollution (Ecological Associates, Inc. 1998). All marine turtle species are currently listed as endangered or threatened under the Endangered Species Act of 1973. State and federal laws obligate the state of Florida to prevent the continued incidental take of any marine turtles due to light pollution (Chaves, et al. 2003, Engman et al. 2002, NMFS & USFWS 1991a, NMFS & USFWS 1991b, NMFS & USFWS 1992).

During recent nesting seasons in Broward County between 4.16 and 22.14 percent of all hatchlings disorient due to light pollution. Coastal development places sources of light pollution close to nesting beaches and also eliminates natural features, such as dunes and vegetation, which can help to shield the beach from excess light (Leong et al. 2003, Witherington & Martin 1996).

The reduction of hatchling mortality from light pollution is an ongoing conservation goal of the State of Florida, Broward County, and the Broward County Sea Turtle Conservation Project (BCSTCP). Conservation techniques and policies intended to reduce hatchling mortality from to light pollution in Broward County have included: mass nest relocation using restraining and self release hatcheries, limited individual relocation of nests, and lighting ordnances in coastal municipalities.

In 1997 the Natural Resources Planning and Management Division of Broward County published a Beach Lighting Management Plan (BLMP). The goal of this plan was to reduce coastal lighting so that the majority of beaches within the county would be safe for emerging marine turtle hatchlings (Ecological Associates, Inc. 1997). The BLMP proposed management strategies designed to reduce the loss of hatchling marine turtles due to light pollution. The strategy called for the implementation of municipal lighting ordnances and mapped zones within the county where turtle-safe lighting could be successfully introduced. In zones where turtle-safe lighting was not possible, relocation of sea turtle nests was to continue. Many coastal municipalities in Broward County now have lighting ordinances that require residences, business, and municipal lights to be turtle friendly (FFWCC 2007b). However the enforcement of these ordinances varies greatly from city to city.

The BLMP determined that all but two areas within the county could, in time, be made safe for emerging hatchlings. The two areas in which the BLMP determined turtle safe lighting would probably not be possible were the Fort Lauderdale Strip and the Hollywood Broadwalk (Ecological Associates Inc. 1997). Both of these areas are highly developed, have high pedestrian traffic at night, and are economically important tourist areas.

The BLMP allowed for the relocation of marine turtle nests from areas of high light pollution to darker beaches as a conservation technique. Until the 2006 nesting season the BCSTCP utilized a mass relocation scheme which removed nests from unsafe and well lighted beach area to areas which were not as severely impacted by light pollution. Nest relocation disturbs eggs which can decrease hatchling success (Wyneken et al. 1988). Relocation of sea turtle nests is labor intensive and requires highly skilled workers (Huff 1994, Türkozan & Yilmaz, 2007). Many nests were transported long distances by ATV or car to hatcheries that could be miles from where the nest was originally deposited.

With this relocation scheme, hatchling success of relocated nests was lower than that of nests left *in situ*. The hatchling success of mass relocated nests in Broward County from 2003-2005 was on average 51.58%. *In situ* hatchlings success for the same years averaged 66.63%. Other urbanized marine turtle nesting beaches have seen similar depressed hatchling success from relocated nests (Mascarenhas et al. 2004). Nest relocation is considered by many within the marine turtle conservation field as a measure of last resort for preventing hatchling mortality (Carswell 2001, Huff 1994, Mascarenhas et al. 2004, Türkozan & Yilmaz 2007).

At the time when the BLMP was drafted, nest relocation was preferred to leaving nests in situ and allowing hatchlings to disorient (Ecological Associates, Inc. 1997). Some municipalities within Broward County favored mass nest relocation over light pollution reduction as an acceptable and long-term solution to prevent hatchling mortality due to light pollution (Huff 1994). However, the decreased hatchling success rates in relocated nests lead the Florida Fish and Wildlife Conservation Commission (FWCC) to determine that mass relocation was no longer a responsible conservation scheme.

In order to determine if a beach is safe for emerging marine turtle hatchlings the BLMP dictated that an arena test should be conducted (Ecological Associates, Inc. 1997). Arena tests assess hatchling orientation and assign a numerical value to how well hatchlings orient towards the sea. Arena tests require specialized apparatus, sea turtle hatchlings as tests subjects, and special permitting from the state.

Instead of conducting arena tests the Hatchling Orientation Value (HOV) has been used to quantify hatchling orientation with a numerical value. The Hatchling Orientation Value (HOV) was developed from the pre-existing Hatchling Orientation Index (HOI) as a means to quantitatively evaluate the severity of hatchling disorientation events (Wilson et al. 2008, Witherington et al. 1996). As with the HOI, the HOV measures the angular deviations and the deviation of the mode of hatchling tracks from the most direct bearing to the ocean. The HOV is based on the hypothesis that the severity (D) of a disorientation event will increase exponentially as the hatchlings deviate from the most direct path to the sea. The HOV uses hatchling tracks found in the morning to determine hatchling orientation. Unlike the arena test, HOV does not require specialized apparatus or the presence of hatchlings (Burney & Margolis 1997).

In 2006 FWCC phased out the mass relocation of nests to self-releasing hatcheries and chain-link hatcheries in favor of continued limited relocation of nests to areas of the beach dark enough for hatchlings to safely emerge. Along with the discontinued mass relocation of nests, there was a renewed effort to implement and enforce sea turtle safe lighting in coastal municipalities.

III. Objectives

The priorities of urban sea turtle management programs should include the following: 1) determine if any changes have occurred as a result of the management strategy, 2) determine if those changes were positive or negative, and most importantly, 3) to use the information to make beaches better for nesting and hatching sea turtles (Salmon et al. 1995). If the BLMP and FWCC policies and conservation techniques were indeed effective at reducing the negative impacts of light pollution on hatchling sea turtles over the past six years then there should have been a significant reduction in the number of estimated hatchlings disoriented, an increase in the hatchling success rate from relocated nests, and reduction in the amount of light pollution present on Broward County beaches.

By examining data collected by the BCSTCP from 2003-2008 I will determine if the changes in conservation techniques and policies intended to decrease accidental deaths of sea turtle hatchlings due to light pollution have achieved their goals. I will test the following null hypotheses:

1. There has been no significant decrease in light pollution in Broward County.
2. There has been no significant decrease in disoriented hatchlings on Broward County beaches.
3. Recent changes to relocation techniques have not improved hatchling production with in Broward County.

IV. Materials and Methods

Data were collected by the BCSTCP during morning surveys in accordance with the FWCC Sea Turtle Conservation Guidelines. The BCSTCP surveys 21.5 miles of beach in Broward County every morning from March 1st through September 30th each year. The following data were collected daily: the number of false crawls, the number of nests deposited including egg count and location, the number of hatched nests, post hatching excavation, and number of disoriented nests and hatchlings. This study included data collected by the BCSTCP from 2003-2008. Broward County beaches have been divided into 1000 ft zones, numbered R1-R128 from north to south. Zone designations were used in lighting reports, disorientation reports, and for relocation purposes. All data included in disorientation reports were taken in accordance with FWCC guidelines and were submitted to FWCC.

Lighting surveys were conducted once a month from March through August starting after 9 pm in the municipalities of Deerfield Beach, Pompano Beach, Lauderdale by the Sea, Fort Lauderdale, and Hallandale Beach which had lighting ordinances. During the 2008 nesting season the city of Hillsboro Beach passed a lighting ordinance protecting an additional 15 zones, but because there were no prior lighting data Hillsboro Beach was not included in this study. Hatchling disorientation events have been rare on Hillsboro Beach, and therefore lights in this area were not scrutinized.

During lighting surveys a member of the BCSTCP catalogs all light sources visible from the beach, the type of offending light, and the property on which the light source is located. Properties included single family homes, businesses, condos, hotels, municipal buildings, vacant lots, construction sites, and street lights. Properties were identified from a comprehensive property list used by BCSTCP which includes the description and address of each building, vacant lot, and construction site along the beach. Each property is a potential point source of light pollution and a property as a whole will either be in compliance with the lighting ordinances or not. For the purpose of this study each of these properties were considered to be one point sources of light pollution regardless of the number, type, or brightness of lights. Hatchlings do not distinguish between these types of light pollution sources. Lighting reports were submitted to municipality code enforcement officers upon completion. The percentage of properties with light pollution sources per zone in municipalities which have lighting ordinances were determined from the monthly lighting surveys from 2003-2008.

The percent emergence of loggerhead sea turtle hatchlings from relocated nests for the 2003-2008 nesting seasons was determined as the number of hatchlings that exited the nest on their own, divided by the total number of eggs times 100. Live hatchlings found in the nest were not included in the percent emergence because hatchlings which did not exit the nest under their own power are not vulnerable to the effects of light pollution.

Estimates of disoriented hatchling numbers for 2006-2008 were taken from spreadsheet of disorientation data used in the synthesis of yearly technical reports. For hatchling disorientation data for the 2003-2005 seasons original spreadsheets were compiled from disorientation data sheets (Appendix 1), including the following information for each disorientation event: nest number or hatchery location, zone, date, beach, species, whether the nest was relocated or not, the estimated number of hatchlings that disoriented, the number of hatchlings found alive, the number of hatchlings found dead, and the estimated angular range of misoriented hatchlings. Estimates of hatchlings numbers were usually reported as a range. One way ANOVA and Newman-Keuls tests were applied to the data to determine if there were statistical differences between the data from any of the nesting seasons and if so which ones were different.

HOV data were collected using the same methodology as the HOI (Witherington et al. 1996). A sample scheme for HOV nests was designated prior to the start of each nesting season. Sample nests included both relocated and *in situ* nests. On Hillsboro Beach every 10th emerged nest was sampled, on Fort Lauderdale and Pompano Beaches every 5th nest was sampled, and on Hollywood beach every 2nd nest was sampled. Sample schemes were in agreement with the FWCC Sea Turtle Conservation Guidelines (FFWCC 2002).

Members of the Broward County Sea Turtle Conservation Project collected the data during morning surveys Upon discovery of hatchling tracks, the worker stood directly behind (westward of) the egg chamber in order to assess the direction of the hatchling tracks. Using a hand-held sighting compass the bearings were determined for the most direct path to the sea, the most frequent general direction of the hatchling tracks (mode), the paths of the two most widely separated tracks on either side of the mode (angular range), and the angular range without considering the single most deviant hatchling track (range minus outlier) (Witherington et al. 1996) (Appendix 1). Figure 1 illustrates these measurements.

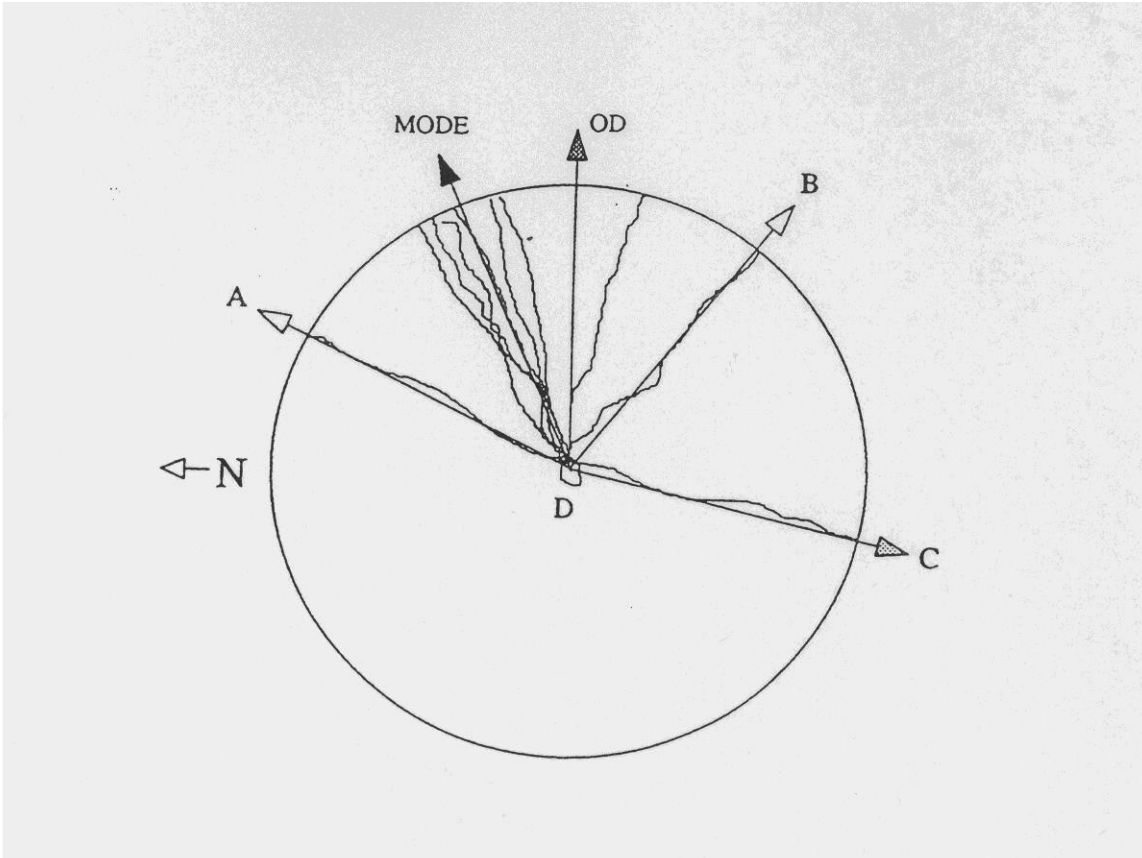

Figure 1. Diagram of HOV track measurements originating from emergence impression (D). The Ocean Direction (OD), the path taken by the most number of hatchlings (MODE), the Angular Range (A-D-C), and the Range minus Outliers (A-D-B) are indicated (Burney and Margolis 1996).

The HOV disorientation index (D) was calculated from the absolute values of the angular deviations of the mode (Am) and range minus outlier (Arr and Arl) bearings from the ocean direction (OD) bearing (Burney and Margolis 1996). The HOV index number (D) was the sum of the mode and range outlier components. The equations below calculate the components of D.

$$Dm = e^{(Am \times (\ln 10)/90)} \qquad (1)$$

$$Drl = e^{(Arl \times (\ln 2.5)/90)} \qquad (2)$$

$$Drr = e^{(Arr \times (\ln 2.5)/90)} \qquad (3)$$

$$D = Dm + Drl + Drr \qquad (4)$$

The constant in the exponent of equation 1 causes the Dm value to vary from 1 to 10 as the modal deviation varies from 0 to 90 degrees, and from 10 to 100 as the deviation varies from 90 to 180 degrees. The constants in the exponents of equations 2 and 3 allow the Drl and Drr values to range from 1 to 2.5 for deviations from 0 to 90 degrees and up to 6.25 at a deviation of 180 degrees. An example HOI/HOV data sheet can be found in Appendix 1. Table 1 shows an example HOV calculation.

There was good agreement between HOV D values and HOI classifications. Angular measurements for some nests with calculated D values of just above 4 (HOV moderate disorientation) were not classified as disoriented by the HOI. Some nests with D values from 10 to 20 fell into the severely disoriented HOI classification. Nests with D values >20 were all in agreement with the HOI classification of severe disorientation.

Table 1. Example HOV calculations.

Ocean Direction (OD)	**Angular Range**	**Angular Range L (rl)**	**Angular Range R (rr)**	**Mode**
95	80-140	80	140	100
Am =|OD-Mode|	**|Arl = OD-rl|**	**Arr = |OD-rr|**		
5	15	45		
1. Dm = e^(Am × (ln10)/ 90)	**2. Drl =e^(Arl × (ln 2.5)/90)**	**3. Drr = e^(Arr × (ln 2.5)/90)**	**4. D= Dm + Drl + Drr**	
1.14	1.16	1.58	3.88	

V. RESULTS

1. Light Pollution Reduction

Table 2 shows the percentage of properties per municipality that were light pollution sources from 2003-2008. Deerfield and Hallandale's percent of properties with light pollution sources fluctuated between 15 and 23.4 over the five year study period. Pompano, Lauderdale by the Sea, and Fort Lauderdale had larger changes in the percentage of properties with light pollution sources. Pompano had the largest change of about 40% in 2003 to 77% in 2007. Lauderdale-by-the-Sea and Fort Lauderdale had ranges of 59%-77% and 51%-82% in the 2003-2008 years respectively.

Figure 2 displays the average number of light pollution producing properties per zone in each municipality.

ANOVA of data from lighting reports from 2003-2008 showed that county wide there was a significant yearly difference between the average number of properties per zone with light pollution sources during the 2003-2008 nesting seasons ($P = 0.0065$). The Newman-Keuls test showed that the 2003 nesting season had the lowest average number of properties per zone with light pollution sources. The 2003 nesting season was statistically different than all other seasons except for the 2006 nesting season. There was no significant difference between the average number of properties per zone with light pollution sources in the 2004-2008 seasons ($P > 0.05$).

ANOVA also showed the municipalities of Deerfield Beach ($P = 0.406$), Lauderdale by the Sea ($P = 0.566$), Fort Lauderdale ($P = 0.464$), and Hallandale ($P = 0.976$) did not significantly decrease the average number of light pollution producing properties per zone during the 2003-2008 seasons. Pompano Beach showed a statistically significant increase in the average number of light pollution producing properties per zone between 2003 and 2004-2008 ($P = 0.003$). Linear Regression analysis supported the ANOVA conclusion that there was no significant overall trend in the number of light pollution producing properties per zone from 2003 to 2008 ($P > 0.05$).

Table 2. Percent of Properties per Municipality with Light Pollution Sources, 2008-2003

Municipality	2008	2007	2006	2005	2004	2003
Deerfield	42.56%	57.19%	50.00%	53.59%	56.48%	57.72%
Pompano	70.59%	77.00%	62.00%	69.50%	69.94%	39.86%
Lauderdale by the Sea	59.90%	77.00%	62.00%	69.84%	71.09%	59.13%
Ft. Lauderdale	60.86%	82.00%	54.00%	60.78%	63.62%	51.11%
Hallandale	84.17%	75.00%	68.00%	60.78%	71.67%	73.33%
County Wide	63.61%	73.64%	59.20%	62.90%	66.56%	56.23%

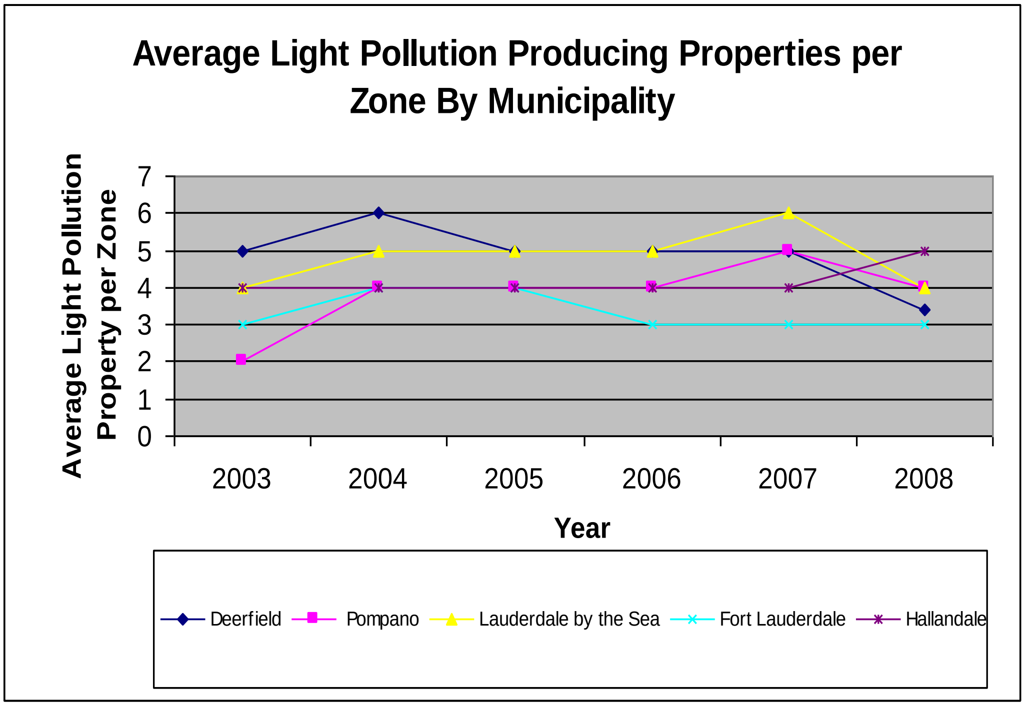

Figure 2. Average light pollution producing properties per zone by municipalities 2003-2008.

2. Hatchling Disorientation

The high and low estimates of the total number of disorientated hatchlings for the 2003-2008 nesting seasons are shown in Figure 3. Both the number of hatchling disorientation reports and the estimated number of disoriented hatchlings increased dramatically in 2006 and 2007. In 2008 the numbers of hatchling disorientation reports and disoriented hatchlings declined. Table 3 gives the number and percentage of disoriented nests and hatchlings. On average during 2003-2005 there were 140 hatchling disorientation events and 5,635 disoriented hatchlings per season. From 2003-2005 the number of disoriented nests and hatchlings remained fairly consistent. In 2006-2007 there was an increase in both nests and hatchlings which disoriented. In 2008 the number of disoriented nests and hatchlings decreased to values similar to 2003-2005. T-tests determined that the maximum number of hatchlings to disorient in 2006 and 2007 were significantly higher then the mean value from 2003-2005 (P = 0.033, P = 0.034) but 2008 was not different from 2003-2005 (P = 0.277). T-tests also showed that the number of reported disorientation events in 2006 and 2007 were significantly higher then the 2003-2005 mean but 2008 was not significantly different from 2003-2005 (P = 0.0016, P = 0.002).

Figure 5 shows the number of nests which were left *in situ* or relocated. The total number of nests relocated within the county decreased from 1,559 nests in 2003 to 437 nests in 2008 while the total number of nests left *in situ* increased from 664 in 2003 to 1595 in 2008.

Figure 6 shows the percentage of disoriented hatchlings from relocated and *in situ*. The percent of disorientation reports which were attributed to relocated nests which ranged from 59.38% in 2004 to 18.82% in 2008. The percent disorientation reports which were attributed to *in situ* nests range from 81.18% in 2008 to 40.25% in 2004.

HOV data were not taken prior to the 2006 nesting season. Figure 7 displays the average D values for the 2006-2008 nesting seasons. The highest average county wide D value was from 2007 (D = 25.39) and the lowest was in 2008 (D = 8.23). Both the 2006 and 2007 county average D values were classified as severe and the 2008 county average D value was classified as moderate. Table 4 displays the agreement between HOV and HOI classifications. As it shows there was good agreement between the two indexes.

ANOVA of county wide D values showed indicated that there was a difference between the D values from the 2006-2008 nesting seasons (P = 0.001). The 2008 D values were significantly different from the 2006 and 2007 nesting seasons ($P = 0.004$, $P = 0.005$). The 2006 and 2007 D values showed no statistically significant difference.

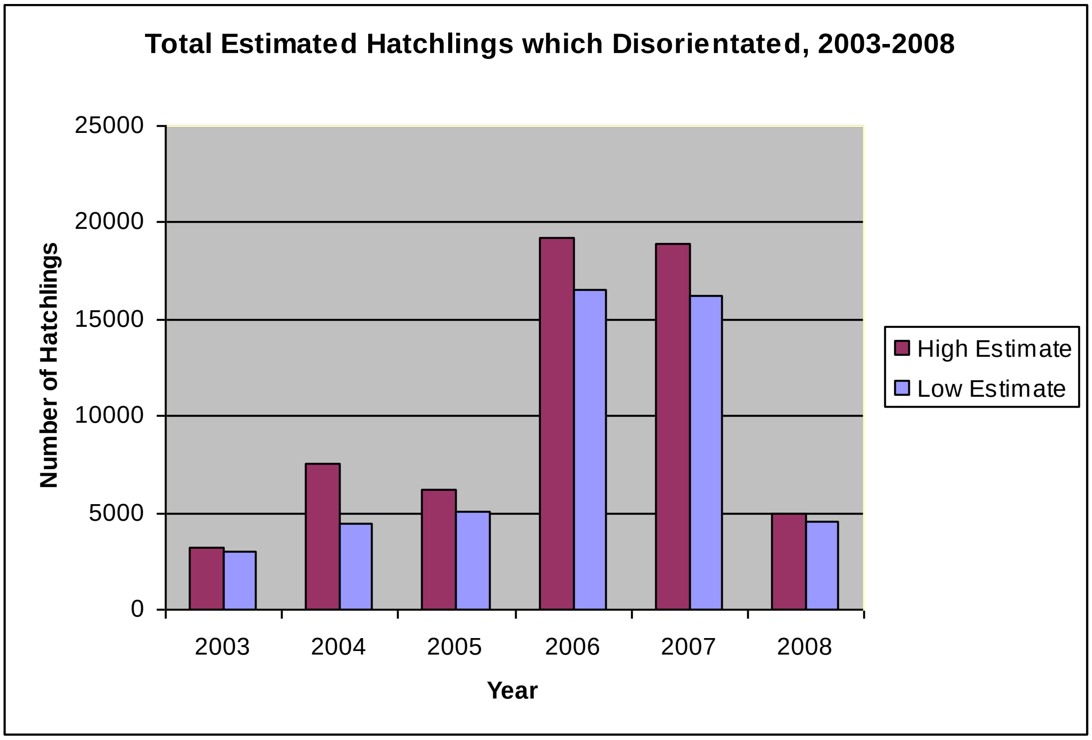

Figure 3. Total Estimated Hatchlings which Disoriented, 2003-2008.

Table 3. Percentage of nests to disorient and percentage of hatchlings disoriented

	Nests	Disorientation Events	Percentage of Disoriented Nests	Total Hatchlings Produced	Total Disoriented Hatchlings (Max)	Percentage of Disoriented Hatchlings (Max)
2003	2223	131	5.89%	70005	3200	4.57%
2004	1822	160	8.78%	61270	7490	12.22%
2005	1888	130	6.89%	36557	6216	17.00%
2006	1779	385	21.64%	46617	19255	41.30%
2007	1714	356	20.77%	32458	18920	58.29%
2008	2032	170	8.37%	120348	5007	4.16%

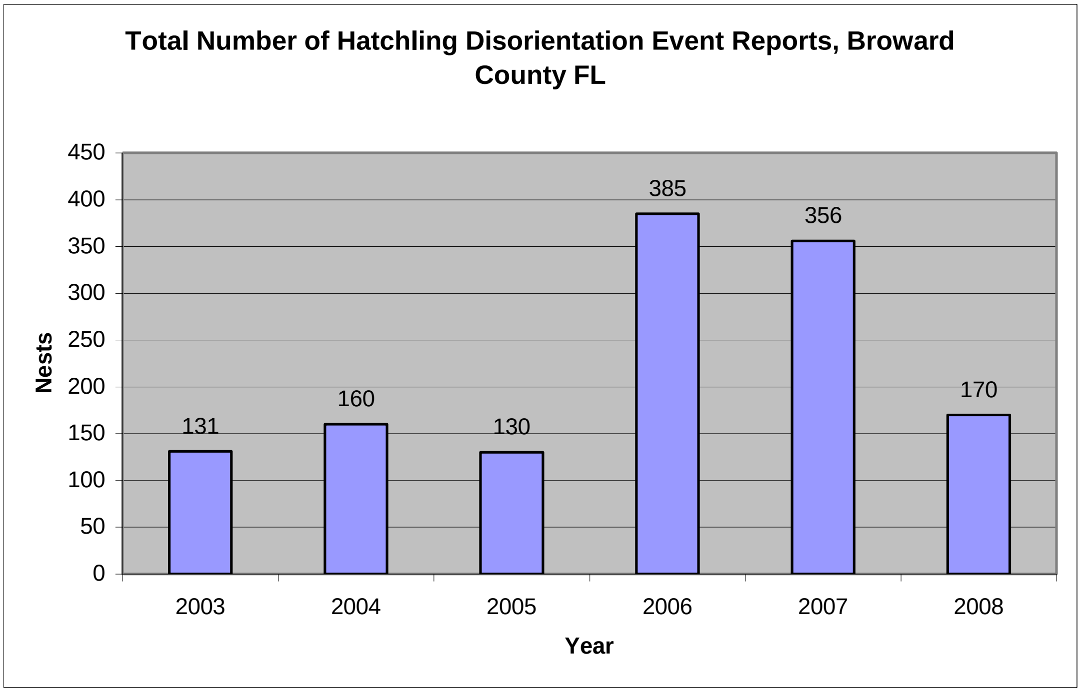

Figure 4. Total number of Hatchling Disorientation Event Reports, Broward County FL, 2003-2008.

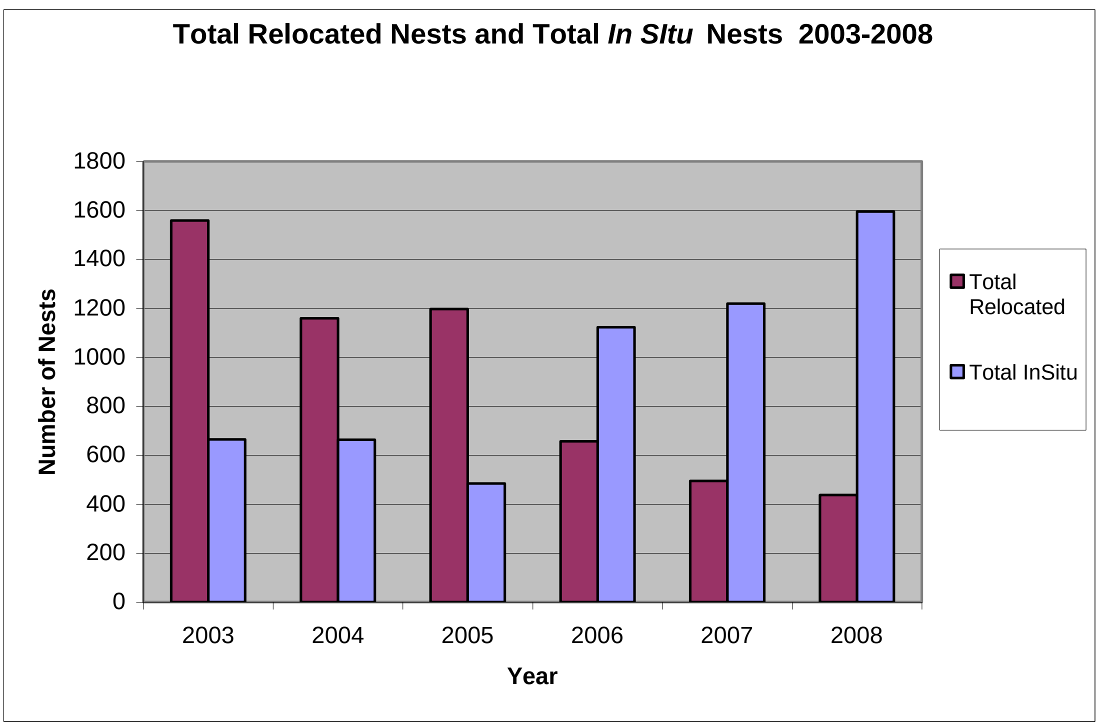

Figure 5. Total relocated and *in situ* nests deposited in Broward County 2003-2008.

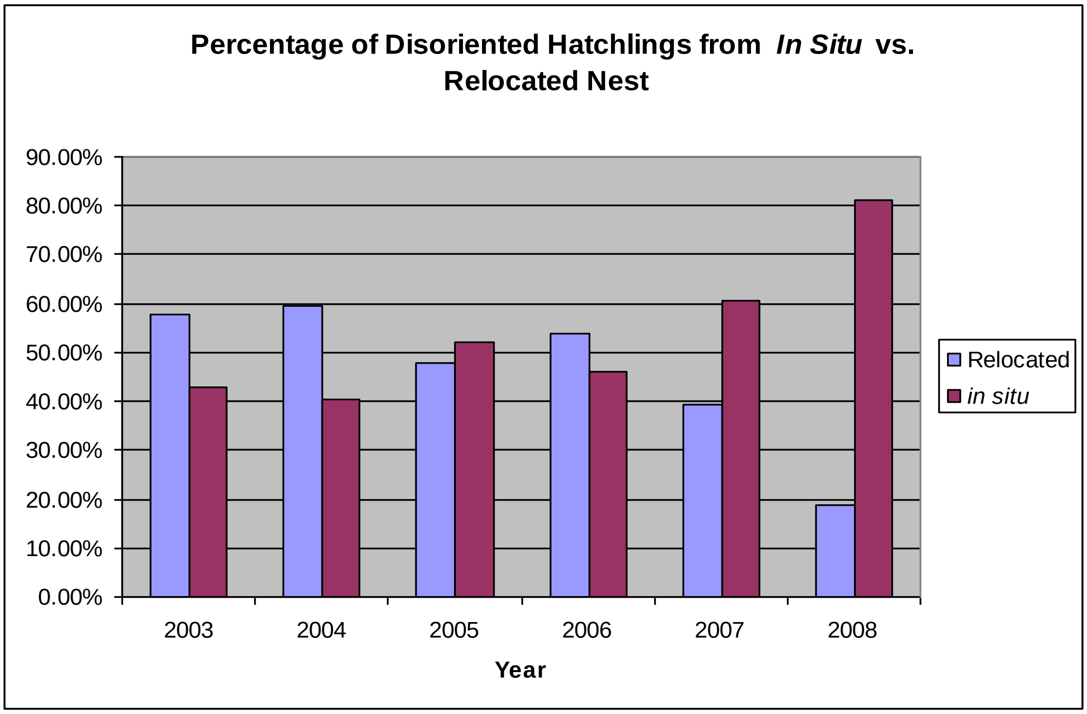

Figure 6. Origin of hatchlings affected by disorientation.

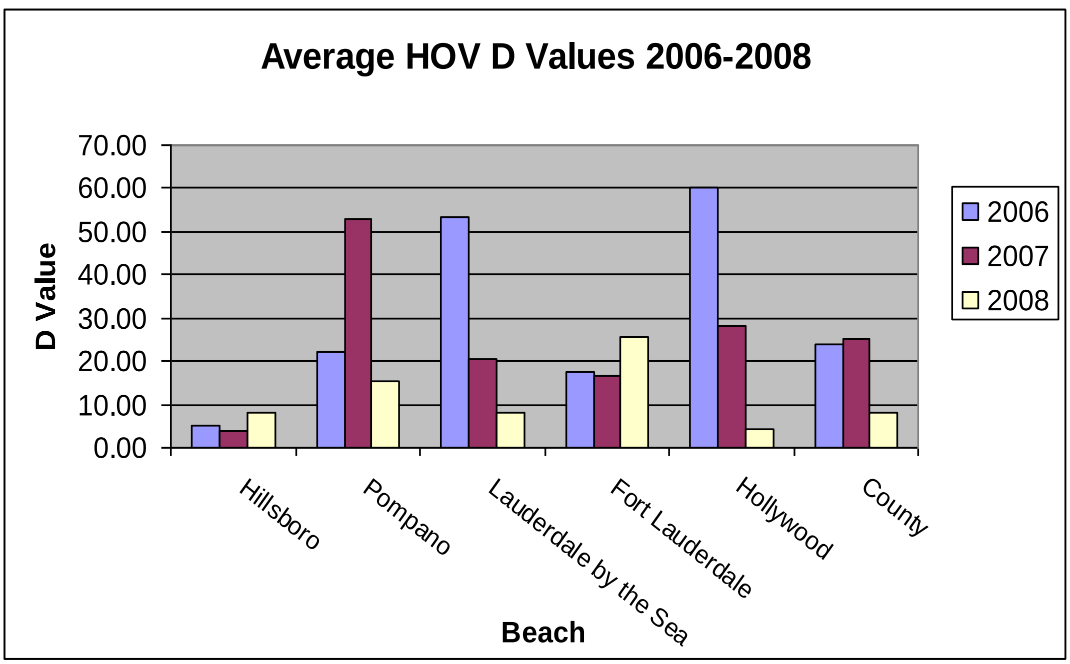

Figure 7. Average HOV D values, 2006-2008

Table 4. HOV and HOI classification agreement.

	2006	2007	2008
None (HOI)	20	27	42
None (HOV)	21	20	33
Moderate (HOI)	3	15	19
Moderate (HOV)	9	28	28
Severe (HOI)	19	24	7
Severe (HOV)	12	18	6
N	42	66	68
Average D (County Wide)	23	26	8

3. Relocation Techniques and Hatchling Success

Loggerhead nests account for the majority of relocated nests, therefore the percent emergence, or hatchling success of loggerhead hatchlings can be used as an indicator of relocation success (Ecological Associates, Inc. 1997). Figure 8 shows the percent emergence of loggerhead hatchlings from relocated nests for 2003-2008 seasons. The percent emergence of loggerhead hatchlings during mass relocation ranged from a high of 56.54% in 2003 to a low of 46.03 % in 2005 (Figure 8). From 2006-2008 the percent emergence ranged from 72.56% - 79.95%. In these years mass hatcheries were not used and there was only limited relocation, which reduced the time the eggs were out of the sand and widely distributes the location of relocated nests throughout safe zones. ANOVA showed that the percent emergences of loggerhead nests during mass relocation were significantly lower then when limited relocation was used ($P << 0.001$).

Figure 9 and Table 5 compare the effectiveness of nest relocation (percent emergence) vs. lighting pollution control (disoriented hatchlings). In order to compare the effectiveness of conservation techniques, the estimate of hatchlings lost due to relocation was compared to the number of disoriented hatchlings. The estimate of hatchlings lost due to relocation, or cost of relocation, was determined by applying the *in situ* percent emergence to the number of eggs relocated and subtracting hatchlings actually emerged from relocated nest. During 2003-2005 the percent emergence from relocated nests were lower then the 2006-2008 nesting as Figure 8 shows. As a result, more hatchlings were estimated to be lost due to relocation in 2003-2005 then disoriented but in 2006-2008 more hatchlings disoriented then were lost due to relocation. In 2007 the percent emergence for *in situ* nests was lower then relocated nests and as a result it was projected that more hatchlings would have been produced if eggs were relocated.

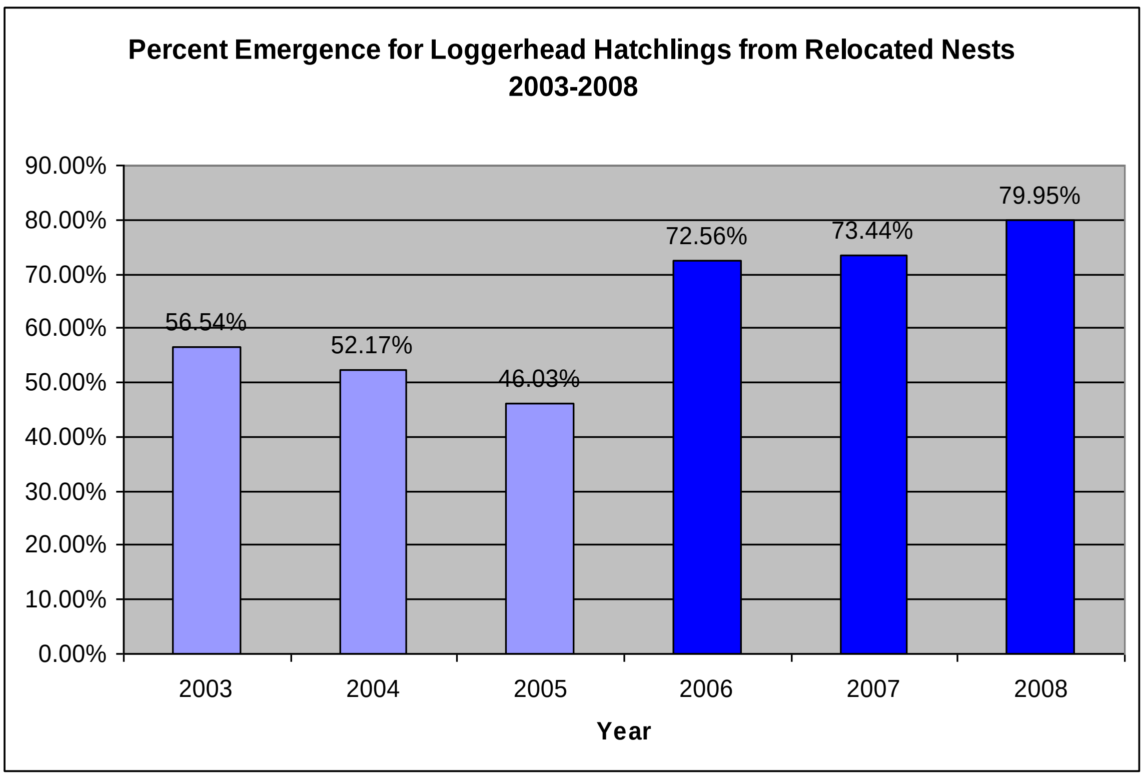

Figure 8. Percent Emergence of Loggerhead Hatchlings from Relocated Nests 2003-2008.

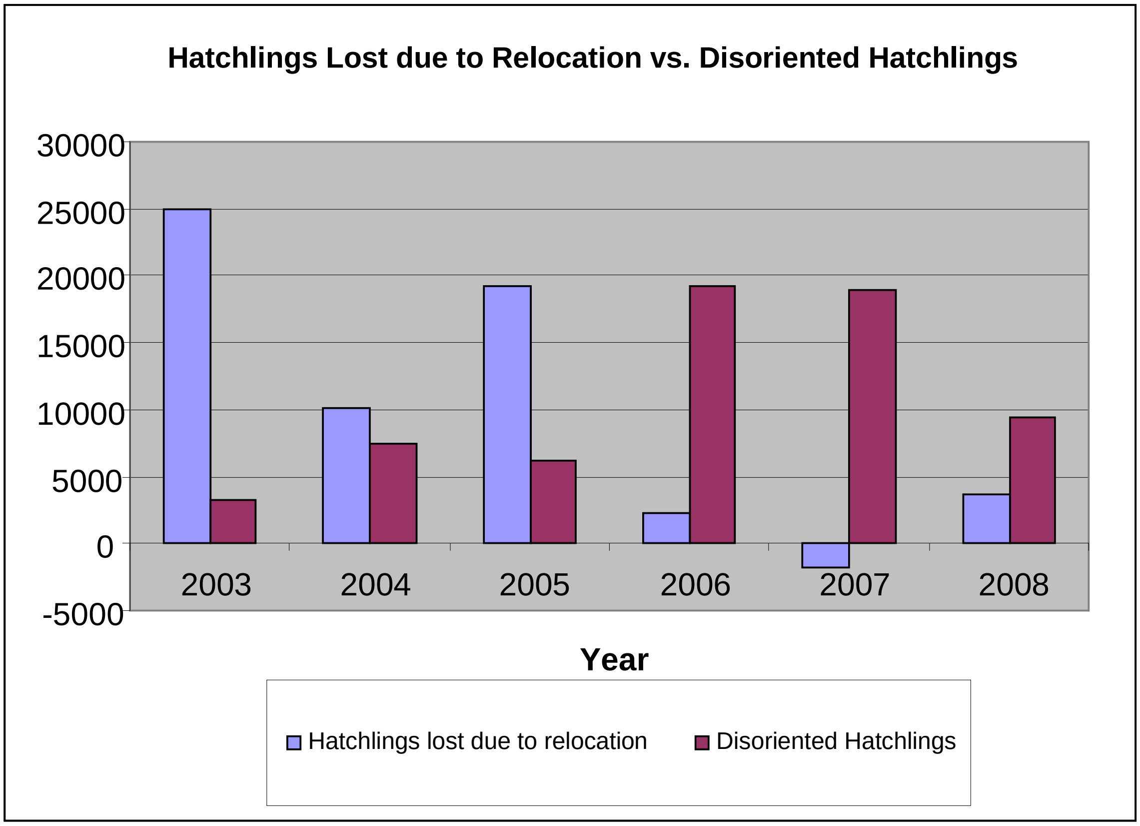

Figure 9. Hatchlings lost due to relocation vs. Disoriented Hatchlings

Table 5. Comparison of Relocation Technique Success (Hatchling Emergence) vs. Disoriented Hatchlings

Year	Total Eggs relocated	Percent Emergence Relocated	Hatchlings from Relocated Nests	Percent Emergence In Situ	Estimated Hatchlings*	Cost of Relocation (Hatchlings)	Disoriented Hatchlings
2003	133956	56.54%	75744	75.16%	100681	**24938**	3200
2004	103148	52.17%	53814	61.96%	63911	**10097**	7490
2005	115104	46.03%	52978	62.76%	72239	**19261**	6216
2006	64211	72.56%	46593	76.20%	48929	2336	**19255**
2007	49291	73.44%	36197	69.80%	34405	-1792**	**18920**
2008	39081	72.67%	28400	82.00%	32047	3647	**9402**

*Estimated Hatchlings from in situ nests when in situ percent emergence is applied to total relocated eggs.

**In 2007 the hatchlings from relocated nests was greater then the estimated hatchlings.

VI. DISCUSSION

1. Light Pollution Reduction

The number and percentage of light pollution producing properties in each 1000 ft zone did not significantly change during the individual nesting seasons, nor were there any major changes between municipalities and between nesting seasons. These data indicate that despite the existence of lighting ordinances, the desired reduction in light pollution affecting the beach was not achieved. Municipalities frequently had four, five, or even six properties per 1000 foot zone with offending light sources during the 2003-2008 nesting seasons, which further indicates the consistently high amount of light pollution present on nesting beaches. Table 2 shows that 2003 had the lowest percentage of properties with light pollution sources. These results could indicate that in 2003 the beach was fairly dark or the methodology of the survey could have been improved since then. There were no special circumstances or explanations in the technical reports as to why 2003 had fewer properties with offending light sources.

The 2004 and 2005 seasons were almost identical in percentage of properties with offending light sources indicating that there were no significant changes in enforcement or compliance during those years. The 2006 season had a slightly lower percentage of properties producing light pollution than 2004 and 2005 but the percentage rose again in 2007. These data indicate the need for constant enforcement of coast lighting ordinances in order to achieve their conservation goal.

The Newman-Kuels Test indicated that there was no change in the number of properties with light pollution sources per zone between the 2004-2008 nesting seasons.

This could indicate that despite any efforts made by municipalities and code enforcement officers there was no noticeable difference in the number of light producing properties impacting the beach. An important objective of the BLMP, as well as FWCC's management scheme, was to reduce lighting pollution.

Lighting Surveys were only conducted one night a month but there are a high number of properties repeatedly cited in the reports as having light pollution sources. The reports are a reliable assessment of the amount of light sources visible from the beach. Lighting reports depend upon the ability of the surveyor to recognize and catalog problem light sources. Lighting surveys were done by the project manager, assistant manager, or experienced workers accompanied by member of the Broward County Natural Resources Planning and Management Division in order to maintain the integrity of the report.

Although the average number of properties with light pollution sources per zone did not show any significant overall changes, some neighborhoods within municipalities were effective in decreasing the amount of light reaching the beach and thus allowing for a greater number of nests to be left *in situ*. While there was no significant overall reduction in the percentage of properties with offending light sources, some portions of municipalities, such as Galt Ocean Mile in Fort Lauderdale which consists primarily of high-rise condominiums, were in compliance with the lighting ordinance. However, nests left *in situ* in front of compliant properties can still disorient because illumination from neighboring properties.

Any success in lighting ordinance compliance is a promising sign, however lighting ordinances in Broward County have still not yet achieved a level of compliance that will reduce light pollution to a point where it will not affect emerging sea turtle hatchlings. Lighting ordinance enforcement must be improved and applied evenly throughout municipalities in order for them to be an effective conservation tool.

2. Hatchling Disorientation

The numbers of hatchlings disoriented was estimated by members of the BCSTCP or trained observers at the time of discovery of the disorientation event. The observer estimated a range of hatchlings which they believed disoriented based on the number of tracks observed. The fate of many disoriented hatchlings was largely unknown as they were not found, nor did they appear to reach the water.

The 2003-2005 nesting seasons had significantly fewer disoriented hatchlings than the 2006-2008 seasons. Mass relocation of nests to open beach hatcheries was used in 2003-2005, but the open beach hatcheries had no light barriers to prevent hatchlings from disorienting upon emergence and relocated nests were susceptible to light pollution. Figure 6 shows that the high number of disorientation events originated from relocated nests in hatcheries. Both *in situ* and relocated nests were equally affected by light pollution even though there were substantially lower numbers of nests left *in situ* during these seasons.

Between 3,020 and 7,490 hatchlings were estimated to disorient per season when mass relocation was used (Figure 3). Because Broward County beaches are almost completely developed, it was difficult to find locations for open beach hatcheries that were not affected by light pollution. It should be noted that mass relocation is not an efficient management strategy if light pollution at the open beach hatcheries could not be controlled. The percentage of hatchlings to disorient prior to limited relocation was consistently low. The data indicate that limited relocation led to an increase in the number of disoriented hatchlings, which was not the goal of the BLMP, BCSTCP, or FWCC.

The number of reported hatchling disorientation events during seasons with mass relocation ranged from 130-160 (Figure 4). During the years in which open beach hatcheries were used, similar percentage of *in situ* and relocated nests experienced disorientation (Figure 6). During the first and second seasons after the policy change the number of reported disorientation events has risen to over 350 per season and the number of estimated disoriented hatchlings also increased. During the most recent season, 2008, the number of disorientation events fell to 170. Both the number of disorientation events and the number of hatchlings disoriented drastically rose which indicated that there were still unsafe levels of light pollution present in safe zones during the 2006 and 2007 nesting seasons. The majority of disorientation events originated from relocated nest in the 2006, however in 2007 and 2008 the majority of disorientation events were from *in situ* nests. Nests were supposed to be relocated to safe zones where hatchlings were able to emerge and find the ocean without the negative impact of light pollution. The 2008 decline in disorientation events from relocated nests indicates that the placement of relocated nests throughout the county has improved in the two years since the policy shift away from open beach hatcheries.

There were relocation related procedural and policy changes which can help account for some of the fluctuation in disorientation data. During the seasons in which open beach hatcheries where used it was not possible to discern the nest from which disoriented hatchlings originated. When multiple nests emerged and disoriented on the same night only one disorientation event was reported. After the change from mass to limited relocation it was possible to discern the origin of disoriented hatchlings and therefore each nest which experienced a disorientation event received an individual report.

During 2006-2008, nests were relocated to a wide range of locations. The year 2008 had the lowest percent of disorientation reports from relocated nests (Figure 5). Although the state has determined which areas of beach are safe and unsafe in regards to lighting hatchlings still disorient in these safe zones. The decline in disorientation events originating from relocated nests from 2006-2008 indicated that the BCSTCP has been better able to identify the safest, and darkest, beach zones for nest relocation. The average HOV D value has been declining on all beaches and county wide since 2006 (Figure 7). The HOV sample sizes for all beaches were small (< 30) due to weather, such as strong wind and rain, and regular beach raking which erases hatchling tracks. In future seasons the number of actual sample nests need to be standardized in order to be able to secure a better statistical sample.

The HOV can help identify areas best suited as safe zones for emerging hatchlings as described in the BLMP. Disorientation reports and supporting HOV data were used at Lauderdale-by-the-Sea to reduce the number of severe disorientations in 2007. Even though this area was designated a safe zone by the state in 2006, hatchlings still disoriented within this zone. HOV and disorientation data from the 2006 season identified which areas within Lauderdale-by-the-Sea were prone to disorientation events and these areas were not used as relocation sites in subsequent seasons. The average D values at Lauderdale-by-the-Sea decreased from the 2006 to 2008 nesting season (Figure

7). In 2008 the relocation sites in Lauderdale-by-the-Sea was further refined to specific locations in front of properties with better light pollution management and intact dunes. Because of this 2008 Lauderdale-by-the-Sea D values do not reflect the same zones as 2006-2007 D values.

3. Relocation Techniques and Hatchling Success

In the 2006 nesting season the use of mass relocation as a conservation tool was replaced with a limited relocation scheme where many more nests were left *in situ*. Instead of using open beach hatcheries, nests were relocated to adjacent zones deemed safe for emerging hatchlings throughout the county.

Past studies have show that careful handling of eggs soon after oviposition can lessen the negative impact of relocation (Wyneken et al. 1988). The percent emergence of hatchlings from relocated nests was used as in indicator of how successful relocation has been as a management tool. As previously mentioned the mass relocation scheme was very time and labor intensive. The percent emergence from mass relocated nests was significantly lower than *in situ* nests which indicated that this was not the ideal relocation scheme. The percent emergence shown in Figure 8 for 2003-2005 was low. However, during these years, weather events, such as hurricanes and hotter temperatures, can account for some of the differences.

One major difference between mass and limited relocation was that the nests were not transported as far during limited relocation. During mass relocation, eggs spent more time out of the sand and on ATVs or in cars. The extra handling experienced by the clutches in mass relocation might contribute to the depressed percent emergence. During limited relocation the eggs were transported much shorter distances.

In the last three years, when limited relocation was used, the percent emergence was over 70% for all seasons. Figure 8 indicated that limited relocation has been a more successful relocation strategy then mass relocation. The higher emergence rate indicates that more hatchlings were produced. The high percent emergence indicated that limited relocation has been a better relocation strategy, although not necessarily a better way to mitigate light pollution.

In theory if more nests where left on the beach, then municipalities would be strongly encouraged to enforce their lighting ordinances and limited relocation would be a solution to the problem of low emergence from relocated nests. However, as Table 2 shows, there has been no statistically significant reduction in light pollution in Broward County in the past five years and more effort is required to make Broward County Beaches darker and safer for hatchling marine turtles.

Nest relocation does not reduce light pollution and does not always prevent hatchling disorientation. In marine turtle conservation choices have to be made in regards to the best way to attempt to reduce the accidental deaths of hatchlings due to light pollution. Mass relocation of marine turtle nests is no longer the preferred mitigation method because it does not address light pollution reduction (Frazer 1997). Currently FWCC focuses on light pollution reduction rather than nest relocation to reduce hatchling mortality. However, there are drawbacks to both approaches as nest relocation does depress the hatchling success and light pollution reduction has not occurred as swiftly or thoroughly as hoped.

In Broward County the change from mass to limited location was done to improve hatchling success (Figure 9). From 2003-2005 the number of projected additional hatchlings was greater then the number of disoriented hatchlings. A large number of hatchlings were estimated not to hatch as a result, or side effect, of mass relocation (Table 5). Clearly mass relocation in this instance appeared to not be the best conservation technique.

In 2006-2008, when limited relocation was used, the percent emergence of hatchlings from relocated nests increased and in some cases was equivalent to with *in situ* percent emergence. In 2007 the percent emergence from relocated nets was higher than the overall percent emergence from *in situ* nests and as a result it was estimated that more hatchlings would have been produced if those eggs had been relocated (Table 5). However, this is a projection and it is important to consider that multiple factors influence emergence success including weather, nest placement, predation, and tidal inundation. Even though limited relocation has improved hatchling success, the number of disoriented hatchlings increased significantly (Figure 9). In 2006-2008 the number of hatchlings disoriented was greater then the cost of relocating the nests. In this instance light pollution management appears to be the least effective conservation scheme.

Nest relocation schemes and techniques have shown improvement in Broward County. However, relocating nests is not an effective way to prevent hatchlings disorientation if there are no dark beaches where to relocate. In Broward county light pollution must be reduced. Even the largest number of disoriented hatchlings was not greater than the largest number of hatchlings lost due to relocation. In Broward County it appears that limited relocation has greatly improved relocated nest success. In 2008 there was the smallest number of disoriented hatchling during limited relocation and a high percent emergence from relocated nests. Hopefully this trend of high percent emergence and fewer disoriented hatchlings will continue and should be closely monitored in the future.

Relocation has been a conservation tool which can be useful under some circumstances. Relocation is labor intensive, time consuming, and depends upon the skills of the workers relocating the nests. The lack of dark beaches further illustrates that relocation schemes, either mass relocation or limited relocation, are not ideal management tools when attempting to reduce light pollution (Ecological Associates, Inc. 1997).

VII. CONCLUSION

In Broward County there has not been a significant reduction is light pollution producing properties per zone from 2003-2008. During the same years there has also not been a significant decrease in hatchlings disorientation events or the number of disoriented hatchlings. However, the change from mass relocation to limited relocation has increased the hatchling success from relocated nests.

In Broward County's situation nest relocation is a halfway fix to the problem of light pollution because nest relocation does not decrease light pollution nor does it prevent all hatchling disorientations. As Nat Frazer (1992:p182) stated, "If the problem is lighting on the beaches, the solution should address lighting on the beaches." Nest relocation does not reduce light pollution and therefore should not be used as a long term solution to hatchling disorientation. Although the limited nest relocation scheme currently used by the BCSTCP has ameliorated some of the problems associated with relocating marine turtle nests, hatchlings still disorient from relocation sites. Any improvements in light pollution control made by municipalities in Broward County should result in an immediate and noticeable reduction in the number of hatchling disorientations. Without serious control of light pollution in Broward County progress towards reducing the number of hatchlings adversely affected by light pollution will be slow.

In summary, light pollution control and reduction is needed in order to reduce the accidental deaths of hatchlings due to disorientation. On other urban nesting beaches in which tourism is a major industry advances have been made which reduce the impact of light pollution on nesting and hatchling marine turtles. Public education, cooperation with businesses, and the use of new technologies have led to fewer disoriented hatchlings and improved light pollution control (Carswell 2001, Horrocks 2001, Lewis et al. 1999, Mascarenhas et al. 2004).

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IX. Appendix 1.

HOI/HOV Data Sheet:

2007 HOI Data Sheet

Name: ________________

Beach: ________________________

Nest # (If available):___________

Species:_______________________

Date Laid:____________________

Hatch Date:___________________

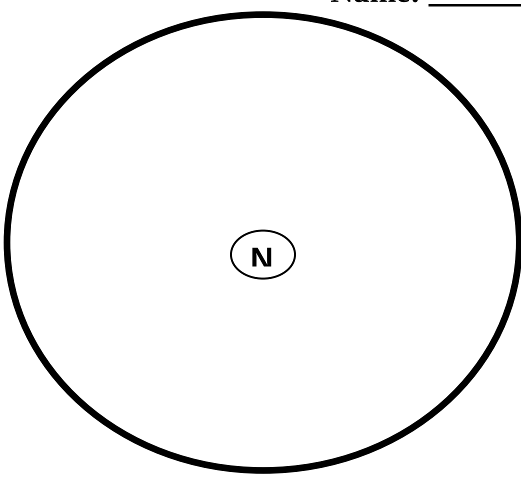
Ocean Direction:______________

Angular Range:_______________

Range – Outlier:______________

Mode:_________________________

Circlers (0,1,2, or >2):__________



MISSED NEST: Y or N

GPS N: __________________________

GPS W: __________________________

Zone: ____________________________

Address: _________________________

FWC Marine Turtle Disorientation Report Form:

☐☐☐-☐☐-☐☐-☐☐-☐☐-☐☐☐

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 #: ________________ Date of Incident: ________________________________

Observer's Name: ____

Telephone (include area code): __________________ E-mail address: ___________________

Location of Disoriented Nest: (address, beach name and/or nearest landmark):______________

____

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

Latitude _________________Longitude _______________

City: ____ County:_________________________

Local nest ID#: ________________________ Zone nest was located in: ___________________

Addresses/landmarks hatchlings disoriented towards: _________________________________

____

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

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

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): ___

____

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

Lat^1 ______________ $Long^1$ _________________ Lat^2 _____________ $Long^2$ ________________

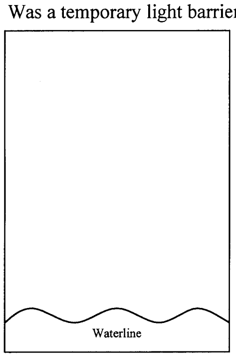
Lat^3 ______________ $Long^3$ _________________ Lat^4 _____________ $Long^4$ ________________

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? ________________

ADULT EVENT: Nest ☐ False Crawl ☐ HATCHLING EVENT ☐

	LOGGERHEAD	GREEN	LEATHERBACK	UNIDENTIFIED
No. OF TURTLE S DISORIENTED				
No. OF TURTLE S FOUND DEAD				
No. OF TURTLES FOUND ALIVE				
No. OF DISORIENTED TURTLES REACHING WATER				

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

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

☐ City: ___________________ ☐ County: ____________________ ☐ Other: ________________

_________________________________ ______________________

Signature of Observer Date

FWC Revised 6/92, 11/96, 9/97, 1/99, 3/01, 1/02, 1/08, 4/08