THE INFLUENCE OF MORPHOLOGY AND ARTIFICIAL LIGHT ON TERRESTRIAL TRANSIT OF THE LEATHERBACK TURTLE (*Dermochelys coriacea*)

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Abstract

The nesting process of leatherback turtles provides a rare opportunity to study the highly migratory species. This study used this opportunity to investigate the influence of morphology and artificial light on terrestrial transit of the leatherback turtle. I found no significant relationship between either body length, mass or flipper length and the dependent variable, terrestrial locomotion velocity (ms^{-1}). However, analysis of terrestrial locomotion in adult turtles was undermined by a small sample and so results are highly contentious.

Artificial lighting levels at certain locations on Turtle Beach now exceed the perceived level produced by celestial sources, even during the full moon phase. This is a cause for concern as excessive and overpowering artificial lighting interferes with turtle's terrestrial orientation systems thus disrupting sea-finding ability. I observed the transit patterns of 50 nesting leatherback turtles and was able to identify 11 instances of misorientation and 16 instances of disorientation on Tobago's Index beaches. From successfully recorded nests it appears that leatherback turtles are less influenced by beachfront illumination when selecting a nest site, beach or zone, compared to other sea turtle species and there is also high intra-specific difference in susceptibility to disturbance by beachfront lighting. Misorientation occurs most in zones 1 and 3 of Turtle Beach where there are visible but distant light sources; and in zone 2 disorientation is more likely as turtles are closer to high level, non-directed sources of broadband light from structures and facilities. The direction of the highest light level may not tightly correlate with transit directionality for all stages of the nesting process but the significant correlation between turtle re-entry bearing and that of highest light level suggests that turtles may experience a misorientation effect on Turtle Beach. Increased time on beach resulting in wasted energy and elevated threat of harassment or poaching are potential consequences for affected turtles. For hatchling turtles the consequences of light 'trapping' may be fatal, particularly in zone 2. The results and discussion of this thesis are used to make recommendations for stakeholders.

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Introduction

Field Site

Fieldwork took place on the island of Tobago, West Indies. Tobago, part of the republic of Trinidad and Tobago, is located at the southernmost point of the Caribbean archipelago. The island is slightly north-east of Trinidad and orientated on a North-East bearing located at a latitude 11°9' N, longitude 60° 40' W (Scarborough 11°11′0″ N, 60°44′15″ W) (Fig.1). It is approximately 26 miles long and 6 miles wide. The island is characterised by a lowland region in the south which is fringed with pockets of mangrove forest swamp and a highland range to the north which is dominated by rainforest. Tobago supports nesting populations of three of the seven species of marine turtle: green, *Chelonias mydas*, hawksbill, *Eretmochelys imbricata*, leatherback, *Dermochelys coriacea*. Leatherback nesting is concentrated on beaches to the southwest of the island. Hawksbills nest in greatest numbers in the north-west where there may also be a small number of egg clutches deposited by green turtles. In addition to nests lost to predation and other abiotic factors the turtles nesting in Tobago face a number of anthropogenic threats: illegal poaching of nesting females; egg harvest; harassment by humans and disorientation from artificial lighting (Dow et al., 2007). The nesting season runs from March to July in Tobago (Clovis, 2005).

Figure 1 - Map of Trinidad and Tobago

Basic Biology

Leatherback turtles (Vandelli, 1761) are the most fecund of all sea turtle species. Gravid female turtles emerge from the sea to deposit single clutch of 80-100 eggs (Pritchard and Mortimer, 1999) at 9-11 day intervals (Hughes et al 1967; Miller, 1997) on 6-7 occasions throughout a nesting season. Deposits are made under the cover of darkness. A period of 2-3 years (Saba et el., 2008) generally elapses between nesting seasons. The incubation duration of eggs is influenced by temperature but is generally estimated to last around 60 days in the species. Marine turtles, like other reptilian species, utilise temperature-dependant sex determination (Yntema&Mrosovsky, 1980; Standora&Spotilla, 1985). Embryos require an incubation temperate which lies in the range of 23-35℃ (Miller, 1997; Ackerman, 1997). Female hatchlings are produced when the mean temperature exceeds 29.4° (Chevalier et al., 1999) during the middle third of incubation, cooler temperatures produce male hatchlings.

Neonate leatherback hatchlings synchronously emerge from the sand and make their way seaward where they can follow wave cues to the offshore environment (Lohmann et al., 1997). It is to this natal beach that sea turtles return although leatherbacks turtles display looser site fidelity compared to other species turtle (Dutton, 1999). It has long been regarded that sexual maturity is reached at 20-25 years of age for the species (Avens et al., 2009) though recent literature suggests that sexual maturity may be reached in half the time (Zug and Parham, 1996; Jones, 2009).

Leatherback turtles are the most pelagic of the seven sea turtle species and spend their lives at productive, high latitudes where gelatinous prey items are found in abundance (Lutcavage and Lutz 1986; Bjorndal, 1997). Therefore, terrestrial encounters with gravid nesting females have historically provided the only opportunities to observe and study this highly migratory species in detail. The beaches upon which leatherback turtles choose to nest are characteristically wide with open sand areas and have a deep water approach (Eckert, 1987). The absence of a reef is ensures the soft plastron is not damaged. Leatherbacks contrast with the hawksbill species which prefer secluded areas often fringed by reef and darkened with vegetation.

The nesting process has several stereotyped stages which are generally similar for marine turtle species (Pritchard, 1971). These stages are: emergence, site selection, body pitting, digging, laying, covering, camouflaging, turning towards the sea and leaving.

Emergence is the initial stage of the nesting process at which point the gravid turtle exits the surf and travels up the beach. She will pull herself perpendicular to the waterline until clear of the high tide mark. The turtle pulls itself up the beach using 2-5 pulls of the front flippers interspersed with rest periods. When selecting a nest site there are species differences, leatherback turtles show preference for nesting in the open sand before the primary dune. Green and hawksbill turtles may nest further up the beach closer to or in the vegetation line (Hays et al., 1995; Wang and Cheng, 1998). Once the site has been chosen the turtle then begins to “body pit” which involves pushing away the surface sand using powerful strokes of the front flippers and swinging the rear flippers from side to side. Eventually the front flippers become immobile once the body pit has been completed. The turtle then begins to dig. The leading edge of the rear flippers is used to scoop upwards and then throw sand out of the body pit. This signifies commencement of chamber construction. As the turtle digs down she takes progressively more sand away from the chamber wall so that a bulbous chamber is created which diameter is narrowest at the surface. Only when the turtle cannot feel the lowest point of the chamber (around 1 metre/3 feet deep) the nest depth has been reached and oviposition can begin. Often one flipper sits just above the tail concealing the eggs as eggs they are dropped in pairs or threes for no longer than 10 minutes. After all the eggs have been deposited the turtle begins to cover the excavated egg chamber. Using the rear flippers she compresses sand on top of the eggs until it has been filled level with the surface of the beach. Finally, the nest site is camouflaged so that the egg chamber cannot easily be located. During this stage the front flippers are again utilised. Much the same as in the body pitting process, strokes of the front flippers and movements of the rear flippers are made to displace surface sand. The turtle covers a large area when camouflaging, often pivoting and may create multiple false nests. This ensures that the site of the body pit is also hard to distinguish. Finally, the turtle departs the nest site and returns to the ocean.

Morphology and Terrestrial Locomotion

Turtles are easily identified from the locomotor adaptations which occurred during the evolution from terrestrial to marine organisms. The development of a streamlined body and the modification of the pectoral limb into a convex, 'wing-like' fore flipper with enlarged pectorial muscles are characteristic. The enlarged pectoral muscles are of proportionately greater mass in marine turtles than in their terrestrial and freshwater counterparts (Wyneken, 1997). In addition, marine turtles have a reduced skeletal component and have incorporated membrane and cartiliage in place of bone elements. The hydrodynamic design of turtles has minimised the cervical, axial, and inguinal pouches and it is because of this design that marine turtles cannot retract their limbs or head.

The leatherback, *Dermochelys coriacea*, is the sole occupant of the Dermochelyidae family and is further morphologically distinct from all other species of marine turtle which belong to the Cheloniidae family. The enormity of the leatherback is the most obvious physical difference when compared to individuals of other species. Leatherback turtles may grow to a carapace length of up to 2 metres and weigh up to one tonne (916kg) (Morgan, 1989). By comparison, adult green turtles (the next largest species) may attain a size of 122cm and a mass of ~200kg (Spotilla, 2004). The other classic visual difference between families is the absence of a rigid shell in Dermochelyidae. A series of bony, overlapping plates form a protective shell in all Cheloniids.

Internal examination reveals unique morphological and physiological adaptations in the leatherback. Unlike other reptilian species, the leatherback has a countercurrent exchange system which involves blood flowing to the front and rear flippers (Davenport, 1997). The endothermic adaptations of leatherback are a thick layer of subcutaneous blubber, between the surface of the skin and muscle, which helps to retain heat and a high volume to surface area ratio. Leatherbacks can maintain a core body temperature several degrees above that of their surroundings (Mrosovsky and Pritchard, 1971; Frair et al. 1972). Such is the effectiveness of these endothermic adaptations that non-breeding adults have been sighted as far North as waters off the coasts of the UK and Canada "swimming vigorously" in waters of 0℃ (Goff & Lien , 1988).

The forelimbs of the leatherback are longer than the other sea turtles and may span up to 270 metres in an adult (NOAA, 1992). The movement of Leatherback forelimbs constitutes a highly efficient gait in water and is unique among turtle species. Propulsion is produced during all phases of the stroke: upward-outward, then downward-inward. Sustained, efficient swimming (Rhodin et at., 1981) allows huge migrations to and from nesting grounds, which may be up to 6,000 miles from foraging grounds (James et al, 2005). When swimming other species of turtles only generate thrust during the backward stroke only (Wyneken, 1997). Together the swimming action, form and physiological attributes of the leatherback turtle make it suited to a marine existence.

As part of the reproductive cycle marine turtles must return to land to complete oviposition (Miller, 1997). First, selecting a suitable location to emerge at and then traverse away from the high tide line until a secure location for oviposition has been reached. During this transit the gait of turtles is laboured. Once emerged from the ocean, turtles lose the buoyancy provided in part by the subcutaneous blubber that supports the substantial mass. The average nesting female is estimated to weigh approximately 400kg in the region (Georges&Fosette, 2006).

Sea turtles exhibit two distinct styles of gait when in the terrestrial environment. In green and leatherback turtles, the contra-lateral limbs move synchronously. This gait is exhibited by few other animals (Lutcavage and Lutz, 1997). The front flippers push against the substrate to lift the body up and the rear flippers push forward. The imbalance created and the horizontal component drags the turtle forward (Carr et al., 1966; Renous, 1993). The posterior portion of the plastron never leaves the substratum. The turtle pulls itself up the beach using 2-5 pulls of the front flippers interspersed with rest periods (Pritchard, 1971). By contrast, the hawksbill uses a typical reptilian style of walking which involves diagonal limbs moving in synchronization. However, a commonality in terrestrial locomotion is that all 4 flippers are utilised in some form by all seven sea turtle species (Wyeneken, 1997).

Emergence and transit in the terrestrial environment is important as turtles attempt to complete the reproductive cycle. Effective locomotive performance may reduce the duration of nesting attempts during which turtles expend a lot of energy (Lutz&Musick, 2000) and are vulnerable to predation. Performance in adults may also influence the accessibility of steeper beach sections for safe nest sites (where turtles can deposit eggs further above the high tide line).

In hatchling marine iguanas (*Amblyrhynchus cristatus*) it was found that larger hatchlings ran faster. After the effect of body size was removed it was revealed that individuals with longer limbs, specifically the tibia bone and shorter pes, or foot, were relatively faster than individuals with shorter tibia and longer pes (Miles et al., 1995). Longer flippers may therefore generate greater velocity during turtle transit by increasing the height of the body and hence potential energy during the “crutching” movement of the leatherback gait (Renous&Bels, 1993). Larger animals can move a given mass over the same area as smaller animals whilst requiring less energy to do so (Tucker, 1970; Taylor et al., 1982; Baudinette et al., 2000).

However, in Painted turtles (*Chrysemys picta*) no effect of body size on locomotive performance was detected (Zani and Claussen, 1994). Garland (1984) demonstrated that *Ctenlosaur* showed a positive relationships between mass and both endurance and total distance run but no effect on speed was found. Therefore, it may be expected that larger animals have reduced velocity but increased transit distance. The locomotor performance of animals may significantly influence the lifetime fitness and persistence of an individual’s genetic material in the population. Alternatively, the effect of morphology and locomotive performance on adult fitness is unclear and there may be no effect (Jayne and Bennet, 1990).

Previous work in Tobago found a narrow carapace and longer flipper reach to be beneficial for locomotion velocity in hatchling leatherbacks (Mickelson and Downie, 2010). However, hatchling leatherbacks have disproportionately long flippers compared to adults so there may be a difference in the morphological traits and body types which translate to quickest locomotive speed. Also, adult turtles face comparably lower predation threat when compared to neonates and so terrestrial velocity may be of little adaptive importance.

Aims

I took the opportunity to collect morphometric data on the female during the nesting process. When the female was making her post-nesting return to the sea I timed the duration of this crawl. I wanted to test whether I could link the morphometric features to locomotive speed. My study looked at the behaviour, free from manipulation, in contrast to maximal animal perfomance, where animals are pushed to the limits in a laboratory setting. This study attempted to examine the relationship between terrestrial transit velocity and individual morphology parameters and also group parameters, referred to as “body types”.

Artificial Light

It is thought one-third of the world population habituate in an area just 4% of the planet's surface - the coastal biome (UNEP, 2006). As urbanization takes place industry, amenities, hotels and residencies have been developed along the many miles of coastline occupied. Artificial lighting of individual structures and the cumulative impact of urbanization causes illumination of the night sky as development is often poorly regulated (UNEP, 2006) with respect to light. Artificial illumination of the night sky causes habitat alteration which can have harmful consequences for nocturnal wildlife (Salmon, 2003) and this is termed 'light pollution' (Witherington and Martin, 2000). With projected coastal population growth (UNEP, 2006) quantifying the effects of light pollution on wildlife and devising management plans should be of the utmost importance. Light pollution, specifically on the beachfront, is a concern for conservationists in Trinidad and Tobago as they host an important nesting population of critically endangered leatherback turtles in the world (Eckert, 2006).

Light pollution can affect a variety of organisms as they try to perform natural behaviours during the hours of darkness (Longcore&Rich, 2004). An unambiguous illustration of the potentially deleterious effects of light pollution was seen in migratory birds. Birds were observed to collide with lighted obstacles such as lighthouses and television towers as they become disorientated (Verheijen,1980; Verheijen, 1981). Similarly, Jones and Francis (2003) recorded up to 2000 migrating birds killed each night after colliding with a bright light house in Ontario, Canada. Bird et al. (2004) investigated the effects of long-wavelength lights — low-pressure sodium vapor and bug lights - on the foraging behaviour of Santa Rosa beach mice (*Peromyscus polionotus leucocephalus*). Mice exploited fewer food patches near both types of artificial light than in areas with little light and harvested fewer seeds within patches near bug lights.

Marine turtles, Cheloniida and Dermochelyidae, are disturbed by light pollution during the nesting season when gravid female turtles must emerge from the sea to deposit clutches of eggs. In recent decades it has emerged just how acutely light pollution affects sea turtles (Salmon, 2003). Light pollution interferes with adult emergence, return to sea and hatchling sea-finding ability (Witherington and Martin, 2000). Interference in hatchling sea-finding ability creates problems for population replenishment of species which are already threatened and in decline. The pacific leatherback population declined by over 90% towards the end of last century though the atlantic population may be more stable (Spotilla et al., 2000).

Light pollution first impacts the nesting process in the marine environment. A negative relationship between beach illumination and the number of gravid turtle emergences at nesting beaches has been shown (Eckert and Horrocks, 2002). The ‘glow’ of artificial light from developed areas, such as cities may be seen up to 100 miles away (Cinzano et al., 2001). Many nesting beaches have been suitable for generations of turtles but relatively recently have become illuminated by light from nearby towns and cities – rendering them less preferable.

Barbados (W.I.) is a small Caribbean island which has seen much of its west and south coast developed for tourism. Here nesting hawksbill turtles are deterred from nesting on wide sandy beaches which are highly illuminated instead choosing to nest on narrow stretches of sand in darker locations. As a consequence nest locations are often sub-optimal and the deposited egg clutch is at risk of erosion. Temporary tidal inundation reduces hatch success in nests which are not exposed or completely washed away (Eckert and Horrocks, 2002). Witherington (1992) carried out experimental manipulation of the nesting environment at important nesting beaches for loggerheads, *Caretta caretta*, in Florida, and greens, at Tortuguero, in Costa Rica. Similarly, he found that on nights when the beach was illuminated with mercury vapour lights there was a significant decrease in successful and non-successful nesting attempts by turtles.

Leatherback turtles generally abandon nesting approaches - make “false crawls” – less than the other turtle species (Pritchard, 1971) and it is because turtles are dissuaded from emerging at brighter illuminated beaches that the ratio of unsuccessful nesting emergences – referred to as ‘false crawls’ - to completed nests may not provide an accurate measure of the disturbance caused by light pollution (Witherington and Martin, 2000). Turtles of other species which do choose to nest on illuminated beaches are observed to avoid brighter areas and emerge in areas which have natural or manmade barriers to the light. For example, Salmon et al. (1995) observed a clustering of loggerhead nests in darker areas of beach at Boca Raton, Florida. These clusters were located in front of dark beachfront properties which shield the beach from illumination produced at a nearby city. Nesting turtles were observed to avoid the gaps between the high rise condominiums where illumination could protrude. Furthermore, increased densities were seen in front of the tallest of condominiums which were able to shield more light. In locations such as Florida where development has progressed unrestricted (Salmon, 2003) this relationship is repeated over a vast spatial scale. This work has provided strong evidence that light pollution influences the beach at which a female emerges and also the area chosen to nest within a beach, the stage referred to as site-selection.

The result of my literature revealed research focus has prioritised loggerhead, hawksbill and green turtle species. This is despite observations of light problems in hatchling leatherback attracted to lights many decades ago (Mrovosky and Shettleworth, 1975). In one recent study, Medicci et al. (2009) found that the use of electric lighting was enough to increase the proportion of false crawls on the beach and decrease the number of emergences. False crawls may result from ‘frustration’ and disorientation from artificial lighting (Bacon, 1973). However, I believe the decrease in overall nesting reported by Medicci et al. (2009) should be viewed cautiously as already explained the false crawl ration may not be an accurate measure (Witherington and Martin, 2000). Further to this, the duration of the treatment was only 2 years which is well within the remigration interval of leatherbacks (Miller, 1997) and hence the number of nesting females can fluctuate. Bacon (1973) classified beach ascent tracks of leatherback during a study at Matura, Trinidad. He observed turtles making “orientation circles” and hypothesised that these occur due to changing light cues on the beach ascent. This would affect the visual cue and result in disorientation.

Once a turtle has satisfactorily camouflaged the nest it will orient by turning to face seaward and the return to the ocean. Experiments with nesting turtles have indicated that vision plays a key role in guiding the turtle back to the sea (Ehrenfeld, 1968). Ehrenfeld (1968) blindfolded green turtles before they began to make a seaward transit in order to ascertain how turtles responded to light reaching their eyes. This research was important in establishing the mechanism by which turtles navigate back towards the sea. Turtles balance the light level between their eyes which enables them to orient on a seaward bearing. This was called phototropotaxis, which is the act of turning or moving with respect to light. Positive phototropotaxis indicates an attraction to light, negative indicates repulsion.

The reflection of light from the moon and other celestial sources on the surface of the ocean creates a low, bright horizon. Vegetation behind the beach absorbs light creating a darkened landward horizon. A bright seaward horizon has safely guided sea turtles off the natal beach into the ocean hence sea turtles evolved to follow this brightness cue (Nicholas, 2001; Tuxbury and Salmon, 2005). Anthropogenic habitat alteration is now compromising the efficacy of this vital cue (Nicholas, 2001). Beach illumination now means there may be two or more sources of bright light and the ocean is no longer the brightest direction. Turtles may become misorientated, travelling in the wrong direction, and disorientated, which is an inability to orient in constant direction (Verheijen, 1985). Misorientation may lead to adults and hatchlings becoming stranded far from the ocean or trapped by debris and vegetation. The consequences of crawling for hours off of the beach off the beach in the landward direction without reaching the sea are exhaustion and dehydration. Deem et al. (2007) report that the continued significant development of coastline in Gabon causes the death of nesting females and thousands of hatchlings every year as a result of disorientation and misorientation by proximal urban lights. Rescued individual adults are also often at risk of death as irreversible physiological changes may already have taken place.

Once emerged from the sand it is imperative that hatchlings orient towards the sea and exit the beach as quickly as possible. It is the temperature drop in the sand that cues hatchling emergence, typically occurring during the night (Mrosovsky, 1968). Emerging at night reduces the risk of exhaustion, depradation and dessication. However, this neo-natal environment may be polluted with light. Light pollution can interfere with the innate cues hatchlings require to orient themselves seaward. Hatchlings use sight to locate the sea, scanning 180° on the horizontal axis and 30° vertically (Salmon, 2003). Using information brightness cues gathered from visible horizons hatchlings make a decision on their bearing of travel. Hatchling sea turtles orient towards the lowest, brightest lit horizon and away from vegetation which absorbs light (Nicholas, 2001; Tuxbury&Salmon, 2005). For many years light was reflected from the ocean and absorbed by vegetation behind the beach so hatchlings would crawl away from the dimmer landward horizon and crawl toward the brighter seaward horizon. Celestial light may play a role in ameliorating the overwhelming brightness of artificial lights by increasing the ambient level. This reduces the relative brightness of artificial lights.

The wavelength and intensity of light is also important to sea turtles. Longer wavelength red light (~650nm) is absorbed by water first and the shorter blue wavelengths (~475nm) penetrate water further. From an evolutionary perspective, animals which spend most of there time in the ocean would be better off with a sensitivity to blue light and lessened sensitivity to red light. Green turtle hatchlings studied were more attracted to blue than red light. Witherington (1992) showed that green, hawksbill and olive ridley turtles were most attracted to light in near ultraviolet and yellow region and weakly to orange and red light.

Sea turtles have a weakly developed sphincter muscle, which is required for focusing the lens (Bartol et al. 2003). Though turtles do not possess outstanding visual acuity on land they are capable of resolving between colour and shape (Ehrenfeld&Koch, 1967). The good depth of focus of hatchlings means they may also be able to orient using shape cues. Tall, dark silhouettes repel hatchling turtles (Salmon et al., 1982; Tuxbury and Salmon, 2005). The terrestrial and marine orientation systems are functionally autonomous (Lohmann., 1990) as hatchlings use wave cues to guide them offshore (Lohmann et al., 1990). However, hatchlings which have been disorientated for a long time (> 2hours) may have problems orienting once in the ocean if there is a lack of a strong wave cue present (Lorne&Salmon, 2007). Additionally, in areas of weak wave action hatchlings may even be attracted back inshore to bright adjacent beaches (Harewood&Horrocks, 2006).

It is because light pollution has potentially deleterious effects for sea turtles that I studied the effect of artificial lighting at Tobago's index beaches during the nesting season of 2010. Trinidad and Tobago hosts a globally important nesting population of leatherback sea turtles (Eckert, 2006). Light pollution is of particular interest and concern as Tobago's most populous Leatherback beach is flanked by a hotel around the middle portion of the beach and by a town, Plymouth, to its northern end. As a result areas of Turtle Beach are illuminated by artificial sources throughout the entire night.

Aims

The aim of this study was to identify and quantify spatial measures of light disturbance. Observations of turtle transit are considered an effective means of elucidating whether light pollution has an effect (Witherington&Martin, 2000) and therefore formed the basis of my data collection. Where significant problems were identified I make management recommendations to stakeholders.

Methods

Equipment

A 2-metre flexible measuring tape and a set of 100cm custom-made callipers were used for morphometric measurements of turtles. A stopwatch was used to time the transit duration of turtles as they exited the beach. A compass was used to ensure the start and finish lines of the 'race track' were parallel and to determine turtle directionality. An ATP LX 20 Digital Lux meter ±3% of reading ±0.5% scale below 10,000 lux (ATP Instrumentation Ltd, Leicestershire), was used to measure the light level.

A Garmin ETrex H GPS (Southhampton, UK) was used to record the location of turtle nests and subsequent observations. These locations uploaded to the computer and used in geographical information systems (GIS) software, ArcGIS (ESRI software, Aylesbury, UK).

Beach patrols and protocol

It is considered that nesting of leatherback turtles is concentrated across three beaches in the south-west of Tobago: Grand Courland Bay (known as "Turtle Beach"), Stonehaven Bay (known as "Grafton") and Mount Irvine Back Bay ("Back Bay"). A local, community based organization, Save Our Sea Turtles (SOS Tobago) has carried out nightly monitoring patrols of these so termed 'index beaches' in each nesting season since 2000. The leatherback nesting season endures from March to July (Clovis, 2005) and peaks around the end of May or the beginning of June. Index beaches are patrolled every night between 20.00h and 04.00h or until the last turtle has returned to the sea, whichever is later. SOS Tobago protocol sees patrollers cover the full extent of the beach throughout the night by walking at 25-30 minute intervals.

Primarily, this frequency of walking ensures that there is a visible patrol presence on the beach protecting the nesting turtles. This is intended to dissuade any illegal poaching activity. Additionally, this frequency means any nesting turtles will be encountered in the initial stages of the nesting process: approach, body-pitting or digging.

Once a turtle was encountered, the time, weather and activity stage was recorded. Each turtle was then monitored until oviposition commenced. Oviposition is a short window in which patrollers can work around the turtle and lasts no more than 10 minutes in duration. Only after the turtle had been observed to drop approximately 20 eggs did patrollers make physical contact with the turtle. This ensures the turtle is well immersed in the “trance-like” stage of egg-laying and will not abandon the nesting process. The posterior end of the turtle was illuminated using a torchlight which had had its lens concealed with red light filter paper.

Where present, tag numbers were recorded and where not, Monel tags were applied to the area of loose skin between the tail and each of the rear flippers. Tags are positioned in the centre of the trailing edge of the skin. A fingers width or approximately 1cm section of tag is left overhanging beyond the posterior extent of the skin in order to allow room for growth. A passive integrated transponder (PIT) tag was inserted into the front right shoulder muscle of the turtle also. PIT tags will remain with the turtle for life whereas external flipper tags show lower rates of retention (Eckert and Beggs, 2006).

Two morphometric measurements were taken using a flexible 2-metre measuring tape, curved carapace length and curved carapace width. Length is measured by aligning the tape to the side of the central longitudinal ridge of the carapace – of which there are seven - which runs from behind the head to the posterior tip. To measure width, the flexible measuring tape is run across the widest part of the turtle close to the shoulder and perpendicular to the longitudinal ridges. There are three pairs of ridges located progressively closer to the plastron (the ventral surface) on each side and bisected by the central ridge. The lowest pair of ridges on either side demarks the boundary between the plastron and carapace. This is used for curved carapace width measurement.

Unique identifying marks or injuries were recorded at this point. The beach, zone, GPS ‘point of interest’ and any landmarks were recorded as location information. The number people (categorized as locals or tourists) who witnessed the nesting event were recorded. Any problems associated with people or light were recorded categorically (yes or no).

Sampling of morphometric data

I simply extended the standard nesting event protocol by measuring the turtle during oviposition only and using similar equipment hence my measurements were equally benign to the turtle. An initial visual check indicated whether there were any flipper injuries or damage to the carapace tip which would prevent a full set of measurements. Nest sites were required to be a minimum distance of >2 metres from the high tide line to allow a 2 metre track to be drawn across which the turtle would be timed.

I recorded tag numbers to prevent sampling the same turtle more than once thus avoiding pseudoreplication. Identification markings, the lay date and small annual growth rates seen in adult turtles (Price et al., 2004) also provided insight into whether untagged turtles had been sampled during deposition of previous clutches. Turtles lay at 9-10 day intervals (Hughes et al 1967; Miller, 1997) so untagged turtles which laid at multiples of these from date of first encounter were excluded as a precaution.

The 100 centimetre calipers were used for head and appendage measurements. Head width was taken as the widest point at the back of the head where the shiny surface of the top of the head and flesh of the body meet. The length of the front flippers was measured along the trailing edge as the front edge is buried in the sand during oviposition (Pritchard, 1971). I aligned the caliper head with the corner of the flipper nearest the carapace and then at the distal point of the fully extended flipper. The width of the flipper was taken at the widest point across the dorsal surface close to the body. Loose sand was removed and the caliper head inserted under the flipper and closed onto the trailing edge of the flipper.

In order to estimate mass I measured body circumference at half of the curved carapace length for use in the formula derived by Georges and Fosette (2006). For this measure of carapace length the 2 metre tape must be aligned along the top of the central ridge. Using Georges and Fosette's (2006) formula, the mass of a turtle can be estimated with 93% accuracy from morphometric measurements:

Body Mass (kg) = *-709.146 + 3.391MedianBodyCirc (cm) + 2.664SCCL (cm),*

where SCCL is the curved carapace length along the ridge and MedianBodyCirc is body circumference at half of curved carapace length along the ridge.

To measure circumference I dug under the ventral surface of the turtle and then passed the end of the flexible measuring tape underneath so it would meet the tape above the central ridge on the dorsal side of the carapace. Digging can be performed solo or with an assistant.

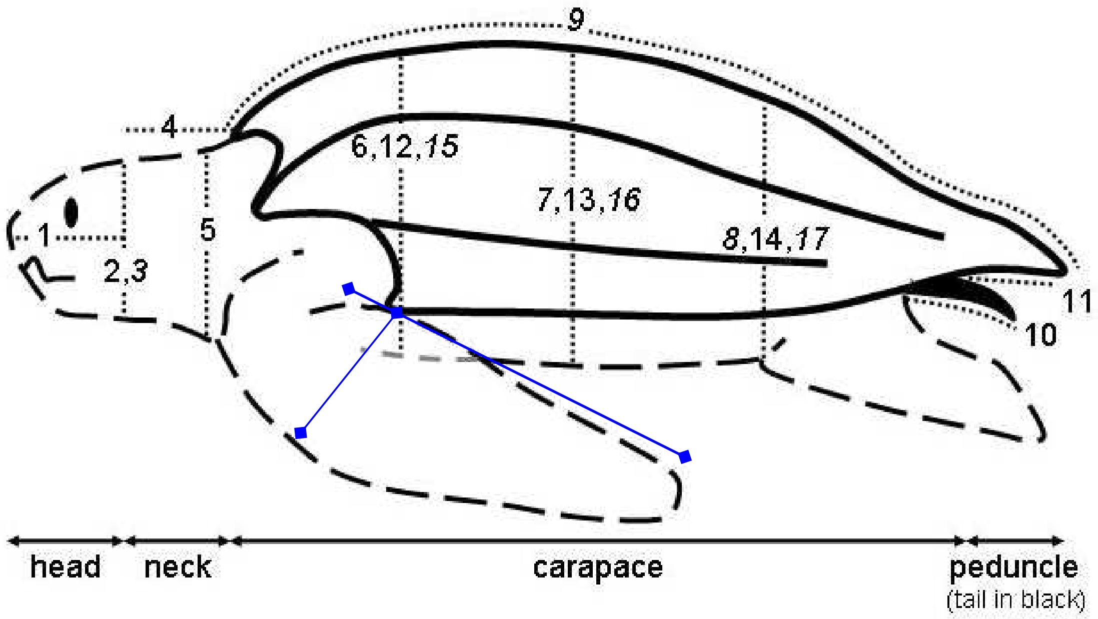

Figure 2 - Modified schematic from Georges and Fosette (2006) shows curved median carapace width (7) and standard curved carapace length (SCCL)(9) measured from nape notch of carapace to distal point of peduncle. Flipper measurements indicated.

In order to sample locomotive speed (my dependent variable) I made a race track on the sand directly between the turtle and sea. This consisted of two 15 metre lines – start and finish - which were parallel to the high tide line. I marked two points on the sand which were perpendicular to the high tide line and 2 metres apart. I used a compass to walk in a straight line and join the two lowest, seaward points (finish line) and the two highest, landward points (start line).

As mentioned previously the minimum required distance of the nest site from the high tide line was >2 metres. A distance of 2 metres for the track limited the potential for a turtle to deviate substantially from a path perpendicular to both the start and finish lines of the track. This ensured all turtles were timed over the same distance.

When turtles were far from the high tide line I created several of the 2 metre tracks. I started the stopwatch as soon as the female's head crossed the start line and stopped it as soon as her head crossed the finish line. I took the shortest time for analysis when multiple tracks were drawn. I avoided positioning the track over a steep beach berm to limit the effect of beach gradient as a potential covariate.

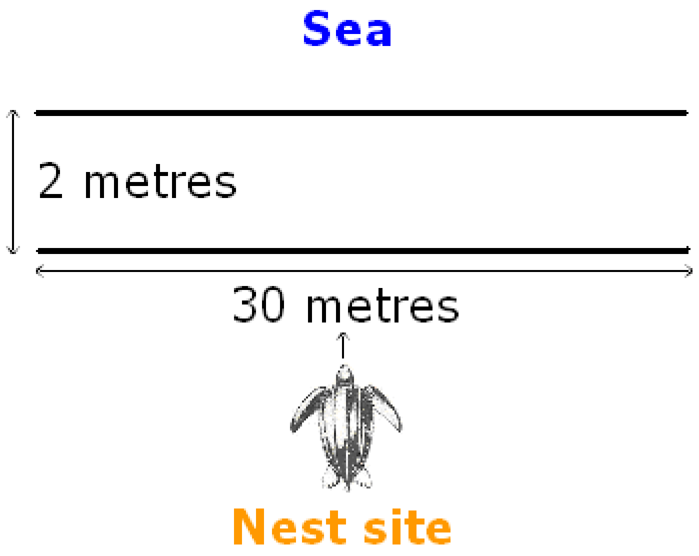

Figure 3 - Race track set up showing turtle (bottom) returning to the water (HTL at image top) and indicating the dimensions of the track (30m*2m)

Sampling of light pollution

I used spatial parameters and observation as a means of detecting whether light pollution was a disturbance factor on the nesting leatherbacks at Tobago's Index beaches: Turtle Beach, Grafton and Mount Irvine Back Bay.

A baseline assessment of light levels was undertaken at Turtle beach. To ensure the light level recorded was entirely from artificial sources and that there was no celestial illumination of the beach the assessment took place during the new moon lunar phase on the night of July 12th 2010. An equipment malfunction meant this had to be carried out by 2 assistants after I departed the field.

Using an ATP LX 20 Digital Lux light meter (ATP Instrumentation Ltd, Leicestershire, UK) the level was recorded at locations along the beach approximately 50 metres apart. Light readings are taken from the middle of the beach to sample from the area of the beach utilised by leatherback turtles when nesting. Each location was marked using the Garmin ETrex H GPS. Readings were taken in 4 compass directions north, east, south and west and up/down. Using the GPS location and the mean light level calculated from the readings I created a raster image in the ArcGIS software. A raster image is comprised of many pixels each of which carry a piece of information. In this instance, the pixels correspond to the light level at a given location. Each of the values has a corresponding colour. The value of intermediate pixels is interpolated within the software to create a continuous transition. This layer of information was superimposed on top of the satellite image of Turtle Beach.

The mean level raster is used to identify brighter areas of the beach. This meant values for spatial parameters and other observations could be compared to the raster output using the gathered positional information.

I observed the turtle transit to and from the nest site. For key stages of the nesting process the bearing of the turtle and the bearing of the highest light level was recorded. To measure the turtle bearing I pointed the compass in the direction of travel and lined up the compass edges parallel to the sides of the smooth depression left by ventral surface of the plastron in between the rear flippers (fig. 4). The bearing of the highest light level as indicated by the light meter and the nature of the light source was recorded.

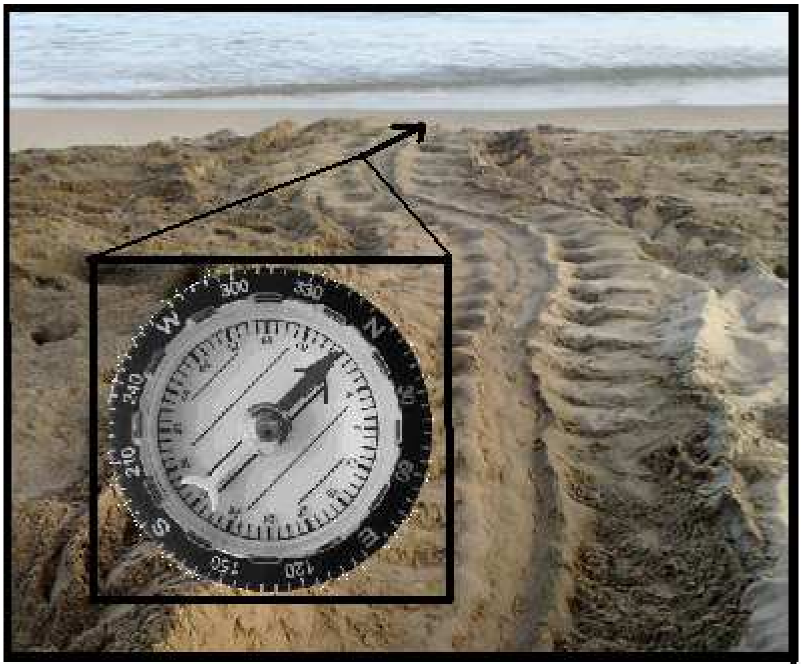

Figure 4 - Example of a turtle track and where compass would be aligned for re-entry bearing during a nocturnal nesting event.

As the turtle crossed the high tide line the bearing of the approach was recorded and that of the highest light level.

At the nest site I recorded the light level in six directions guided by the compass: north, east, south and west, up and down. I also recorded the turtle finish bearing and strongest light bearing and level. The position of the nest chamber was marked positioning the GPS directly above the nest chamber.

As the re-entry bearing is logically determined by the orientation of the beach I recorded the bearing of a direct return to the sea. As the turtle re-entered the ocean her bearing at the high tide line was recorded as was the bearing of the strongest light.

Pritchard (1971) reported a renewed vigor in turtle locomotion upon contact with water. This may cue the turtle to the proximity and directionality of the sea hence we used the high tide line as a cut off.

The most important measure of light pollution as a disturbance factor may be revealed through the tracks left by turtle transit (Witherington&Martin, 2000). Hence, I observed turtles during their approach stage, camouflaging and return to sea. On square delineated paper 1cm by 1cm, a scaled sketch was made of my observations. I categorised the tracks of females in the following manner: 1 sinuous approach – straight return; 2 straight approach – straight return; 3 sinuous approach - sinuous return and 4 straight approach - sinuous return (fig. 5)

A description of diagnosed misorientation, parallel movements to shore and any disorientation and changes in directionality was made. Turtles were given a tolerance of 7.5 degrees either side of a direct bearing to sea before an event was classified as misorientation. Any occasion when a turtle performed a 360° revolution, hereafter referred to as ‘circles’ or ‘circling’ (fig. 5) and whether it was deemed necessary for myself or another trained member of the SOS patrol staff to intervene was recorded. Intervention is sometimes required to direct the turtle back onto a seaward bearing. This is implemented by standing in front of the turtle’s front flipper so that she will contact the patroller when moving forward. In other words, the turtle will brush her front flipper against the leg of the patrol staff. By positioning oneself in this manner the turtle will turn in the direction of the unaffected flipper. For example, a patroller would stand by the left flipper to send a turtle to the right. Circling excludes the movements of covering and camouflaging behaviour.

I can declare that all the observations of turtle transit behaviour were performed by the author. Consequently the potential for inconsistency between observers and decreased reliability of transit observations is eliminated. The baseline light survey required the help of assistants but there is no subjectivity in this assessment.

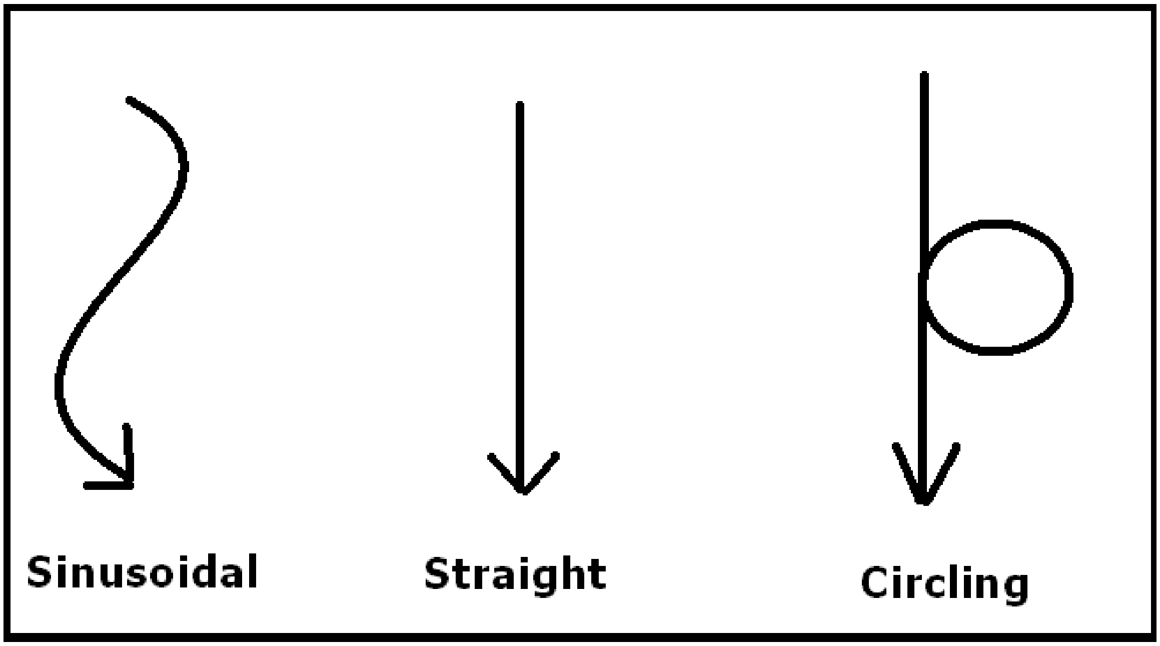

Figure 5 - Example of transit tracks which comprised sketches. From left: sinusoidal, straight and circling.

Data relating to hatchling emergences for the 2009 season was used to predict the consequences of nesting in a given area for the hatchlings.

Statistical Analysis

Statistical Analyses was carried out in SPSS v.15 (Middlesex, UK). Data were checked that they satisfy assumptions of normality of residuals, variance and independence of data.

PCA was used to group morphological traits into body types. PCA scores were then tested against a dependent variable - locomotive velocity.

Pearson and Spearman ($n<30$) correlations were used for bearing analysis as appropriate. Data relating to the bearing of transit had to be screened and corrected for location as appropriate. In these instances, where the compass angle exceeded 360 degrees these were adjusted to continue the number. This was necessary as angles would revert back to single digits after passing zero and hence destroy any correlations in analysis.

Given the small range of values it was not necessary to perform log transformations of mass for any of the tests.

Results

Morphology relationships

The mean head width of turtles was 22±1.41 cm. Mean left flipper length 71.7±4.17cm and width 33.7±1.28 cm; right flipper length 71.9±4.13 cm and width 33.2±2.31cm. Curved carapace length (ridge) 158.54±6.94cm; width 114±3.14cm and curved median carapace width 193±10.4cm. Mean turtle mass was estimated at 368.97±44.53kg.

Table 1 - Descriptives of morphometric data of nesting turtles

Variable	N	Mean	±s.d.
Curved carapace length (on top of ridge)	26	158.54	6.94
curved carapace length (alongside ridge)	15	155	6.6
Curved carapace width	24	114	3.14
Curved median carapace width	26	193	10.4
<u>Left flipper</u>			
Length	25	71.7	4.17
Width	25	33.7	1.28
<u>Right flipper</u>			
Length	25	71.9	4.13
Width	25	33.2	2.31
Head	22	22.5	1.41
Mass	26	368.97	44.53

Lengths in centimetres (cm) and mass kilograms (kg).

Pearsons correlation coefficient, r = 0.090 (22), showed no significant relationship between curved carapace length and curved carapace width, n = 24, p = 0.675. The data points are generally clustered in the centre of the scatter plot.

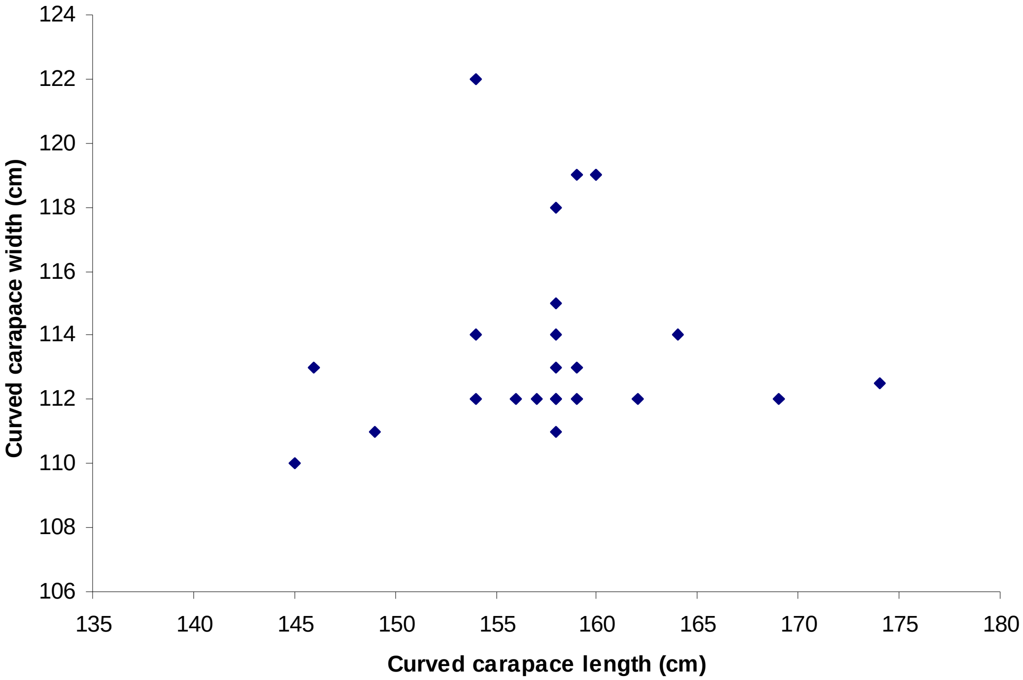

Figure 6 - Relationship between curved carapace length and curved carapace width

Pearson’s correlation coefficient, r = 0.295 (24), showed a weak positive relationship between curved carapace length and mean body circumference. This relationship was not significant, n = 26, p = 0.144. The mean body circumference of turtles increased as curved carapace length increased.

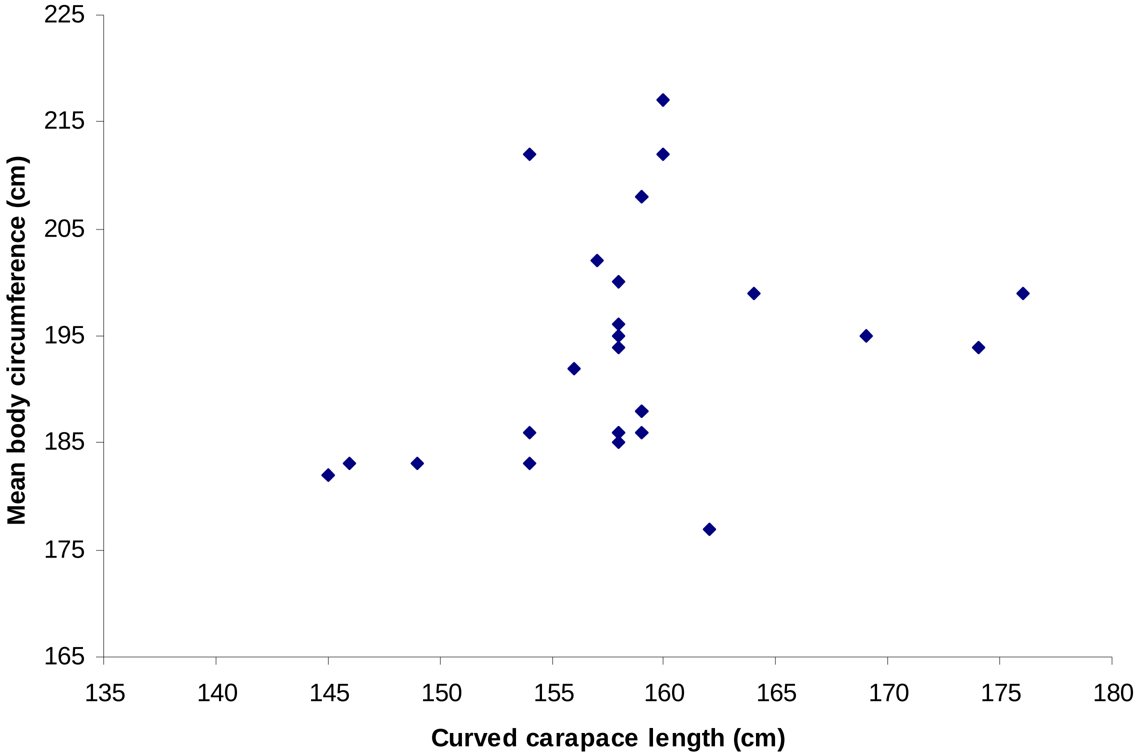

Figure 7 - Relationship between curved carapace length and mean body circumference

Pearsons correlation coefficient, r = 0.650 (24), showed a significant relationship between curved carapace length (ridge) and mass, n = 26, p < 0.000. The data points are generally clustered in the centre of the scatter plot.

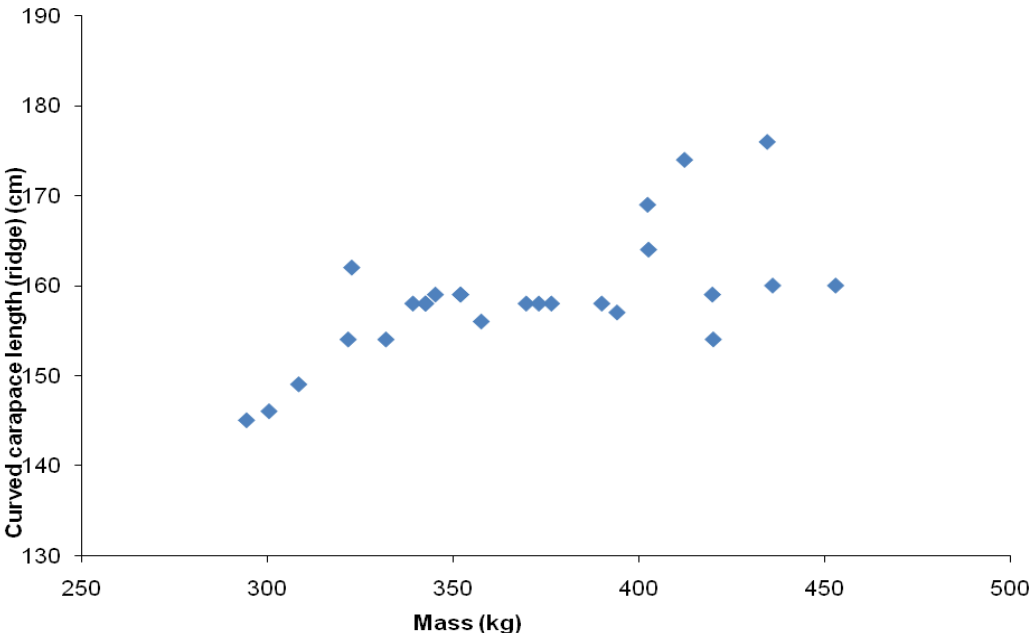

Figure 8 – Relationship between curved carapace length (ridge) and mass

Pearsons correlation coefficient, r = 0.595 (23), showed a strong relationship between curved carapace length and mean flipper length (left and right front flipper). This relationship was highly significant, n =25, p = 0.002. As curve carapace length increased the mean front flipper length increased also.

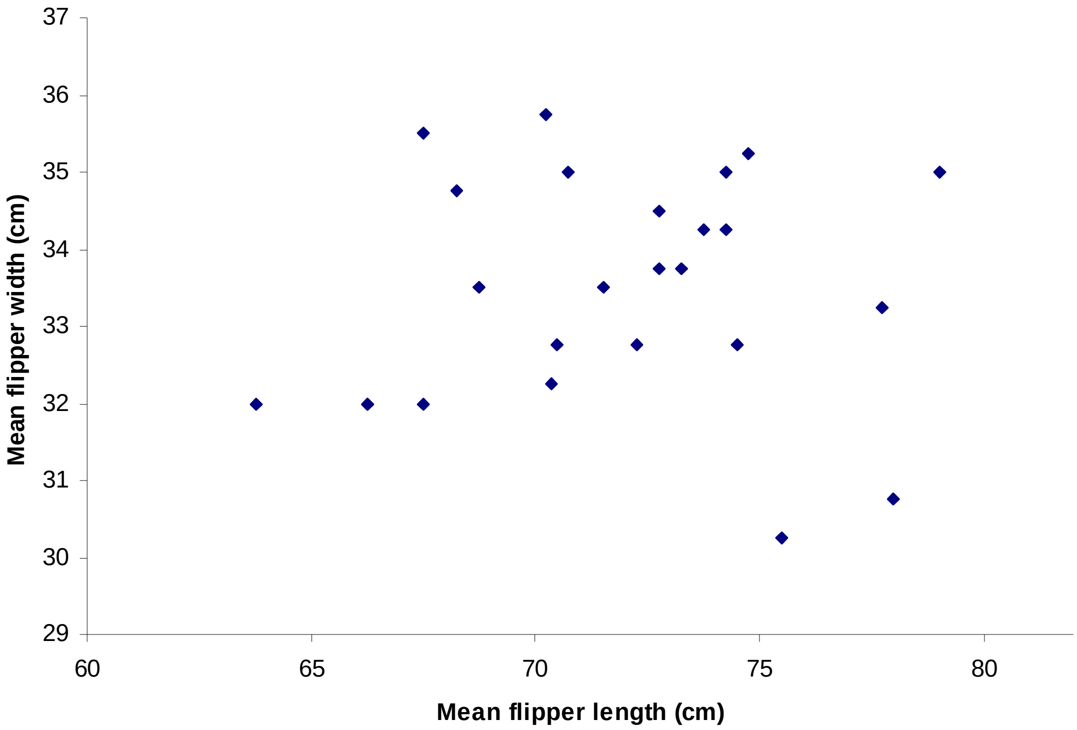

Figure 9 - Relationship between curved carapace length and mean flipper length (left and right front flipper)

Single morphological traits and velocity

Pearson’s rho value, r = 0.259 (23), indicated that there was no significant relationship between curved carapace length (along the ridge) and velocity, n = 25, p = 0.211. Both the lowest and highest value for velocity was achieved by the two longest turtles. Points appear clustered around the mean length for nesting turtles (fig) of 158.54±6.94cm.

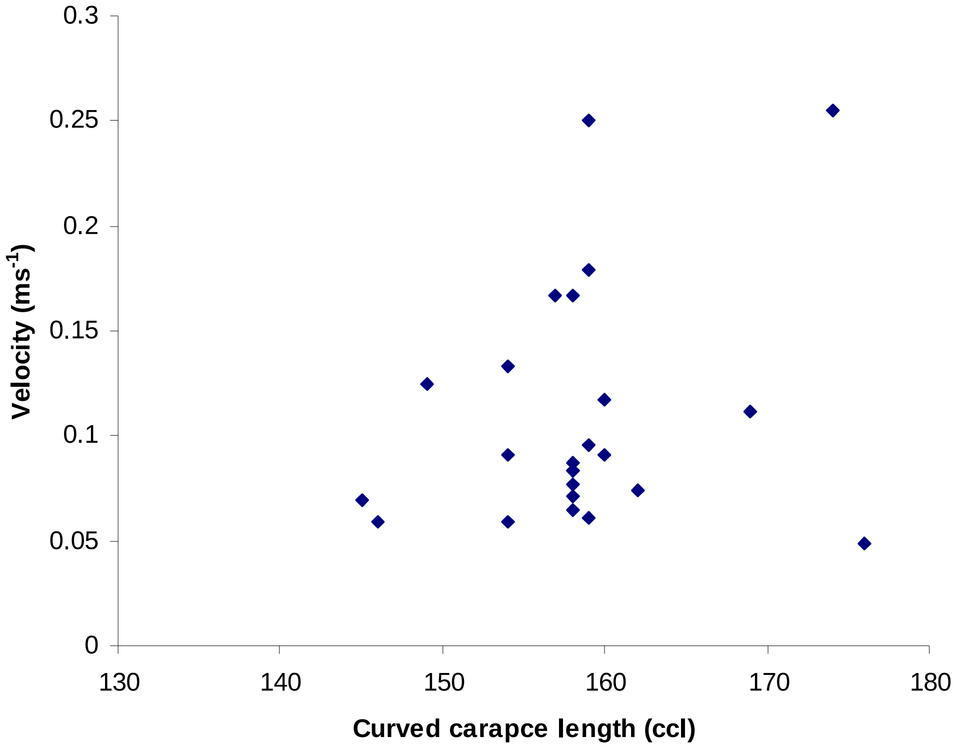

Figure 10 - Relationship between curved carapace length (along the ridge) and velocity

Pearson’s correlation coefficient, indicated that there was a positive relationship between mass and velocity but this was not significant, n = 25, p = 0.095. As turtle mass increased so did velocity but not significantly.

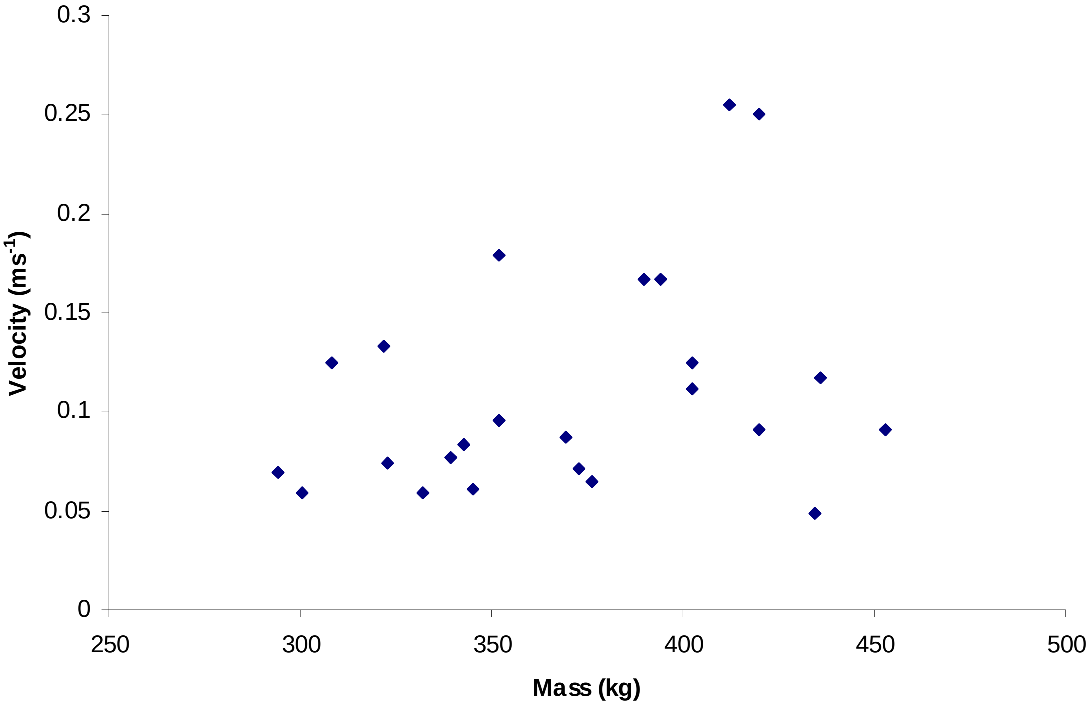

Figure 11 - Relationship between mass and velocity

Pearson’s correlation coefficient, r = 0.039 (23), indicated that there was no significant relationship between mean flipper length and velocity, n = 25, p = 0.854. Given the bellshaped curve it would appear that the highest velocities occurred at an optimum flipper length around 70-75 with slower velocites at lower and higher than average flipper lengths.

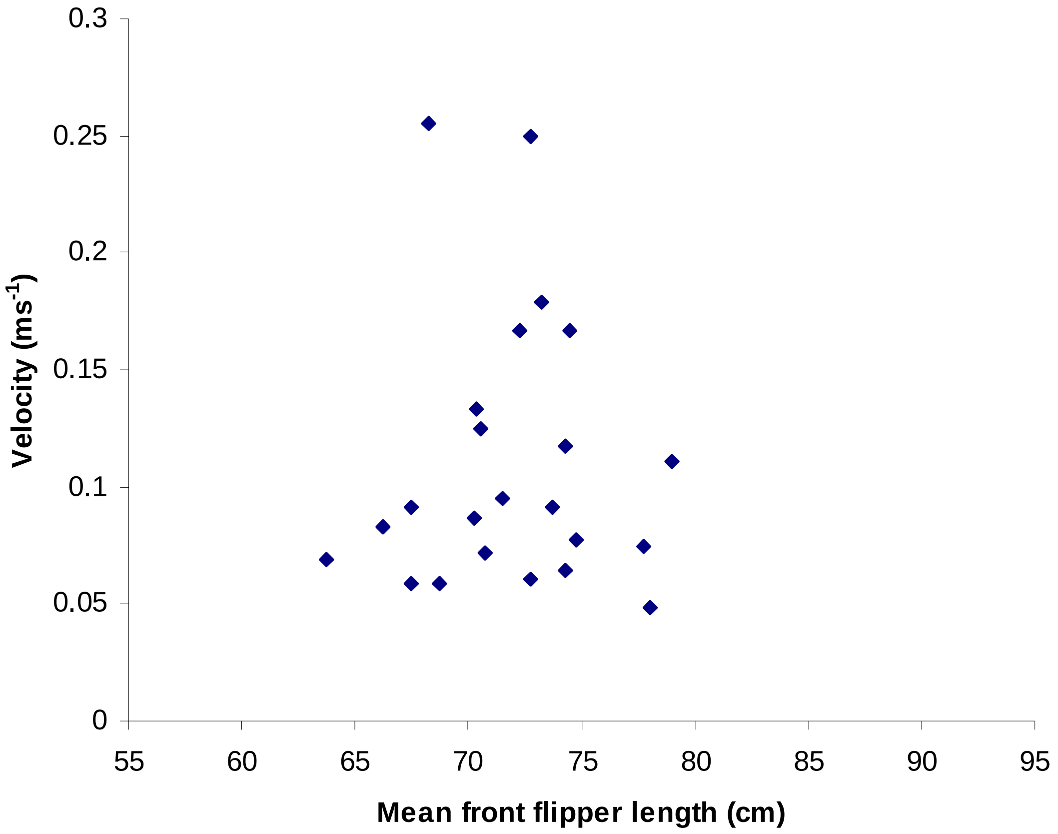

Figure 12 - Relationship between mean flipper length and velocity

Grouped morphological traits and velocity

Analysis was performed using complete morphology data from 20 individual nesting turtles. Nine principal component combinations were calculated. The results of the PCA indicated that a three component solution accounted for 77.906% of the variation in adult morphology and size. The scree plot indicated that it was correct to retain only the first three components. Descriptions for these three components can be found in table 2.

Table 2 - Results of the PCA analysis

	PC1	PC2	PC3
Eigenvalue	3.816	1.881	1.314
Proportion of variance	42.405	20.900	14.601
Cumulative proportion of variance	42.405	63.305	77.906
Variable			
Curved carapace length (along ridge)	0.236	**0.748**	0.224
Curved carapace width	**0.826**	-0.111	0.388
Curved median carapace width	0.976	0.120	0.044
<u>Front left flipper</u>			
Length	0.071	**0.867**	-0.073
Width	0.413	0.217	**0.643**
<u>Front right flipper</u>			
Length	0.028	**0.905**	0.107
Width	0.139	0.133	**0.789**
Head	0.037	-0.041	**0.831**
Mass	**0.886**	0.391	0.124

*Dominant loadings are in bold

In the first component we can see that circumference, mass and width are 3 large positive loadings – this comprises the body type ‘bulk’. PC1 = 0.976 (Curved median carapace width) + 0.886 (mass) + 0.826 (curved carapace width)

In the second component we can see all components load positively. Front left and right length, ridge load well – this comprises the ‘body and limb length’ type. PC2 = 0.905 (front right flipper length) + 0.867 (front left flipper length) + 0.746 (curved carapace length along ridge)

In the third component we see head and left and right flipper width load well and positive – this comprises the ‘broadness’ body type. PC3 = 0.831 (head) + 0.789 (front right flipper width) + 0.643 (front left flipper width)

Table 3 - Loadings for each of the principal components from rotated component matrix

Rotated Component Matrix[a]

	Component		
	1	2	3
circ	.976	.120	.044
mass	.886	.391	.124
CCW	.826	-.111	.388
FRL	.028	.905	.107
FLL	.071	.867	-.073
CCLridge	.236	.748	.224
head	.037	-.041	.831
FRW	.139	.133	.789
FLW	.413	.217	.643

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

The results of Spearman’s correlation showed no significant relationship between the PCA scores of body type 1, ‘bulk’, and locomotive velocity, r = 0.215, n = 20, p = 0.363. It is difficult to interpret but there appears to be a greater concentration of points in the area of the scatter plot which corresponds to negative PCA scores and low velocities. This may indicate that less bulky turtles may perform with lower velocities.

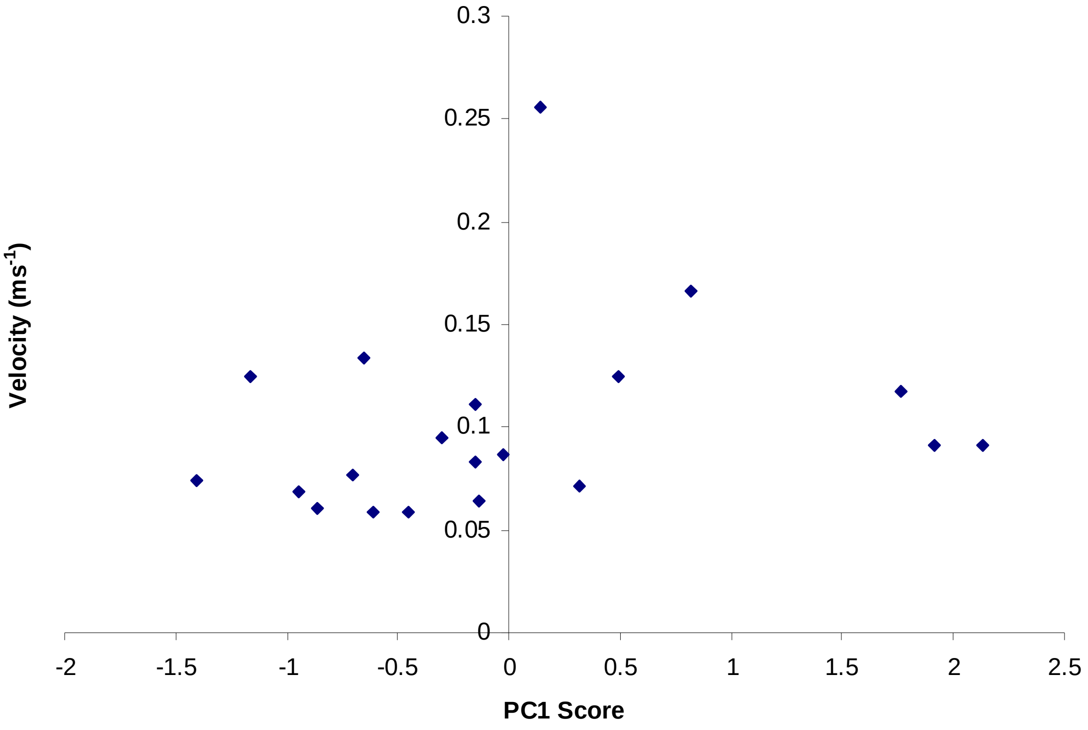

Figure 13 - Relationship between the PCA scores of body type 1, ‘bulk’ and velocity

Pearson's correlation showed no significant relationship between the PCA scores of body type 2, 'body and limb length', and locomotive velocity, r = 0.209, n = 20, p = 0.376 (Figure 12). There may be a hint of a subtle trend of increasing velocity with longer body and limb lengths (the mean velocity for turtles with positive PCA2 scores looks higher those with negative PCA2 scores). However, the highest velocities were achieved around the 0 score for PCA2.

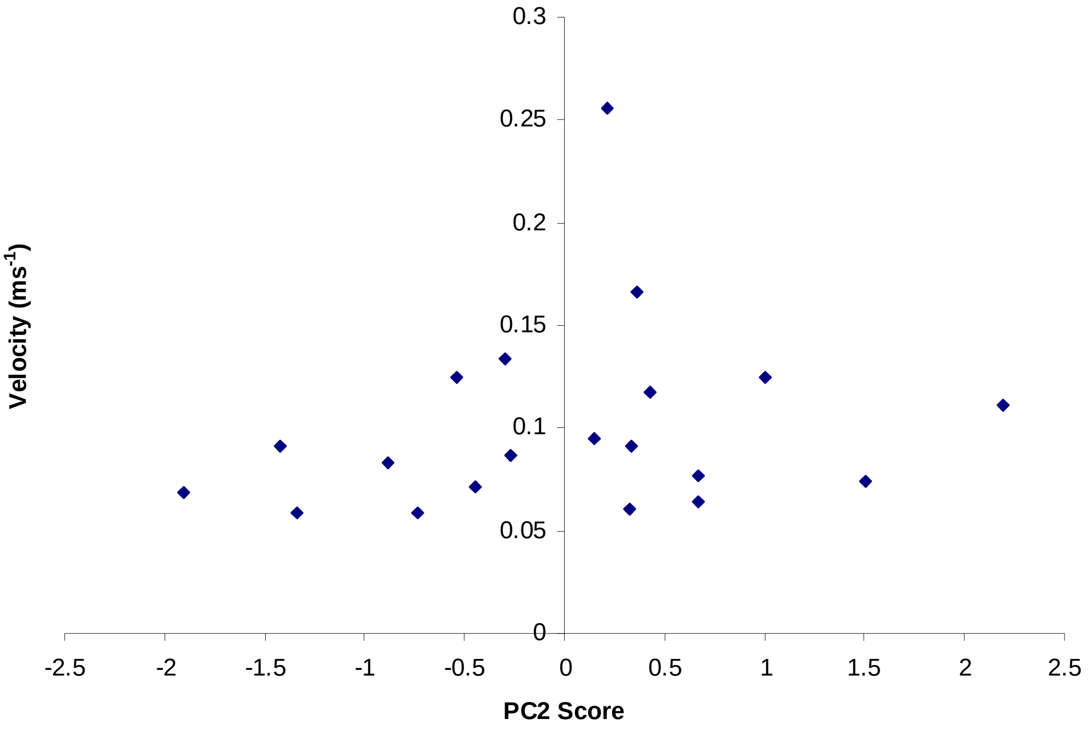

Figure 14 - Relationship between the PCA scores of body type 2, 'body and limb length' and velocity

The results of Spearman’s correlation showed no significant relationship between the PCA scores of body type 3, ‘broadness’, and locomotive velocity, r = -0.148, n = 20, p =0.534 There appears to be a subtle trend between decreasing velocity and increased body broadness. The highest velocities, approximately 0.1ms$_{-1}$, were achieved with decreasing head and flipper width whilst the lowest, around 0.06ms$_{-1}$, were achieved at with increasing broadness.

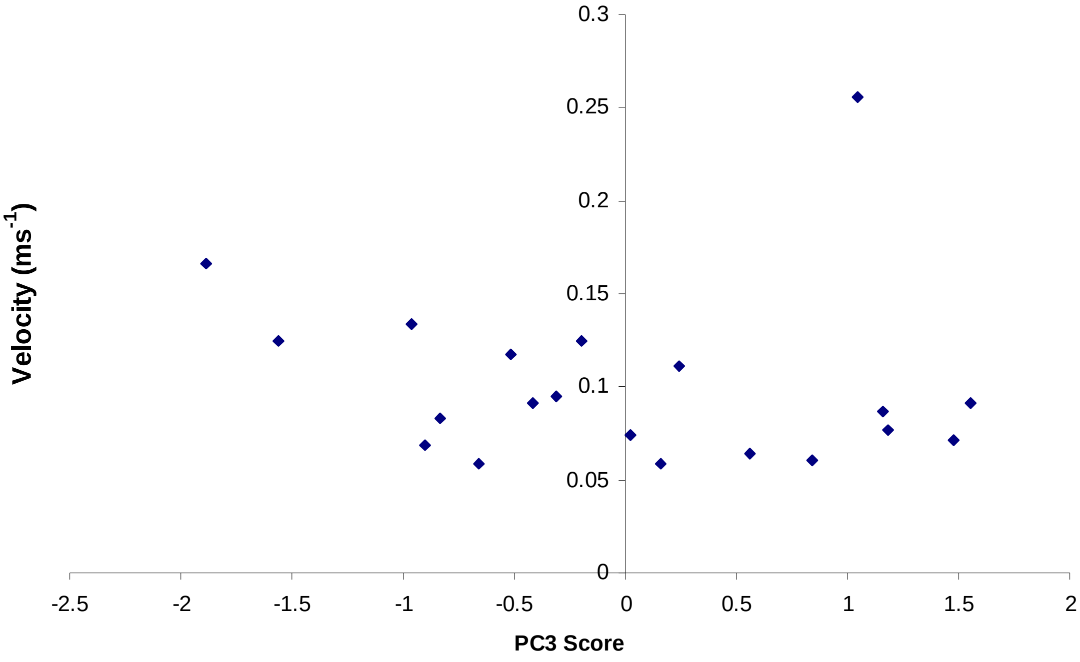

Figure 15 - Relationship between the PCA scores of body type 3, ‘broadness’ and velocity

Results of the Effect of Artificial Lighting on Nesting Turtles

The raster image shows the mean light level at the 16 locations. The raster shows (from north to south) the extent of zone 1 is largely illuminated to an intermediate value band in our range, around 0.26 lux on the light level meter. This is because of floodlights at the Plymouth sports stadium located to the top left of the picture (de-marked ‘PLY’). Zone 2 is less evenly illuminated but has an overwhelmingly bright source of light by the northern zonal boundary – this intense illumination is from the fisheries building, 1.53 lux on the light level meter (marked ‘FISH’). The fishing depot is situated next to the Turtle Beach hotel, the latter snakes diagonally across the centre of the image. Light level data is not available for zones 3 or 4. From observation, zone 3 is the darkest of zones whilst illumination levels increase once more as the observer approaches the village to southern most point of the beach, Black Rock (marked ‘BLK’).

Green denotes areas of low artificial light levels ~0.1 lux, and orange intermediate levels ~0.25 lux through to red >0.3lux which is brightest. The minimum light reading obtained was 0.07lux at the southernmost surveyed point. The highest light reading obtained was 0.48lux at the fisheries building.

The moon level went as high as 0.33 lux. Of the 96 light level recordings (6 readings for each of 16 sites) 7 exceeded 0.33 lux. Of the 60 light level recordings (6 readings for each of 10 sites) 11 exceeded 0.33 lux.

The mean light level at the nesting site of n=10 turtles was 0.3595lux. For 6 of 10 nest sites light levels exceeded 0.5lux; 4 nest sites exceeded 1lux and 2 turtles had light levels at the nest site in excess of 4lux. One turtle nesting near the fisheries depot had light level readings of 4.33 lux and 4.74lux with a mean at site of 1.86lux.

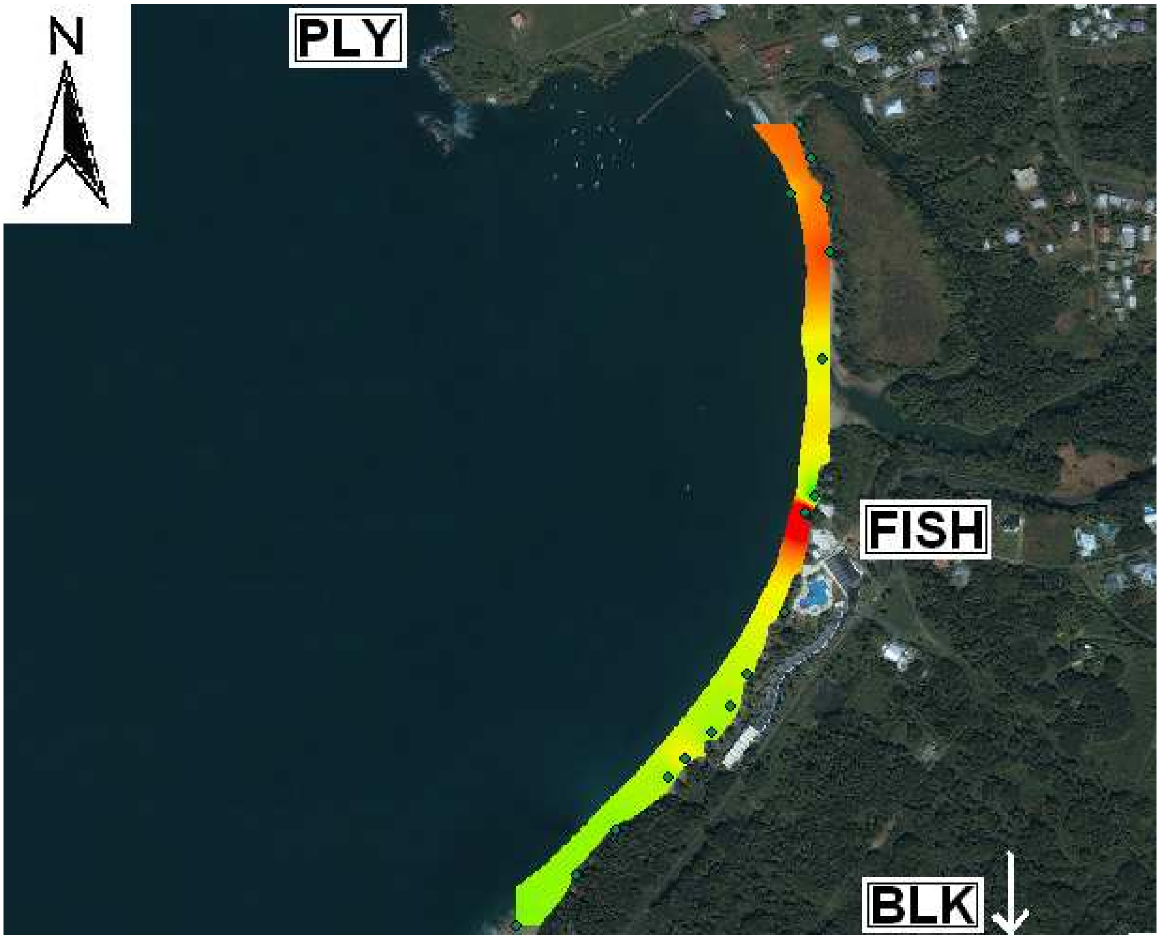

Figure 16 - Baseline GIS raster of mean light levels on Turtle Beach at new moon on 12th July 2010. The fishing depot marks the boundary between zones 1 and 2. Green denotes areas of low light, red equals brighter areas.

Bearing analysis

Pearson's correlation coefficient, r = 0.199 (30) indicated that there was no significant relationship between the bearing at which a turtle approaches the nest site after emerging and the bearing of the highest light level, n = 32, p = 0.275. In general approach values ranged from 140 to 160. The strongest source of light was around the 350 to 370° bearing.

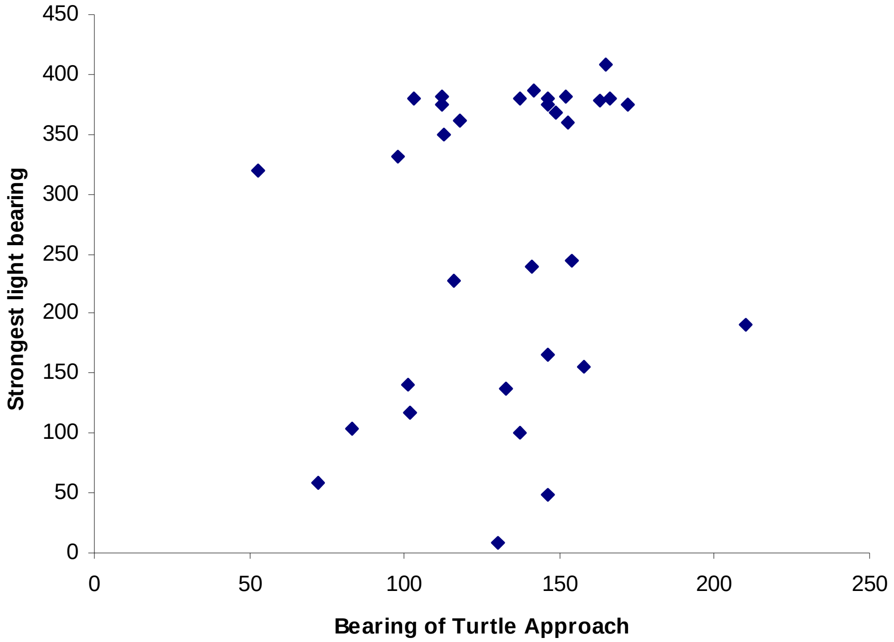

Figure 17 - Relationship between bearing of turtle approach and the bearing of the highest light level

Person’s correlation coefficient, r = -0.143, showed no significant relationship between the bearing at which a turtle approached the nest site once emerged and that of her re-entry bearing, n = 25, p = 0.494.

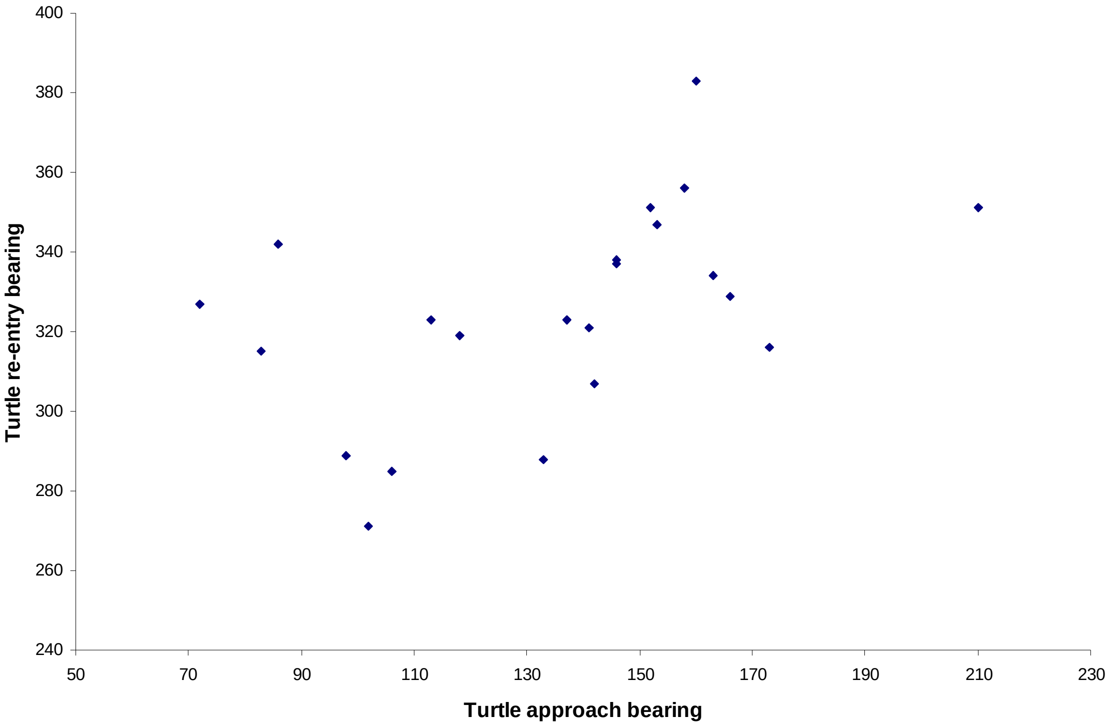

Figure 18 - Relationship between bearing of turtle approach and that of re-entry

Spearman's rho value, r = 0.255 (17), indicated that there was a weak positive relationship between the bearing at which a turtle finished camouflaging and the. This relationship was not significant, n = 19, p = 0.324.

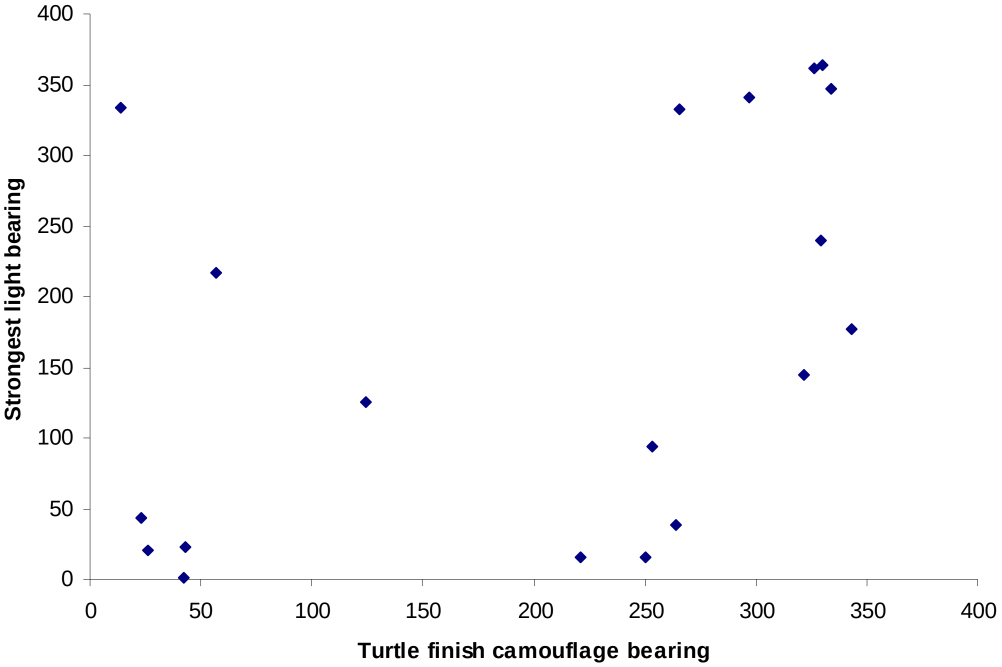

Figure 19 - Relationship between the bearing at which a turtle finished camouflaging and the highest light level

Pearson's correlation coefficient, r = 0.-323 (17), indicated that there was no significant, n = 25, p = 0.191.

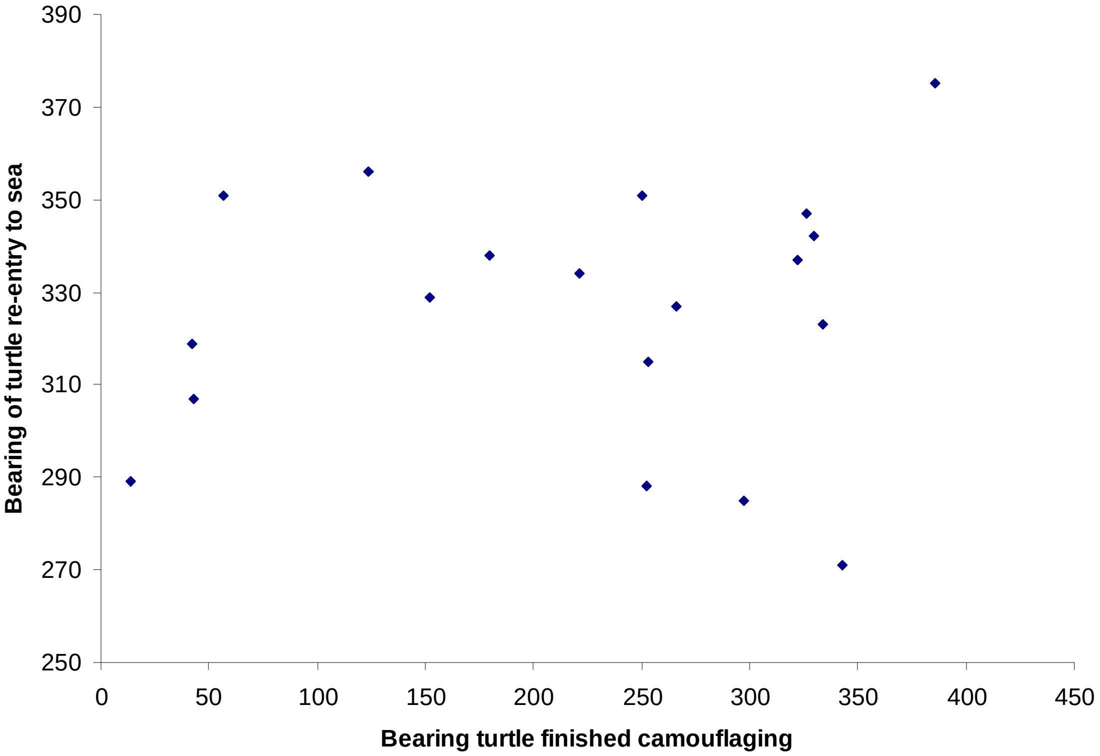

Figure 20 - Relationship between bearing at which the turtle finished covering and re-entry bearing

Pearsons correlation coefficient, r = -0.514 (27), indicated that there was a significant moderate negative relationship between the bearing at which a turtle re-entered the sea and that of the strongest light direction, n = 29, p = 0.004.

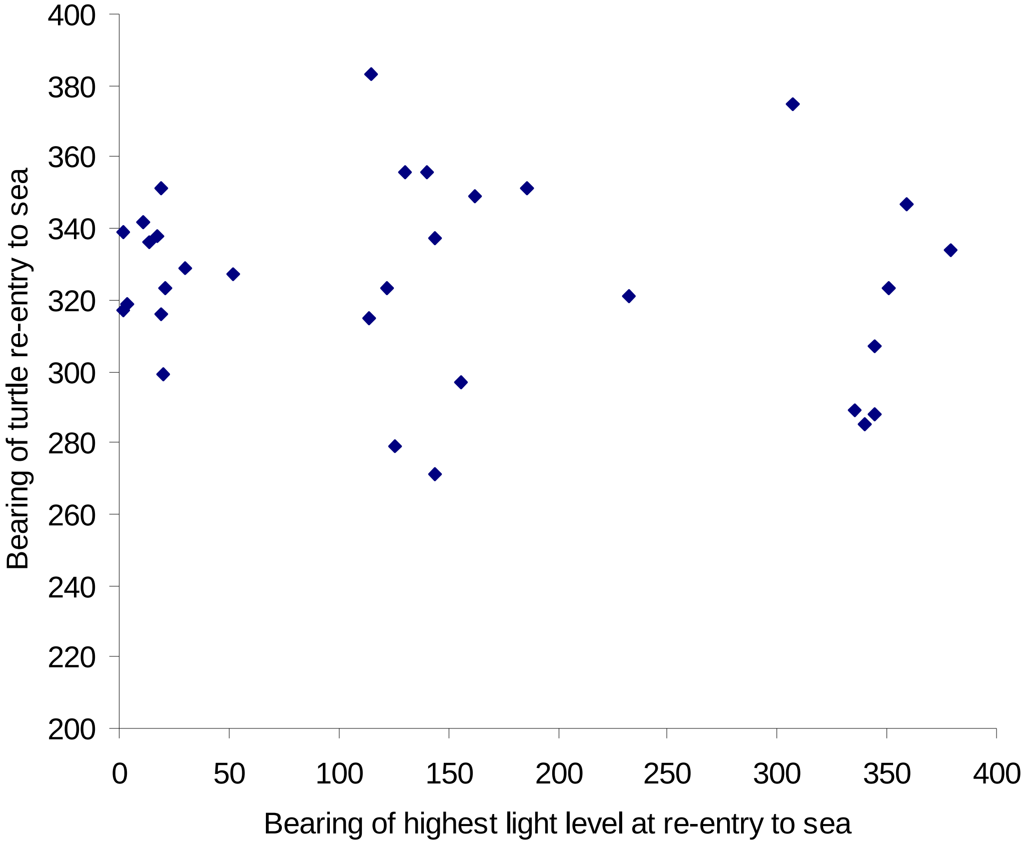

Figure 21 – Relationship between the bearing of the highest light level at re-entry to the sea and the actual bearing of turtle re-entry

Spearman’s rho value shows that there is a very weak, not significant relationship between the straight bearing out to sea and the actually bearing of turtle re-entry, r = 0.521 (8), n = 10, p = 0.122.

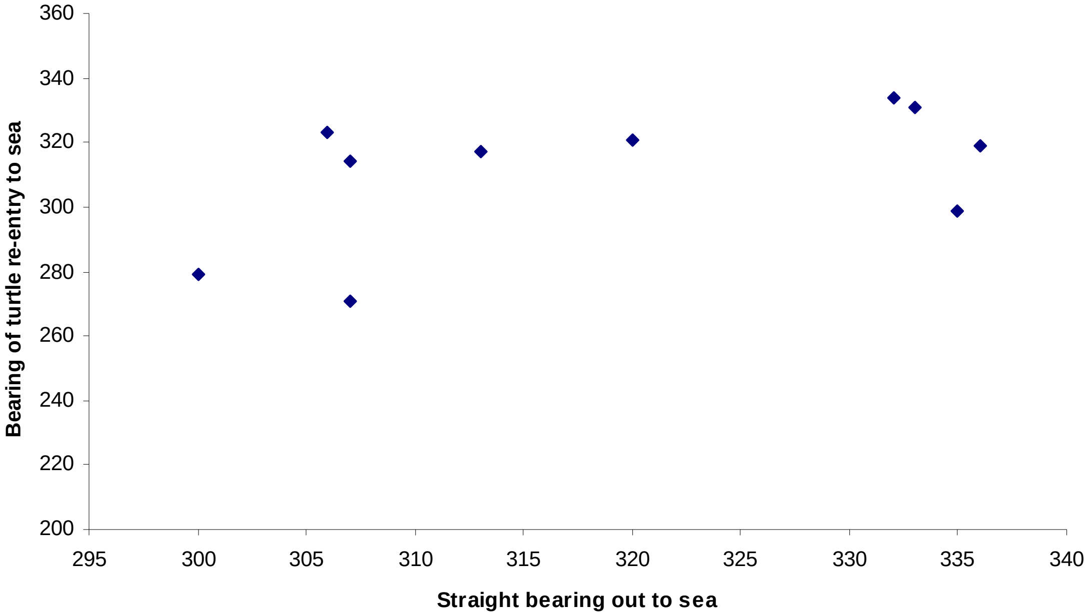

Figure 22 - Relationship between the straight bearing out to sea and the actual bearing at which the turtle re-entered the sea

Transit observations

I observed and sketched the tracks produced during 50 separate nesting events. Observations from Turtle Beach constitute the bulk of the sample, n = 43. Seven events were observed on the other two index beaches, Grafton Beach n=3 and Mount Irvine Back Bay n=4.

The approach tracks of turtles were not too dissimilar as 46.00% had a sinuous approach (n=23) and 54.00% had a direct approach (n=27) to the nest site. There was a greater difference in the tracks produced by turtles when returning to the sea with 60.00% making a direct return (n=30) and 40.00% making a sinuous return track (n=20) (table 8).

On Turtle Beach we have 42 observations:
In zone 1, incoming tracks were 28.57% sinusoidal (n=2) and 71.43% direct (n=5). Returning tracks were direct for 71.43% of turtles (n=5) and sinusoidal for 28.57% (n=2).

In zone 2, 47.62% of tracks in were sinusoidal (n=10) and 52.38% were direct (n=11). Outbound tracks were 42.86% direct (n=9) and 57.14% sinusoidal (n=12).

In zone 3, 80% sinusoidal in (n=4) and 20% straight in (n=1). 60% straight out (n=3) and 40% sinusoidal out (n=2).

In zone 4, 66.67% of incoming tracks were sinusoidal (n=2) and direct tracks were produced by 33.33% of turtles (n=1). Direct out tracks were produced by 66.67% of turtles (n=2) and sinusoidal tracks out were produced by 33.33% of turtles (n=1).

In unknown zone locations, 66.67% of incoming tracks were sinusoidal (n=4) and 33.33% of tracks were direct (n=2). Outbound tracks were evenly split between direct out 50% (n=3) and sinusoidal out 50% (n=3).

Tracks were observed in each of the type categories: 24% sinuous approach - direct return (n=12), 36% direct approach - direct return (n=18), 22% sinuous approach - sinuous return (n=11), 18% direct approach - sinuous return (n=9).

For turtle beach tracks were observed to fall into each of the 4 categories: 6.98% sinuous approach - direct return (n=3), 48.84% direct approach - direct return (n=21), 13.95% sinuous approach - sinuous return (n=6), 6.98% direct approach - sinuous return (n=3).

The chi-square statisitic.,$\times_{2}$ = 0.500 (2), revealed that there was a significant difference in track type observed in the leatherback turtle transit to an from the ocean, n = 50, p = 0.779. The track category two, direct approach – direct return, was observed on significantly more occasions (n = 18) than expected. Category one, sinuous approach - direct return, and category 3, sinuous approach - sinuous return, were both observed on equal occasions, n= 12. Category four, direct approach - sinuous return, was observed marginally the least observed (table 8).

I recorded 10 instances of misorientation all of which were on Turtle Beach out of the 50 observations overall (table 4).

Table 4 - Misorientation on Turtle Beach

Zone	Nests (n)	Affected turtles	% turtles affected
1	9	3	33.33
2	21	6	28.57
3	6	1	16.67
4	3	0	00.00
Total	39	10	25.64

17 instances of disorientation were observed. 15 of these occurred on Turtle beach. 1 of 3 events on Grafton Beach 33.33% had disorientation. 1 of 4 events on Back Bay 25.00% had disorientation (table 5).

Table 5 - Disorientation on Turtle Beach

Zone	Nests (n)	Affected turtles	% turtles affected
1	9	3	33.33
2	21	8	38.10
3	6	1	16.67
4	3	1	33.33
Unknown	5	2	40.00
Total	44	15	34.10

A cumulative total of 16 individual 360° revolutions were made by turtles on Turtle Beach (table 6).

Table 6 - Circling behavior on Turtle Beach

Zone	Nests (n)	Circles	Circles per nest
1	9	3	00.33
2	21	9	00.38
3	6	1	00.17
4	3	1	00.33
Unknown	5	2	00.40
Total	44	16	00.36

For the disorientation events intervention was deemed necessary by a patroller on 7 occasions (table 7).

Table 7 - Nesting events requiring patroller intervention

Zone	Nests (n)	Intervention	% events intervened
1	9	1	11.11
2	21	5	23.81
3	6	1	16.67

An interesting observation which appeared in 12 of 50 events (24%) what is best described as paired latitudinal directional changes (or “gradient kinks”) on the beach between the nest site and high tide line. In these cases, turtles returning to the sea were seen to change transit bearing at exactly the same distance from the sea as when they approached the nest site. Turtle beach had 10 of the 12 gradient kink events.

Table 8 - Summary of observations made of turtle transit

Beach	Zone	n	Sinuous app	Straight app	Sinuous out	Straight out	mis	dis	circles	required intervention	grad snake
TB	1	9	3	4	2	5	3	3	3	1	0
	2	22	10	11	11	8	6	8	9	5	7
	3	6	4	2	2	4	1	1	1	1	1
	4	3	2	1	1	2	0	1	1	0	0
	Unk	5	3	1	2	2	1	2	2	0	2
GB	2	2	0	2	1	1	0	1	1	0	0
	3	1	0	1	0	1	0	0	0	0	1
BB	1	2	1	1	0	2	0	1	1	0	0
	2	2	0	2	1	1	0	0	0	0	1

32 hatching events were recorded in the 2009 season details are contained in Table 9. Thirty-one hatching events were witnessed on Turtle Beach in 2009. Thirteen of these nests encountered problems with light. These nests were located in zone 1 (10 nests) affecting 30% and zone 2 (13 nests) affecting 77% of the nests in the zone.

Nineteen hatching events were witnessed on Grafton Beach in 2009. Eight of these nests encountered problems with light. These nests were located in zone 1 (n=3), zone 2 (n=12) and zone 3 (n=4) and affected 33.33%, 50% and 0% of the nests in each zone, respectively.

Four hatching events were witnessed on Mount Irvine Back Bay in 2009. None of these nests encountered problems with light. All four of these nests were located in zone 1 of Back Bay.

Table 9 – Hatching events and light problems

Beach	Zone	Hatching events	Light problems	% events affected
TB	1	9	3	33.33
	2	14	9	64.29
	3	8	0	00.00
	4	0	0	00.00
GB	1	3	2	66.66
	2	12	6	50.00
	3	4	0	00.00
BB	1	4	0	00.00

Discussion

Results Summary

This study looked at the influence of morphology and artificial light on terrestrial transit of the leatherback turtle. I found no significant relationship between either body length, mass or flipper length and the dependent variable, velocity (ms^{-1}). I did not find the significant relationship of Mickelson and Downie (2010) between narrow carapace width paired with longer flipper reach in hatchlings and increased terrestrial velocity. Unfortunately, during the study period a large sample of individuals could not be obtained and so analysis of relationships between morphological traits and the dependent variable are extremely low in power.

As shown by the raster, I found much of Turtle Beach zone 1 and part of zone 2 to be illuminated (seen as yellow/orange/red) above the ambient level (green). The mean light level for all survey locations was 0.16 (±0.03) lux. By comparison an overcast day 1000lux; a very dark overcast day 100 lux; twilight 10 lux and a full moon overhead, 0.267 lux.

However, the mean level of light at a nest site (above the nest chamber) for n=10 randomly selected turtles was 0.36 (±0.17) lux. Three from ten turtles were exposed to light exceeding 0.5lux in level and two turtles were within sight of sources exceeding 1 lux. At its brightest, light from celestial sources may range from 0.25 to 0.33 lux according to my readings. My most extreme example comes from a turtle nesting near the fisheries depot which within sight of a light source at 4.33 lux and 4.74lux. As these readings were taken from two different compass directions (East and South) the large angle (>90°) and lack of directionality which characterises harmful light sources is evident on Turtle Beach (Blair and Witherington, 2000).

These results are a cause for concern as many hundred metres of surveyed area on Turtle beach may exceed the ambient light level reaching the nest environment. As ambient moonlight plays a role in guiding turtles back to the sea, sea-finding problems may occur as a result of disrupted orientation systems in both hatchling and adult turtles. On brighter nights approaching the full moon phase, the level of ambient light is increased due to the scattering of light from distant celestial sources. This light may aid in ameliorating the affects of bright seaward light in and around the nesting environment. Thus turtles would be able to utilise other cues for orientation (Tuxbury and Salmon, 2005). However, on particularly darker nights approaching the new moon misorientation and disorientation could occur (Salmon and Witherington, 1995).

Though the level of light on the darkest of overcast days is around 100 lux, any development and increased irradiance around Turtle Beach may be enough to emulate twilight light which is around 10 lux. Certainly from these results it is clear that turtles would not confuse the light levels with that of daylight (ranging from 10,000 – 25,000 lux) and so a mass negative effect on nesting emergences is not experienced.

Morphology and terrestrial locomotion velocity

Measurement of nesting turtles revealed a mean carapace length of 158 ±6.94cm (table 1). This result exceeds the range of lengths given for leatherbacks nesting in the western atlantic ocean, which is 152–156cm, and provides a further record of the size difference between that of the pacific ocean, 145-146cm (Saba et al., 2008). Leatherbacks nesting on the nearby island of Trinidad have a mean length of 156cm (no standard deviation is given by the authors). This result is expected as the islands are considered to be part of the same regional rookery (Girondot&Fretey, 1996) and so turtles may deposit nests on several different island within the same nesting season (Eckert et al., 1989).

I found no significant relationship between curved carapace length and curved carapace width, r = 0.090, n = 24, p = 0.675 (fig.6). This result is similar to the relationship seen in loggerheads, r = 0.57, (Gallagher et al., 1971) but contrary to the isomorphic relationship found by James et al. (2007) for leatherbacks. By comparison, James et al. (2007) used a sample size five times the size of mine (n=115) from 8 seasons of fieldwork and it hence their result is more reliable for the species. I found a weak, non-significant relationship between curved carapace length and mean body circumference, p = 0.144 (fig.7). The mean body circumference of turtles increased as curved carapace length increased but not in direct proportion. This result is to be expected as it encompasses the curved carapace width measurement from above whilst extending further round the turtle. I can support Bacon's (1973) assumption of increased mass with carapace length, p < 0.000 (fig.8).

The moderate and significant (p=0.002) correlation between curved carapace length and mean flipper length (front left and right) is logical as appendages grow proportionately to body length (fig.9). This is consistent with isomorphic growth.

I found no significant relationship between a single morphological trait and velocity the response variable, velocity. For curved carapace length, p = 0.211, both the lowest and highest value for velocity was achieved by the two longest turtles (fig.10). Points appear clustered around the mean length for nesting turtles (fig.10) of 158.54±6.94cm. This result is surprising as I expected to see a correlation between body length and velocity because of the significant limb length/body length relationship (p=0.002). The longer limbs that come with increased body size generally facilitate greater velocity (Miles et al., 1995).

The positive but slightly not significant (p=0.095) relationship between mass and velocity is interesting (fig.11). As the significance level is so marginal a larger sample size may provide the power to detect the true effect of mass. It may have been that the small sample size, n=25, was sensitive firstly to the technique used to estimate adult turtle mass. Using the equation formulated be Georges and Fosette (2006) my mass estimations are considered to be 93% accurate assuming the technique of measuring mean body circumference was executed correctly. Though a weak trend is revealed, r = 0.341, it could be the case that turtles show increased velocity with increased mass. As muscle weighs more than fat, a heavier animal may be more powerful turtle (if corrected for carapace length). Muscle mass may allow higher crutching. Bigger animals are able to move with less energy expenditure than smaller animals (Tucker, 1970; Taylor et al., 1982; Baudinette et al., 2000) and so with a greater sample size I believe this assertion would hold true in leatherback morphology and locomotion. If larger size does confer benefit to locomotive velocity females could avoid longer transit during the tiresome nesting process (Pritchard, 1971; Jackson&Prange, 1979). Turtles which spend more time completing all the stages of nesting and manoeuvring their substantial bulk across the sand (Salmon, 2003) may have reduced performance as lactic acid builds up during extended terrestrial transit (Deem et al., 2009).

The lack of a significant relationship between mean flipper length and velocity (p = 0.854) was surprising (fig.12). There was absolutely no indication of a relationship between appendage length and velocity, r = 0.039 (23). This is a surprise as this variable is typically seen to increase speed in a number of different taxa. Given the bell-shaped curve it would appear that the highest velocities occurred at an optimum flipper length around 70-75 with slower velocites at lower and higher than average flipper lengths. This result was a surprise given that limb length correlates positiviely with locomotor speed in a number of different taxa (Miles et al., 1995). Longer limb length would presumably allow for greater elevation of the body off the ground and therefore increased potential energy for the forward ‘lurch’ in the species gait.

The variability in body shape means several factors in combination probably influence locomotion velocity. All measures of locomotive velocity may have been affected by the exclusion of two covariates, beach slope and duration of nesting event, for which data was not recorded. It could be that animals traversing a steeper slope, for instance over a sharp berm, could have been aided. However, attempts were made in the methodology to ensure that 'race track' was positioned on as flat a portion of beach as possible and so this can be ruled out as an influencing factor.

PCA analysis of morphology data for 20 nesting turtles revealed no significant relationships between locomotive velocity and PCA scores of body type 1, 'bulk', p = 0.363. (Figure 11); body type 2, 'body and limb length', p = 0.376. (Figure 12); body type 3, 'broadness', p =0.534 (Figure).

PCA scores for body type 'bulk', are difficult to interpret but there appears to be a greater concentration of points in the area of the scatter plot which corresponds to negative PCA scores and low velocities. From the graph the mean velocity for turtles with negative PCA scores (n=13) is approximately 0.08ms^{-1}. For turtles with positive PCA1 scores (n=7) the mean velocity is 0.11ms^{-1}. This deserves further study as increased width could create additional drag slowing locomotive velocity or turtles with increased bulk may perform with greater speed due to greater muscle mass.

For the 'body and limb length' body type there is hint of a subtle trend of positive increasing velocity with longer body and limb lengths. However, the highest velocities were achieved around the 0 score for principal component 2 scores. A significant and pronounced affect was expected with regard to sea turtles as we have seen Mickelson and Downie (2010) show a significant positive relationship in the hatchling life-stage of the same species. In the literature it can be seen that the affect of body and limb length on locomotive velocity is mixed: with both positive outcomes (Miles et al., 1995; Mickelson&Downie, 2010) and no effect detected (Zani&Claussen, 1994).

There appears to be a subtle trend between decreasing velocity and increased body broadness (PCA 3 scoring system). The highest velocities, approximately 0.1ms^{-1} , were achieved with decreasing head and flipper width whilst the lowest, around 0.06ms^{-1}, were achieved at with increasing broadness. A trend of decreasing velocity and body width was expected as this would increase the cross-sectional area of the animal moving across the sand and thus there may be increased drag and resistance to forward movement.

To summarise, I did not find the significant relationship of Mickelson and Downie (2010) who demonstrated that narrower carapace width and longer flipper reach conferred faster terrestrial speed than those with opposite characteristics. I was surprised not to see emerge as unlike members of the cheloniid family, the leatherbacks show no ontogenetic shifts in locomotor behaviour (Wyeneken, 1997) and so it was expected that the same body type which was of importance to hatchling transit would be represented in sample of the adult nesting turtles in Tobago.

A couple of things may explain this. Although we used terrestrial locomotive velocity as the dependent variable in our PCA analyses of morphological features this may have little fitness benefit for the adult lifestage. Morphological differences may have little effect for adults which are suited to a marine existence and face little threat from predation as adults. Adult leatherbacks have few predators with jaguars and crocodiles among thos capable of inflicting mortal damage (Heithaus, 2008). The low levels of mortality due to predation of adults is therefore unlikely to exact any selective potential. There may be no link between locomotive performance and survivorship (Jayne and Bennet, 1990). With the existing data I cannot rule out a low importance of morphological variation to adult survivorship. To the contrary, we do not have data relating to the size of the rear flippers. However, assuming that the rear flippers grow proportionately to the body then there may be some differences in the nesting process of the turtle, specifically nest depth, depending on the size of the animal. Deeper nests may be buffered from excessive high temperatures or infiltration by dogs or ants. Hence if the optimal nest depth was to shift with projected climate change for example (IPCC, 2007) then the size of the animal could become an important factor.

The most compelling explanation is that the results of our testing of adult morphology was undermined by the meagre sample size (table 1). It would seem logical that the ideal body type would have strength (possibly through increased muscle mass), long limbs to lift the body high and a thin carapace to minimise drag and so I expected similar findings to those in the hatchling life-stage. The subtle trends perceived in this study may be found significant with an increased sample size. My sample size was a fraction of that used by Mickelson and Downie (2010) mainly due to the fact that hatching events provide many individuals to be sample where as nesting events provide only one individual. In future investigations a sample of at least 50 individuals would be preferable.

An observation that I made was of great variance in individual resting behaviour. Leatherback typically make 2-5 pulls in their gait when manoeuvring across the beach interspersed with recovery intervals (Pritchard, 1971). Whilst we were able to use ‘race’ times for turtles that were not affected by this stalling behaviour it may be worth examining the prevalence of this in nesting turtles. For example, do bigger turtles intersperse the gait with rests periods more frequently? And do turtles which have nested for an extended duration require more of these stalling periods as the increased transit duration causes the build up of lactic acid (Deem et al., 2007).

Discussion of the Effect of Artificial Lighting on Nesting Turtles

I observed the transit patterns of 50 leatherback turtles which nested successfully on Tobago's Index beaches during the 2010 season. By using the definition of misorientation, as travelling in the wrong direction, and disorientation, as the inability to orient in a constant direction (Verheijen 1985) I was able to identify instances on Tobago's Index beaches. I identified 11 instances of misorientation and 16 instances of disorientation during terrestrial transit. Emergence location does not appear to be influenced by light or most turtles appear to favour other beach characteristics such as a deep water approach and a high-energy beach (Bacon, 1970; Eckert, 1987; Pritchard, 1971) ahead of beach illumination levels. Misorientation occurs most in zones 1 and 3 where there are visible but distant light sources; and in zone 2 disorientation is more likely as turtles are closer to strong directional sources of light emanating from nearby structures. The direction of the highest light level may not tightly correlate with transit directionality for all stages of the nesting process but the significant correlation between turtle re-entry bearing and that of highest light level suggests that turtles experience a misorientation effect on Turtle Beach.

I observed turtles closely during all stages of the nesting process and so was able accurately measure the transit bearings. No significant relationship between the bearing at which a turtle approaches the nest site and the highest light level was observed (fig.17), r = 0.199 (30), p = 0.275. This result was expected for two reasons. Firstly, in other marine turtle species a decrease in nesting emergences has been attributed to the disturbance effect of light pollution. Hence in the approach stage of nesting we did not expect to see turtles attracted to light sources rather the opposite effect was expected. The lack of correlation may indicate a scattering effect. This result suggests that the leatherbacks emerging here are indifferent to direction of the brightest artificial light sources. Secondly, the effects of light pollution are typically manifested in misorietation and disorientation during the sea-finding stage. Hence no attraction was expected until after the turtle had completed oviposition.

I found no significant correlation between the bearing at which a turtle approached the nesting site and that of the bearing on which she returned to the ocean (fig.18), p=0.494. This result is most likely influenced by the apparent randomness to the finishing position of a nesting turtle.

I found no relationship between the bearing at which a turtle finished camouflaging the nest sited with that of the strongest light bearing (fig.19), p=0.324. This result would appear to tie in with the summation by Witherington and Martin (2000) that once a turtle is immersed in the stages of the nesting process she does not deviate from a normal performance of each of the functions, one of which is apparent random manoeuvring when covering the nest site.

No significant relationship between the bearing at which the turtle finished covering and the bearing at which she re-entered the sea (fig.20), p = 0.191 is to be expected. The turning of a turtle during the covering process seemed to be highly variable and turtles are observed to begin oviposition at an orientation which appears to be entirely independent of ocean directionality. Our observations revealed some females making tight pivots when covering compared with others who meandered across the beach covering a large area. The reasons for such differences are unknown. After these random movements a turtle could be facing any direction requiring use of the terrestrial orientation system to locate the sea. However, the implications of facing away from the sea are potentially problematic given the proximity of bright light sources at Turtle Beach hotel.

One of our most important results is the finding of a significant relationship between the bearing at which a turtle re-entered the sea and that of the highest light level, r = -0.514 (27), n = 29, p = 0.004 (fig.21). This indicates that there was significant misorientation of the majority of adult leatherback turtles returning to the sea. As turtles approached the sea other cues or the affects of celestial light were sufficient that turtles did not become disorientated. It may be the case that the bright lights from the football stadium help to ameliorate the effects of the hotel as they are in a roughly seaward direction. The near seaward direction of this light source may also explain the moderate correlation.

It is very difficult to draw conclusions from the non-significant test of straight bearing out to sea and the actually bearing of turtle re-entry (fig.22), r = 0.353, (8), p = 0.318 as the sample size was so small (n=10). However, I felt this analysis was worthy of inclusion as quantifying the direct path to the sea rather than simply estimating it could provide a reliable means of recording misorientation. Interpretation of the figure 22 reveals that the two lowest points were at lower values and the two highest were at the upper right. This could suggest a linear relationship, that turtles are going directly back into the sea. However, it would be wrong to make this assertion based on the sample and the findings. This parameter is of importance in future analysis.

Taking our bearing analysis as a whole it is seen that the bearing of the strongest light source has little effect on positioning and transit of the leatherback turtle (figs 17-22).

The effects of light pollution are more likely revealed through the intermediate position (the shape of the track) than a discrete bearing at the start or end of transit. Since a turtle may leave the nest site relatively straight but then a short distance from the nest site circle 360º before heading relatively direct for the sea again. In terms of directionality, the bearing analysis would suggest that no misorientation has occurred yet in the intermediary period the turtle appears to have been disorientated. The correlation ($p=0.004$) between turtle re-entry bearing and that of light suggests that light on Turtle Beach is having a moderate misorientation effect on the turtles. However, as the strongest light source is often the stadium floodlights which, “as the crow flies”, is separate from the nesting beach in seaward direction. Hence it is difficult to separate the effect.

From the sketches it can be seen that individual turtles vary greatly in approach tracks. Though ‘straight approach – straight return’ track category was observed on significantly more occasions ($n = 18$) than expected, $p = 0.779$, there were also many turtles showing sinusoidal patterns on entry and exit. Since movements did not take turtles on a set bearing or significant distance from light sources it is unlikely that sinusoidal incoming tracks are a consequence of light repulsion. Sinusoidal tracks on entry to the beach can are likely explained by the natural process of nest site selection. 54.54% of incoming tracks were found to sinusoidal on Turtle Beach in comparison to the 30% of nesting emergences found by Bacon (1973). Bacon suggested that the deviations in incoming tracks may be caused, in part, by changes in light conditions. Hence this may explain the higher proportion of turtles showing sinusoidal tracks on Turtle Beach than on Matura (in Trinidad) 30 years ago. Differences between the sensitivity of sinusoidal classification and that of Bacon (1973) may have exaggerated the difference.This suggests that most turtles emerge and nest relatively direct.

However, the other 32 cases indicate that at least one leg of the transit journey was sinusoidal, the approach, return or both. This ratio of 2:1 tracks with a sinusoidal component versus straight in and out (category 2) is further evidence that leatherback turtles rarely make tracks that are straight to and from the sea.

All instances of misorientation occurred on Turtle Beach, comprising 25.58% of the nests on that beach (table 4). Misorientation occurred most in zone 1, 33.33%, and then in decreasing levels across the beach zones two to four affecting 28.57%, 16.67% and 0.00% of turtles respectively. From the raster (fig.16), it can be seen that the light in zones 1 and 3 is of a relatively level value for much of the zone area. Zone 1 is bathed in light for most of its area compared to zone 3 which is relatively dark by comparison bar the exception of some road lights circa 50m from the vegetation line. Disorientation is considered a stage beyond misorientation with regards to the negative impact of light. This explains why there is a lower proportion of misorientated turtles in zone 2 where there are more impacting sources of light.

Fifteen instances of disorientation occurred on Turtle Beach with the greatest count of 8 (from 21 nests) in zone 2 (table 5). This was also the zone with the greatest proportion of affected nests, 38.10%. Zone 1 and 3 had substantially lower total of disorientated turtles 1/9 and 1/6, respectively. Zone 2 has most the most proximal directional artificial light sources along the beachfront though these do not all show up on the raster (fig. 16). Bacon (1973) did not give attention to the return tracks of turtles citing disturbance during nesting by the application of a tag and the presence of observers as his reason therefore there is little data to compare disorientation in leatherbacks. However, Bacon did record 30% of beach ascents which showed circling behaviour. This observation was not replicated on any occasion in my observations. A cumulative total of 18 individual 360° revolutions by turtles were recorded in each of Turtle Beach's four zones (table 6). From zone 1 to 4 there was a total of 3, 9, 1 and 1 circle observed in each zone. In unrecorded locations 2 circles from 5 nests were observed.

From my results the potential consequences of nesting on Turtle Beach are misorientation in zones 1 and 3 and in zone 2 possible disorientation for some turtles. Increased time and thus a build-up of acid in muscles (Deem et al., 2007) are likely after becoming disorientated during an already energy taxing process (Pritchard, 1971; Jackson&Prange, 1979).

Bacon (1973) caused disorientation (during ascent) using a flashlight for 45 minutes. It would be interesting to know how events deemed to need intervention would have turned out. In the interests of the turtle, disorientated animals were redirected seaward when headed landward since animals may become stranded (Deem et al., 2007). However, in some instances I observed animals to right themselves when faced with dark vegetation. Adults can therefore recover from disorientation events hence is not necessarily fatal.

The consequences for hatchlings are, to the contrary, likely to be much more severe: exhaustion, depradation and dessication. The threshold of light required to disturb hatchlings is lower than for adults. The effects of light on hatchlings would therefore appear to be more predictable. We see light problems as we expect in the brighter zones with a greater proportion of hatching events having problems in Turtle Beach zone 2 and the brightest part of Grafton, zone 2. Light problems were not observed in the darker areas of either beach which is zone 3. For affected hatchlings they are often observed landward and on the roadway. Therefore actions to darken these illuminated beach sections and prevent hatchlings leaving the beach would therefore have merit from a conservation perspective.

As some turtles in bright areas showed no ill affects then there is intraspecific variation in turtle susceptibility to light disturbance. Observations of events in the same place on the same night with different outcomes for the nesters indicate this. It could also be that the presence of silhouettes and shielding very specific to the turtle location and perspective has an influence in what direction they travel. The raster shows light an order magnitude higher at the fisheries. Despite this, some turtles nesting nearby didn't have disorientation problems anywhere near the extent of other turtles. I suggest this is because of the presence of silhouettes created by beached boats which may direct hatchlings and adults seawards (Salmon et al., 1992; Tuxbury and Salmon, 2005).

Sinusoidal tracks on exit are little more difficult to explain. Bacon (1973) tried to explain variance in transit directionality from the perspective of changing light conditions. Sinusoidal tracks may occur when there is only slight brightness favouring a seaward direction and hence the turtle manoeuvres left and right in order to sample light which is initially in the peripheral vision.

It may be that the occurrence of some behaviour is not always linked to light. Amongst the interesting results to emerge from studying the transit sketches was that of a paired latitudinal directional change or "gradient kink" (fig.24). These sometimes occurred in dark locations, e.g. TB Zn3, GB Zn3 and BB Zn2, indicating there may be some other factor or a visual input influencing transit direction rather than just light. As a turtle is no longer searching for a nest site then the track kink when sea bound would presumably not be in response to a factor used in the nest site selection process.

Importantly, direction changes appear to occur at exactly the same latitude on the beach (imagine a line drawn parallel to the tide line) for the in and out tracks though they may remain parallel, converge or diverge. I postulate this is a response to an external stimulus such as a change in the environmental conditions during seaward transit. Several factors are suggested to influence the precise location chosen for oviposition by marine turtles and I believe they may influence the seaward journey. These are beach gradient, temperature gradients in sand, sand grain size and compactness/moisture, visual cues, light (Witherington&Martin, 2000). These may act exclusively or in combination to influence the turtle. For example, a consequence of a gradient change is that sand will be more or less perpendicular to the sun. One of the areas could become cooler or hotter during the day and retain more of this heat at night. I am inclined to believe that the factors influencing these gradient kinks are of a topographical or a cue in the substrate as opposed to the effects of beachfront lighting.

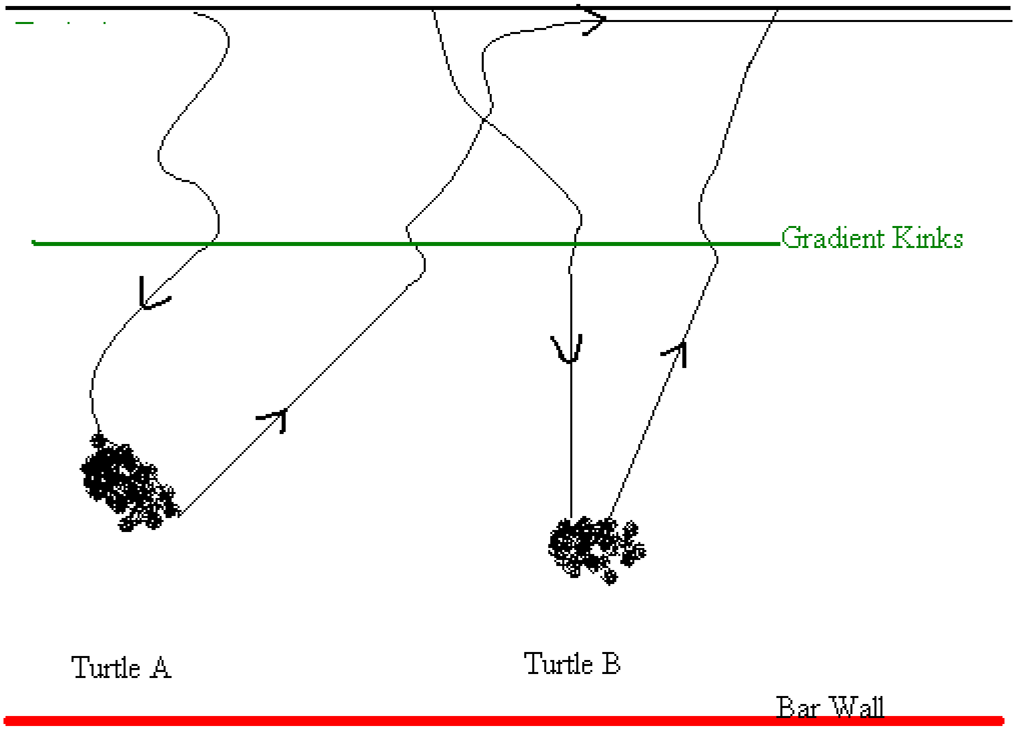

Figure 23 - Illustration of the observed 'gradient kinks'. Red line indicates the human structure and the green line indicates the latitude along which each of the turtles turned.

On one evening, two turtles (herein turtle A and B) were nesting on the beach at the same time, located close to the boundary wall in front of the Turtle Beach hotel bar (fig.24). The emergence time of these two turtles were slightly offset and approximately 30 metres apart. Both individuals displayed the gradient kinks across the same beach latitude on their inbound tracks (that is, all 4 legs kinked at the same place) and successfully completed oviposition. However, turtle A had a major misorientation and disorientation problem whilst trying to return to the sea. Turtle B made her way to the sea relatively direct but for second gradient kink. Turtle A made 2 full circles whilst travelling at an angle of 45º to the high tide line. This may have been due conflicting sources of bright light by the hotel bar and also by the fisheries building (see raster). Turtle A proceeded to travel at the 45º after the two full revolutions before she also made a gradient kink in line with her entry track and the pair of tracks left by turtle B. It should be mentioned that several turtles over the course of the season despite circling managed to locate the sea without the intervention of the beach patrol.

The interesting thing about these two turtles is that turtle B was located closer to the brightest source of light from that location, that of the fisheries building, whilst turtle A was 30 metres further away. It could therefore be that the light at fisheries does not consist of wavelengths which are attractive to turtles rather the bright light – though of a lower level - from the hotel bar induced the misorientation and disorientation in turtle A. Nonetheless, turtle A proceeded towards the water making another gradient kink in line with her entry track before turning sharply away from the waters edge and travelling approximately 70 metres parallel the sea. This travel was in the direction of the fisheries building and hence the misorientation at this stage must be attributed to those lights. This turtle was eventually redirected into sea after a failed attempt and the shutting off of the offending light. However, she then made her way back onto the beach after circling back on herself before returning to the sea for final time. I have yet to come across any other documented evidence of a nesting female turtle being so disorientated as to turn back out the water and onto the beach though this behaviour is been well documented in hatchling turtles (Harewood&Horrocks, 2006; Harewood&Horrocks, 2008).

It could simply be that turtle B had a reduced sensitivity to light, perhaps as a result of variation in the quantity or efficacy of the different coloured photopigments in the eyes of individual sea turtles (Granda&Dvorak, 1977). It would have been interesting to observe the transit of the hatchlings from these nests also. If hatchlings from each nest displayed a similar response to the beachfront lighting then this could have evolutionary potential in an increasingly illuminated world.

Alternatively, when turtles nest proximal to physical obstructions it may be the case that this cue is enough to supersede that of light. When turtles are in open areas there are most likely to have misorientation problems (Deem et al., 2007). For example, in front of the hotel a turtle was observed to circle away from the sea and progress landward. A human barrier was created to block out the light but at the same time would have emulated a physical obstruction. Either way, the relatively high silhouette created was effective an may explain the lack of problems encountered by turtle B in the earlier example as she had nested near to shored boats. Furthermore, a turtle was observed to emerge and nest right beneath the hull of a fishing boat which was positioned immediately in front of the fisheries building. This turtle was exposed to bright for the full duration of the nesting event which attracted a large crowd ~40 people. The turtle covered neatly on the spot and returned directly to the sea.

It may also be possible to eliminate sand compactness or moisture levels from the potential root causes of gradient kinks. During site selection turtles may test the surface sand for with a few flipper beats (Pritchard, 1971). If this site is unsatisfactory then the turtle may change direction and move on. However, this does not occur on the sea ward transit hence it is unlikely that these factors influence the gradient kinks. Stoneburner and Richardson (1981) suggest tracks may kink as a response to non-visual cues such as temperature gradients because turtle is also facing opposite directions hence the thing she saw when approaching is out of site on return. Orientation circles were hypothesised to occur due to changing light cues on beach ascent causing disorientation by affecting visual cues (Bacon, 1973).

Pritchard (1971) suggest that sinusoidal tracks of leatherbacks were an effort to minimise the gradient of the beach. I believe this postulation is worthy of consideration. In other observations I noticed turtles would turn down into the body pit/false nests of other turtles by turning with the slope then emerging by turning to the side and out. That is, turtles did not travel straight across older nest sites rather they meandered with the contours. I believe that turtles may change there directionality relative to beach slopes. These gradient kinks have been observed to have occurred at clear gradient changes in the beach but also in what appeared to be relatively flat, albeit steeper, sections of beach. Hence it may be that the gradient cue is a very subtle one.

Turtles observed to make an arc or 180º turn away from nest site even when facing seaward initially suggests that some require to orient themselves (Pritchard, 1971). However, after covering, some turtles were observed to pivot tightly on the spot and misorient towards a bright light source. From this it can be deduced that some leatherbacks appear to give very little consideration to beach lighting when selecting a nesting beach and site rather they give more precedence to other environmental cues often to the detriment of themselves and their young. Three turtles were even observed to nest in extremely bright areas and after covering, perform tight pivots before orienting on a bearing which would have taken them off the beach landward. These particularly bright areas were the fisheries depot and the back gate of the hotel. One of these areas, fisheries, is identified by the raster while the other was not detected because of methodological issues to be discussed in due course. Personal observation reveals a light at the back entrance of the hotel as one of the brightest on the beach.

A small number of turtles were observed to return to the sea once sunrise had commenced. These turtles returned directly from the nest and did not leave sinusoidal tracks.

Our sample for Grafton and Back Bay is very small so it is difficult to make any conclusions as the small sample size is highly vulnerable to individual variation. Grafton is illuminated for much of its length and the beachfront properties and hotels most likely exceed the brightness of Turtle Beach making it the worst affect of the 3 Index beaches. From our 3 samples on Grafton a very bright beach it was found 1/2 turtles in zone 2 and 0 from 1 in zone 3 were disorientated. It may not be unreasonable to suggest that up to 50% of turtle in this bright zone 2 may be disorientated. This hypothesis merits further investigation. It is difficult to say just how many turtles are affected by light pollution for two reasons: we do not have data from a control beach, one which is free from the proximal illumination of artificial light sources, which could show the natural levels of deviation from direct transit paths. Additionally, unusual tracks have been observed in dark areas, e.g. Back Bay.

In conclusion, though the long-term affect of beachfront development on the number of nesting turtles emerging on Tobago's Index beaches is unknown I can say that the present state of illumination is causing problems for turtles. I believe my sample of observed nest events is representative and turtles in zone 2 of Turtle Beach can suffer from disorientation. Many turtles may also suffer from a misorientation effect. Though adults are unlikely to succumb to the effects of disorientation the levels of light and the proximity to the nesting beach will have mortal consequences for hatchling turtles. As the consequences of light 'trapping' for hatchlings of this critically endangered species turtles may be fatal a set of recommendations for key stakeholders is important. It is vital that actions are taken to limit future development of Tobago's Index beaches otherwise this problem will increase.

Limitations

Morphometrics

The formula of Georges and Fosette (2006) for mass estimation of adult leatherback turtles is 93% accurate. Given our small sample size this error, though small, may be enough to destroy any subtle correlations. Inaccuracies in measuring mean body circumference caused by the tape deviating from a course which is completely perpendicular to the top of carapace and the bottom of the plastron may have further contributed to error in results.

Difficulties were encountered in accurately measuring the straight flipper length of nesting turtles. This was because some turtles had one or both of the forelimbs slightly curled and covered in sand. By brushing away loose sand and holding the flipper in position this measurement was taken. Mistakes in identifying the start point of the flipper (nearest the body) can be the cause of error in measurement. Some turtles have a smooth transition from the flipper to the shoulder muscle making identification of the boundary on a fine-scale (<0.5-1cm) difficult.

Light

Our data collection was hampered by equipment malfunction in the field and the acquiring of a replacement. For this reason the sample size used in analysis of light and it’s effect on turtles was particularly small for the length of the field period.

Budget constraints limited access to equipment which could accurately assess light sources in great detail. The wavelength of a light source is important as the spectral properties of longer wavelength lights impact sea turtles less (Witherington & Martin 2000). The conventional light meter used in this study could only give a multiband reading of the light level and so the analysis is limited by failing to differentiate between wavelengths. This could leads to over- or under-estimation of the potential impact of a light source by basing judgment on the light level alone. Caution is necessary when drawing conclusions on the light readings from light sources.

Notwithstanding, quantifying light levels are not fundamental to assessing whether coastal light sources could have detrimental affects for marine turtles. A visual assessment can gather more information than a directional light meter (Witherington and Martin, 2000). For this reason my observation of the turtle behaviour was a suitable proxy. Additionally, my light meter had a high directional cone of acceptance and so was adequate for the purpose of determining the bearing of the highest light level.

Location information referring solely to zones does not accurately indicate the nest position relative to light sources. The interpolation of values between survey points may inaccurately reflect the true level of light at that point as the raster assumes that light fades at a constant rate. Artificial light appears bright because of its proximity, but fades rapidly with distance (Verheijen, 1985) hence there is a need to perform light assessment from the front to the back of the beach. By sampling only the middle of the beach for light the raster is not a true reflection of beachfront lighting rather of the view from the middle of the beach. This explains why we observed problems in apparently darker sections of the beach and not in assumed brighter areas. The brightness of the light at the hotel back entrance is a noticeable omission from the raster, figure 16. By increasing the resolution of the survey points we can improve the picture of light level on the beach. To do light measurements should be taken at multiple points perpendicular to the shoreline and at regular intervals along the shore. This must be captured in future as personal observations reveal this light was problematic for turtles and misoriention had to be corrected on several occasions. Because of the equipment limitations the raster should be a loose guide to areas of the beach which are illuminated. It is still useful as there cannot be light problems where there are no light sources and hence an extent of control may be attained from such darker areas. The baseline light assessment is a great tool for use in comparison of the effectiveness of mitigating light technologies if carried out before and after changes have been made.

The light meter will have been held at a height substantially greater than that of the turtle’s perspective thus reducing an effect of light shading and silhouettes.

The raster of light level is limited by wavelength negligence. This may explain why the apparent intraspecific variation in turtles. Rather than turtles being highly variable perhaps it is the case that they nested near bright lights which were themselves highly variable in terms of their spectral properties. This remains to be explored. If wavelength analysis could be incorporated into future data collection then a directivity index could devised and displayed in the raster form. Directivity is where one light source is overwhelmingly brighter than others due to it’s proximity, power and wavelength. This index would provide a means of identifying areas of beach where a single, harmful source was dominant. This index may be created by calculating a mean value of the light readings per survey point and an index of the standard deviation used in the raster.

In future analysis the lunar phase and cloud cover are additional factors which must be considered. Lunar phase can play a role in ameliorating the affects of artificial by increasing the ambient light level and thus the relative brightness of artifical lights is diminished. Though cloud cover may limit the brightness of a full moon also.

A vital parameter for which I did not gain enough data was that of the straight bearing out to sea. Although our results appear to show no relationship between turtle transit bearings and light pollution – the effect is seen in a low to intermediate travel – it would still be worthwhile to approach track category analysis with an additional variable which quantifies just how direct the turtle returns to the ocean.

Two key changes would improve the method: single band analysis of light and increased resolution of light sampling. This would allow a more representative picture to be obtained of light levels on the Index beaches. It would also allow the creation of directivity index which would be a more accurate reflection of how harmful light sources could be.

Future

Morphometric

Future morphometric analysis should attempt to include measurements of the rear flippers as they are involved in propelling the turtle forward (Carr et al., 1966; Renous, 1993). This is difficult to do given that the primary data collection of the patrol protocol must rightfully be taken first and this limits space to work around the posterior of the turtle. Also, the rear flippers are often positioned awkwardly over the nest chamber and so measurements would be difficult to obtain.

If adult turtles could be sampled repeatedly throughout the nesting season it would be interesting to see how their mass loss and changing condition index relates to transit velocity. Turtles may lose up to a third of their body weight when completing the nesting cycle (James et al., 2005).

In future it would be interesting to explore the relationship between mass and distance traveled (Garland, 1984) or to look at the beach gradient scaled by a particular turtle morph. By making ‘race tracks’ longer, any rest periods or stroke patterns could be logged also.

Light

There exists an opportunity for future researchers to carry out a full light assessment of the beachfront across each of 3 index beaches patrolled by SOS Tobago. Grafton is perhaps the worst affected by light pollution. Back Bay is beach with no development behind it and so would act as a control. Assessment should consider factors such as the height, distance, technology and constituent wavelengths of light sources. Using a detailed light assessment as a basis, before and after comparisons of the effectiveness of mitigation measures could be made. These would again use observations of turtle behavioral as the primary response variable.

It would be interesting to look at the nest area covered by a turtle with respect to Blair and Witherington's (2000) postulation that inaccuracies in the stages of the nesting process may occur. Specifically, observations of the covering saw the whole process occur entirely by within the body pit by pivoting. This was only observed on a small number of occasions (n=<5) and so may be attributed entirely to the apparent randomness in covering patters. However, it would be interesting to explore the relationship to light sources as it was once seen in a turtle which showed signs of disorientation in Turtle Beach zone 1.

Changes in nest stage duration timings may be a manifestation of light disturbance and deserve attention. Johnson et al. (1996) found the duration of covering behavior in loggerhead turtles which were watched by ecotourism groups decreased. The effect could be manifested in two different ways: turtles may be disturbed and abbreviate covering and camouflaging behaviour or they may invest extra time and energy in disguising a nest which is perceived to be in the open and exposed. The actions in the performance of nesting stages remain unchanged but decisions regarding the timing, duration and accuracy of these could be influenced (Witherington&Martin, 2000). Mean light level at the nest site could be used as a covariate in analysis of stage duration and from this a threshold value or index for disorientation may emerge.

Johnson et al. (1996) measured return track length and the straight distance out to calcluate an index of the tracks. I think this would be extremely useful in order to quanitfiy the indirect nature of the leatherback tracks I observed. This places a figure on the horizontal component of transit which may prove useful where comparing the magnitude of misorientation at different locations.

It would be interesting to see if the same turtles displayed similarly sinusoidal tracks on repeat visits as this may indicate intraspecific variation as opposed to differences in the environment.

I recommend a dedicated hatchling transit study which incorporates orientation arenas.

This could be used to identify on which beaches and locations they have problems. Group effects and the consequences of emerging from the egg chamber seaward, landward and parallel to shore orientations would be useful. It would be interesting also to look at whether the adult turtle encountered problems and to see if this is present also in the hatchlings.

Recommendations for stakeholders

The findings of this thesis indicate that important actions are necessary to ensure the successful nesting of all leatherback turtles at Tobago’s Index beaches. Actions will be required from a number of stakeholders: law makers, property owners, security staff, turtle patrol staff, turtle watchers and researchers. With the exception of legislative change all actions can be readily implemented by aware and educated stakeholders. Here follows a list of recommended actions.

Law makers

The predicted population rise by UNEP (2006) mean much more coastline than present will be developed. In many places the current environmental laws in place offer inadequate protection of nesting habitat for marine turtles in the face of this intense urbanisation (Mascarenhas et al., 2004). Therefore, an environmental impact assessment (EIA) should be carried out for proposed developments of the beachfront area and encorporated into future legislation. Legislation to place a ‘curfew’ on bright lights is perhaps something that would best be reserved for more developed regions such as Florida as many of the visible sources of light in the Index beach area are from residential properties. Ideally, with increased awareness of the plight of the sea turtles the regulation of beachfront lighting would come from the legislative level. This recommendation may be perhaps the most challenging as properties may be constructed without land owners engaging in the correct planning process. Additionally, Trinidad and Tobago fail to enforce current turtle laws. However, it is often not the small residencies owned by local people rather the sizeable properties of foreigner owners and facilities which cater for tourists which have the most troublesome light sources. Therefore, it is not unreasonable to recommend investment in mitigation measures. Legislative action could be taken in 12 to 24 months.

Property owners

Use of low pressure sodium vapour lighting which emits longer wavelengths of light which is less harmful to turtles (Witherington, 1992). This would obviously require investment. Property owners may be unable to absorb the costs of new lighting technologies or unwilling to extend themselves in the name of conservation. However, other simple actions could be undertaken to benefit both owners and conservationists: turning off unnecessary light sources will be beneficial economically and prevent unnecessary disturbance of neonate and adult turtles.

Room and balcony lights on the 1st and 2nd floor of properties are an obvious example of unnecessary light sources. Often these remain on when guests are attending dinner, evening entertainment or whilst asleep in bed. From a security point of view the ground floor lights could remain on if required. If adequately educated this measure could be implemented by conscientious tourists. Either posters on viewable walls or weekly lectures would convey this message.

Manual lights should be switched off to coincide with the closing time of the bar, for example, after which time guests return to there respective rooms. Motion detectors can be installed on remaining light sources in order to provide light in response to movement of guests or other passers. The presence of security guards is an important deterrent to would be criminals in the area surrounding the index beaches. Motion sensors could, in fact, be beneficial to detection of human activity by alerting security guards to the presence of an individual. A constant light source would otherwise mask movement making passers inconspicuous.

Turtles would benefit from shielding and focussing of light direction at a specific location. Particularly as this study detected wide-angled light sources which were harmful to turtles. This would prevent light reaching areas where it is not required, specifically the nesting environment. Frequently used walkways should have sunken, low-level lighting.

Erection of lights screens would make an immediate contribution to reducing light pollution and could be implemented at relatively low cost. Light screens can be made from natural, locally sourced material or synthetics. Obviously an optimum height would need to be established in order to prevent restriction of views. Light screens are useful for two reasons: prevention of light reaching the beach (reducing negative impact) and also enhancing orientation cues by creating sihouettes where a problematic light source cannot be altered. If hatchling turtles remain oriented landward then a small ditch seaward of the screen would prevent animals from exiting the beach further landward (Carswell, 2001).

Fisheries

Turtle Beach fishing depot has been identified as a key light polluter. Though lights may play a role in guiding night fisherman back ashore they should be switched off at all other times.

Plymouth recreational stadium

The floodlights lighting the nearby recreational facilities in Plymouth are very overpowering and equally unnecessary during the hours of ‘darkness’. If they are used to guide fishing boats ashore then they may have a role during late night hours. However, there is no need for them to illuminate the nesting environment. It has been known for decades that bright lights such as these disorientate hatchlings (Philibosan, 1976). These should be shielded initially and shut off in the late evening.

Security staff

The use of torches for scanning the beach may not dissuade turtle emergences but once on the beach turtles may become disorientated (Bacon, 1975). Use of broadband torchlight is therefore not encouraged amongst security staff for the purpose of turtle detection.

Turtlewatchers

Demand for turtle watching experiences may exceed supply (Johnson et al., 1996). Excessive numbers of tourists per turtle event can diminish the intimate nature of the experience for those present. It is important that turtle watchers behave correctly. The education provided by the SOS patrol staff is a key starting point for addressing this. Resources permitting, a weekly talk (of short duration) or welcome pack in hotel rooms could lower problematic behaviour as well as advising guests to cut back on balcony light use for example. By educating and inspiring visitors from other villages, Trinidad and the wider international community the message of turtle conservation can be spread beyond the nesting beach. Thus enhanced turtle watching experiences may yield an economic benefit for future generations through the proceeds of ecotourism.

Turtle patrol staff

From observation, several turtles finished camouflaging the nest site and facing landward which I found not to be influenced by light. These turtles initially set off on that course before sharply turning seaward. Therefore, I would recommend for patrol protocol that turtles are initially allowed to begin transit landward (when already facing that direction) in order that they have the opportunity to initiate the terrestrial navigation system themselves. Turtles completing more than 1 circle within the vicinity of the nest site may disorientated.

A decrease in nesting emergences may be caused by beachfront illumination (Medicci et al., 2009). The long-term effect impact of beachfront lighting on the number of nesting emergences should be closely monitored also.

Researchers

The baseline light assessment is a great tool for use in comparison of the effectiveness of mitigating light technologies if carried out before and after changes have been made. A greater data set for the parameters outlined in this study, additional parameters and better equipment should be explored in future studies. Further to this, adequate data will reveal that Grafton beach is the most light polluted of all the index beaches. From naked eye observation Grafton beach is illuminated for a greater proportion of its length and deserves attention.

Conclusions

With projected coastal population growth (UNEP, 2006) understanding the effects of light pollution on wildlife and devising management plans is of the utmost importance. This thesis addressed the impact that light pollution had on the nesting leatherback at Tobago’s Index beaches. As I believe it is representative of the in-situ problem at Turtle Beach it provides a useful foundation for future researchers. The other strand to this thesis involved exploration of morphological traits and terrestrial locomotive velocity.

Unfortunately, analysis of morphological traits and terrestrial locomotive velocity was critically undermined by a small sample size of nesting turtles, n=20 and so the efficacy of the results is in doubt. In summary, I found no significant relationship between any single morphological trait or grouped traits and the dependent variable. The discussed limitations and methodological changes will ensure future researchers are able to perform a more comprehensive examination of the influence of morphology and its relationship with terrestrial locomotion velocity.

By utilizing both quantitative and qualitative measures of disturbance I was able to capture the nature and magnitude of problems associated with light pollution. Artificial light levels are exceeding those of perceived natural levels at locations on Turtle Beach and I recorded evidence of disruption to the orientation systems of nesting turtles through counts of both misorientation, disorientation and circling behaviour. Instances of these were observed in illuminated areas of the nesting beach.

Given these findings I make recommendations for stakeholders. It is important that managers implement changes to the way urban and beachfront lighting is deployed. Ideally, with increased awareness of the plight of the sea turtles the regulation of beachfront lighting would come from the legislative level.

This will aid the efforts of conservationists who seek to replenish already depleted populations. Future development around nesting beaches must be carefully regulated and monitored as further light pollution may ultimately decrease nesting emergences in affected areas (Medicci et al., 2009). Trinidad and Tobago hosts a globally important nesting population (Eckert, 2006) of the critically endangered leatherback sea turtle (Spotilla, 2000). Implementation of these actions will also enhance the turtle watching experience, nurturing ecotourism prospects and thus contributing to the viability of the conservation effort.

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