# Impact of *Casuarina* Plantations on Olive Ridley Turtle Nesting along the Northern Tamil Nadu Coast, India

**2009**

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## Citation

Chaudhari, S., K.V. Devi Prasad and K. Shanker. 2009. Impact of *Casuarina* Plantations on Olive Ridley Turtle Nesting along the Northern Tamil Nadu Coast, India. ATREE, Bangalore and MCBT, Mamallapuram, India. pp. 44.

# Impact of *Casuarina* Plantations on Olive Ridley Turtle Nesting along the Northern Coast of Tamil Nadu, India

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# Acknowledgements

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# Executive Summary

This study examines the possible impacts of *Casuarina equisetifolia* plantations on olive ridley (*Lepidochelys olivacea*) turtle nesting beaches along the northern Tamil Nadu coast. The study was carried out across three habitats, namely open beaches, vegetated beaches and beaches with *Casuarina* plantations. All three sites lie along the northern Tamil Nadu coast, starting from the mouth of the Adyar estuary till Vadanemmeli, which are separated by an approximate distance of 40 km. Parameters such as beach slope, beach width and temperature of beach were measured to examine the effect of *Casuarina* on these beaches. Twelve quadrats of 4 × 4 m were laid to examine the effect of *Casuarina* on native sand dune vegetation. Data on beach profiles and independent data on nesting was collected by patrolling these three types of beaches. Nesting data was collected for 45 days and a total of 47 nests were encountered. Nesting in beaches with *Casuarina* was significantly different from the other two types of beaches. Slope and beach width were also significantly different among the three types of beaches. The temperature at different distances from the high tide line showed a similar pattern across the beach types, but the mean temperature of beaches with *Casuarina* was significantly lower than in the other two beach types. We suggest that *Casuarina* has potentially negative impacts on sea turtle nesting. Further, since it is an exotic, it may not be an appropriate species for large scale plantation on the coasts of India. We recommend that native species be planted, where appropriate, and that if *Casuarina* plantations exist, they should be at a minimum distance of 50 – 100 m from the High Tide Line.

# 1. Introduction

At present, seven species of sea turtles are found in the world's oceans, representing two families; Cheloniidae: hard-shelled sea turtles, and Dermochelyidae: soft-shelled sea turtles. These include the loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), Kemp's ridley (*Lepidochelys kempii*), olive ridley (*Lepidochelys olivacea*), flatback (*Natator depressus*) and leatherback (*Dermochelys coriacea*) turtles. Every year, sea turtles migrate thousands of kilometers exploiting a range of habitats from deep oceans to the shallow waters of their feeding grounds. This enormous range of movement makes them a key representative of a variety of habitats in the world's oceans, as well as coastal areas around the world. Favorable nesting habitat is important for sea turtle reproduction and long term survival, and estimates of hatchlings surviving to maturity range from 1 in 100 to 1 in 1000.

Five species of marine turtles, namely green, hawksbill, loggerhead, leatherback and olive ridley turtles, have been reported in Indian waters. Olive ridley turtles are most abundant and nest along the west and east coasts with *arribadas* occurring on the coast of Orissa.

Coastal areas with long stretches of sandy beach are favorable nesting habitats for sea turtles. Coastal areas have also been a source of livelihood for millions of people. This has resulted in the migration to and settling of human societies in these areas. As a result, these nesting habitats are increasingly exposed to human induced pressures. In recent years, construction activities such as shipping ports and the erection of sea walls, sand mining, rapid urbanization, beach armoring and plantation of exotic plants along the coast have posed threats to nesting habitats.

In India, the history of coastal plantations can be traced to the early 19th century where the plantation of *Casuarina* was taken up to prevent drifting of sand and to protect heritage sites and monuments. In recent years, *Casuarina equisetifolia* has been planted as a measure of control for beach erosion, for creation of vegetation shelterbelts against cyclonic storms and afforestation of the coastal zone (Shanker *et al.* 2008; Mukherjee *et al.* in press). Immediately after the tsunami hit the coast of India in December 2004, many government and non government organizations initiated extensive coastal planting programmes in Orissa, Andhra Pradesh and Tamil Nadu with aid from foreign agencies (Mukherjee *et al.* in press). This drive has covered almost the entire coast of Tamil Nadu with long stretches of *Casuarina* plantations (Mukherjee *et al.* in press).

This study examines the possible impact of *Casuarina* plantations on the nesting of sea turtles, in terms of beach width, beach slope and temperature of beach along the northern Tamil Nadu coast between Chennai and Puducherry.

## 1.1. Olive Ridley (*Lepidochelys olivacea*)
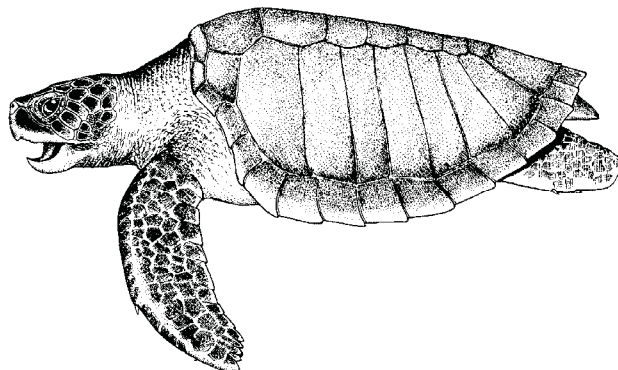


**Figure 1.** *Lepidochelys olivacea* (Source: Marquez 1990).

The olive ridley turtle (*Lepidochelys olivacea*) (Fig. 1.) is one of the smallest species of sea turtles with a short and wide carapace. The straight carapace length (SCL) measures approximately 60 - 70 cm and adults weigh up to 50 kg. The olive ridley is widely distributed in the tropics of the Indo-Pacific and Atlantic Oceans (Fig. 2.). Olive ridley turtles often migrate great distances between feeding and breeding grounds. In the eastern Pacific, *arribadas* occur along the coasts of Mexico, Nicaragua and Costa Rica (Marquez 1990). In the northern Indian Ocean, *arribadas* occur on three different beaches along the coast of Orissa, India (Shanker *et al.* 2003). Sporadic nesting occurs throughout the country (Kar & Bhaskar 1982).
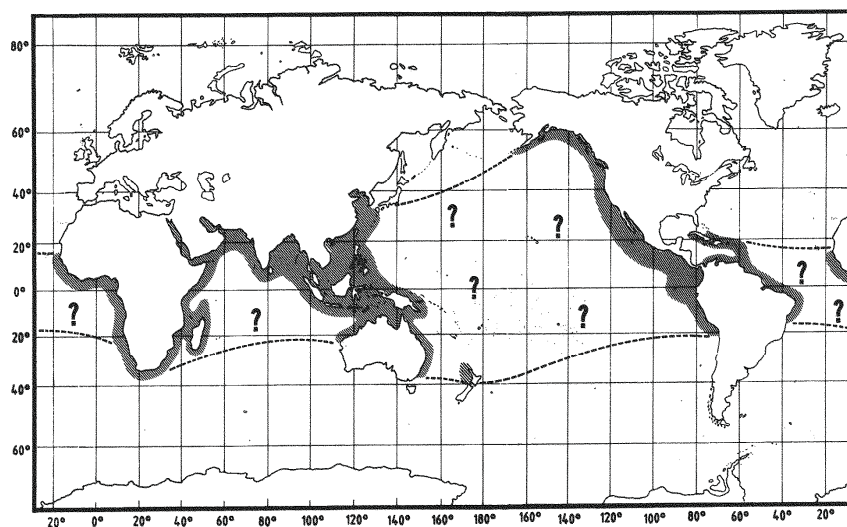


**Figure 2.** Global distribution of *Lepidochelys olivacea* (Source: Marquez 1990).

## 1.2. Life cycle

At the onset of the breeding season, which varies in different places, adults of the species leave their feeding grounds and migrate to courtship areas, which are near nesting areas. The mature males and females mate in nearshore waters close to the nesting beaches. After successful mating, males return to their feeding grounds. The female ridley crawls out onto the beach to lay eggs. She digs a pit and lays roughly 100 to 120 eggs. She then covers and camouflages the nest to protect the eggs from predators. The eggs hatch after 45 to 50 days and the hatchlings make their way to the ocean to begin a new journey. Following this, the hatchlings are carried by currents across ocean basins for several years till they move to nearshore developmental habitats, and eventually to adult feeding grounds. Figure 3 below is a diagrammatic representation of the life cycle of the olive ridley turtle.
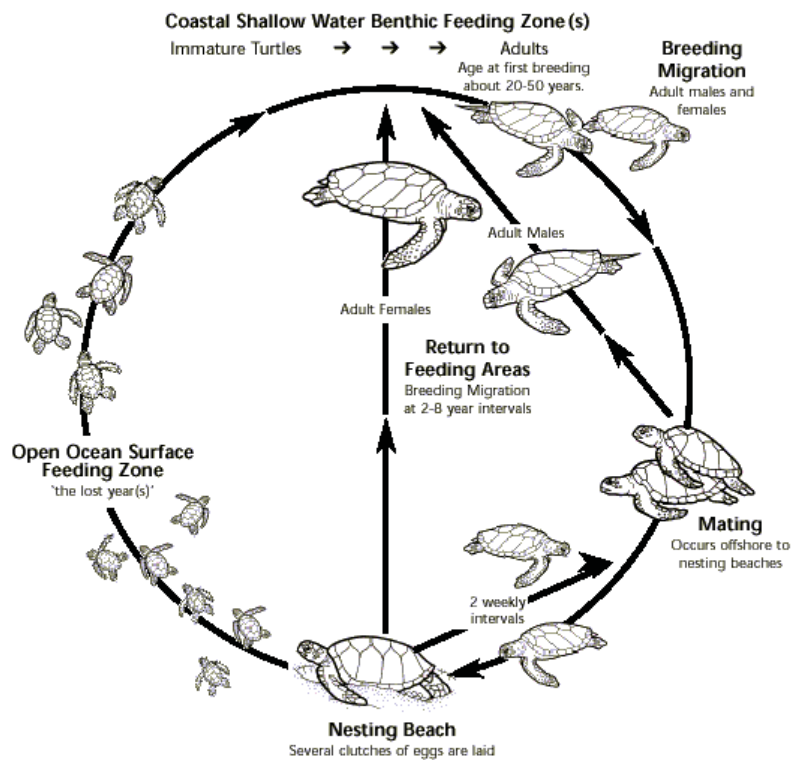
**Figure 3.** Generalized life cycle of sea turtles
(Source: Lanyon, J. M., C. J. Limpus & H. Marsh 1989)

# 2. Literature review

## 2.1. Natural history

Olive ridley turtles usually nest on open and wide beaches and on sand bars at river mouths. Beaches backed by coastal sand dunes with natural vegetation such as *Ipomoea pes-capre* are typical nesting sites for olive ridley turtles (Shanker 2003; Bhupathy *et al.* 2007). For solitary nesting turtles along the Tamil Nadu coast, the average distance of nests from the high tide line is approximately 15 m (Bhupathy *et al.* 2007). Thus the availability of sufficiently wide beaches is important for nesting.

The selection of a nest site by the female is based on several physical and chemical factors, such as sand grain size, dune configuration, compressibility of beach sand and smell; thermal variation in beach sand may also be an important environmental cue for nest site selection (Stoneburner & Richardson 1981). Nest success is believed to be influenced by a number of interacting ecological factors such as sand temperature, sand particle size, water content and salinity (Mortimer 1980; Horrocks & Scott 1991; Sivasundar & Devi Prasad 1996). For sea turtles, the survival of offspring may be strongly related to the distance at which the nest is laid from the sea, and from the supra littoral vegetation behind the beach (Mrosovsky 1983). For nests laid too near the sea, there is a risk of egg loss due to erosion and mortality due to salt water inundation; for nests laid too far from the sea, there is a risk of disorientation of hatchlings into supra littoral vegetation. Sand texture and moisture must be such that females are able to dig an egg chamber without the walls of the chamber collapsing, and the hatchlings must be able to dig their way out of the nest (Mortimer 1980).

Hatching success is influenced by several abiotic factors such as temperature (Mrosovsky *et al.* 1984), oxygen levels (Ackerman 1980), chloride levels (Bustard & Greenham 1968) and moisture content (Mortimer 1980). Moisture content of the sand is believed to be one of the cues for hatchlings to finding the sea, and this varies along the sea-to-vegetation axis (Sivasundar & Devi Prasad 1996).

In some organisms, sex determination is influenced by environmental factors and is known as Environmental Sex Determination (ESD). Sea turtles lack heteromorphic sex chromosomes and their sex is determined by incubation temperature. This is called Temperature Sex Determination (TSD). TSD in sea turtles has been demonstrated in green turtles (*Chelonia mydas*) (Miller & Limpus 1981; Morreale *et al.* 1982), loggerhead turtles (*Caretta caretta*) (Yntema & Mrosovsky 1980), olive ridley turtles (*Lepidochelys olivacea*) (Morreale *et al.* 1982; Dimond & Mohanty-Hejmadi 1983) and leatherback turtles (*Dermochelys coriacea*) (Mrosovsky & Yntema 1980).

Lower temperatures produce males while higher temperatures produce females. Nests laid under dense vegetation are likely to produce more number of males than those laid in open zones, which are likely to be warmer (Mrosovsky *et al.* 1984; Spotila *et al.* 1987; Godfrey & Mrosovsky 1999). The distance from the high tide line at which the nest has been laid also influences sex because the distance might affect the height of the water table which influences the incubation temperature of the nest. It is also likely that sex ratios will be different at different times during the nesting season.

### 2.1.1. Nesting along the coast of Tamil Nadu

Tamil Nadu's coast is predominantly along the east, with a small stretch of coast along the west. All the five species of marine turtles found in Indian waters - olive ridley, green, leatherback, hawksbill and loggerhead - are reported in Tamil Nadu. Barring the loggerhead, all other species have been reported to nest along the Tamil Nadu coast (Kar & Bhaskar 1982), but nesting of all species other than the olive ridley is extremely rare with virtually no reports over the last 2 – 3 decades.

Although there is a long stretch of sandy coast, most of the area available for nesting is declining and this could affect turtle nesting directly and indirectly. Sandy areas are also impacted by sand mining, especially between Kanniyakumari and Tiruchendur. Sea walls built to protect the land from sea erosion have left no place for nesting in most parts of west coast, and elsewhere, sandy beaches on the eastern coast (especially between Nagapattinam and Chennai in Tamil Nadu) have a large number of human settlements and industries (Bhupathy & Saravanan 2001).

The Chennai coast in particular, has been monitored since 1974 by the Madras Snake Park Trust, the Tamil Nadu Forest department, the Central Marine Fisheries Institute (CMFRI), the Madras Crocodile Bank Trust (MCBT) and the Students Sea turtle Conservation Network (SSTCN) (Shanker 2003).

Olive ridleys are reported to nest along almost the entire Tamil Nadu coast starting from Chennai up to Kanniyakumari, although nesting frequency varies along the coast (Bhupathy & Saravanan 2001). In northern Tamil Nadu, nesting occurs along the stretch from the mouth of the Adyar River, Chennai to Kalpakkam in the south (Valliapan & Whitaker 1975; Shanker 1995; Bhupathy & Saravanan 2001; Shanker 2003).

The coast between Puducherry and Chennai has approximately 75 km of sandy beach suitable for turtle nesting, with an average of 9.8 nest/km/season (Bhupathy & Saravanan 2001; Shanker 2003). Nesting starts in the middle of December and lasts till the end of March, attaining its peak in February (Bhupathy & Saravanan 2001; Subramanean 2001). The population which nests on the Chennai coast is part of the same lineage which nests in Orissa; this population is considered to be globally significant as they are distinct from, and ancestral to, olive ridleys found in the Atlantic and Pacific Oceans (Shanker *et al.* 2004).

## 2.2. Beach processes

The movement of sand up and down the coast is called long shore transport. Obstacles in the path of long shore transport of sand causes accretion on one side resulting in the build up of sand on the beach, and a similar amount of erosion occurs on the other side. Structures built perpendicular to the coast, which are intended to control long-shore movement (e.g. groynes and jetties) present additional threats to nesting habitats. Such structures typically exacerbate erosion on the down-current sandy beaches (Witherington 1999). The best way to reduce the threat of erosion is to eliminate its necessity by allowing natural ecosystem flows to shape the beach. Natural dune vegetation and sand dune structures are closely interrelated and have co-evolved to support floral and faunal communities that are obligate to coastal sand dune habitats (Desai & Untawale 2002).

The coastal dune plant community (Barbour & Johnson 1988), also called active coastal dune (Holland 1986), is the only vascular plant community at the shoreline, and is subjected to the constant rhythm of wind and tide.

Vegetation plays an important role in the formation and development of coastal sand dunes. Dune plants accumulate sand around their foliage and their ability to grow upward through accreting sand layers also affects dune formation. Dune plants are especially effective in stopping and holding wind born sand. Their growth produces surface roughness which decreases wind velocity near the ground, thereby reducing wind erosion at the sand surface. Also, plant stems and leaves above the sand surface greatly interfere with sand movement by siltation and surface creep (Woodhouse 1982). Foliage of dune plants in turn slows down erosive activity of wind on the leeward side of the dune (Chapman 1976; Olson & Vander 1989).

## 2.3. Shelterbelts

The systematic development of plantations of particular species to mitigate wind and cyclonic action along the coast has been occurring for decades. Plantations of *Casuarina, Eucalyptus* and Cashewnut have been established, ostensibly to protect communities residing along the coast. The theoretical principle behind the shelterbelt is that wave energy is progressively absorbed as it passes through the rows of trees (Forbes & Broadhead 2008). Proponents of shelterbelts suggest that they allow a portion of a tsunami to pass through the forest with its force gradually attenuated, whereas a solid wall may be broken apart, lifted up, or overtopped. They also argue that plantations greatly reduce impact forces, flow depths and velocities, which in turn limit the extent of flooding (Forbes & Broadhead 2008). The effectiveness of shelterbelts as a protective measure against salt spray, wave action and mini tsunamis mainly depends on its width, height, inter-spacing of trees, undergrowth and species composition (Forbes & Broadhead 2008). Such a role was ascribed to vegetation after the December 2004 tsunami (Danielson *et al.* 2005; Kathiresan & Rajendran 2005).

However, many recent studies have shown that vegetation may have played little role in protection against the tsunami (Bhalla 2007; Chatenoux & Peduzzi 2007; Kerr & Baird 2007) and other storm events (Pandav 2000). It has been pointed out that there is no experimental evidence to support the idea that vegetation can reduce the effect of long-period waves such as a storm surge or a tsunami (Kerr & Baird 2007; Feagin *et al.* 2009). The impacts of these extreme events are highly dependent on topography, near-shore bathymetry, distance from the shore, and other physical factors (Chatenoux & Peduzzi 2006; Bhalla 2007). Most importantly, it has been pointed out that protection from waves is different from protection from rising water levels, which is the leading cause of death during these events (Feagin 2008).

### 2.3.1. Plantations along the Tamil Nadu coast

In recent years, *Casuarina equisetifolia* has been planted as a measure to control beach erosion, offer protection against cyclonic storms and for afforesting the coastal zone (Mukherjee *et al.* 2003). *Casuarina* is popular because it is hardy and can grow almost anywhere, which makes it a favoured species for most shelterbelt development projects. Unfortunately, these same characteristics also make *Casuarina* detrimental to beach ecosystems. *Casuarina*, a spindly tree with needle-like leaves, was introduced in Tamil Nadu 100 years ago. Following the December 2004 tsunami, the World Bank funded an Emergency Tsunami Restoration Programme (ETRP) in Tamil Nadu, which included the establishment of 'bio-shield' shelterbelts on beaches, mainly composed of stands of *Casuarina* (GoTN 2006).

Most of the plantations constitute a single species of *Casuarina* while some plantations have other species such as Neem (*Azadirachta indica*), *Calophyllum inophyllum* and *Thespesia populnea*. The state

forest department has covered an area of 4,850 ha with bioshields and 2,250 ha with mangroves since 2005. An estimated 18 lakh *Casuarina* saplings have been planted in a 450 ha stretch in Kanchipuram district of Tamil Nadu alone. Almost a third of the state's coastline has been covered with plantations. The saplings have been planted on a 26-kilometre stretch from Kovalam south to Mamallapuram along the East Coast Road.

## 2.4. Impact of *Casuarina* plantations

When trees like *Casuarina equisetifolia* are planted on fore dunes instead of hind dunes they do not serve as wind breakers but are uprooted and have detrimental impacts on the fore dunes instead of protecting them. Sand dune vegetation throughout the world has been recognized for its ecological significance. Natural disturbances have always been a part of beach and dune building processes. Ongoing abrasions, heavy load of salt spray, sand accretion and wave action are some of the natural processes that affect the coast. Dune plants act as an obstruction, increase surface roughness and cause reduction in the surface speed of sand carrying wind. The reduction in speed results in the deposition of sand around the plants. These cycles of sand deposition and growth result in dune formation. *Spinifex littoreus* and *Ipomoea pes-caprae* are two of the most successful sand trapping plants. They are known as *psammophytes*. Pioneer plants trap and hold the sand and create conditions which encourage development of taller plants.

Human activities compound disasters along the coast by the removal of natural vegetation. The sand dune ecosystem acts as a buffer between the sea and inland areas and reduces the impact of extreme events. If dunes are properly managed, the damage caused by such events will be reduced. Moreover, if appropriate vegetation is maintained on moving dunes, they would check sand erosion. Hence, studies on various aspects of dune vegetation have gained momentum throughout the world (Desai & Untawale 2002).

The conversion of natural sand dunes to shelterbelts has accelerated in most coastal districts of Tamil Nadu in the belief that plantations mitigated the impact of the 2004 tsunami. But recent studies have revealed that there was no significant relationship between tsunami inundation and vegetation (Bhalla 2007). *Casuarina* shelterbelts were also ineffective in situations where they were too narrow or had become too old and were therefore without flow-resisting branches lower down on the trunk. Post-tsunami field surveys in Sri Lanka and Thailand showed that older *Casuarina equisetifolia* shelterbelts withstood the tsunami, but failed to provide protection (IUCN 2005; Tanaka *et al.* 2007). Ironically, the shallow root system of *Casuarina* makes them more susceptible to the effects of storm winds and erosion, and the lack of undergrowth allows much of the tsunami to pass through the plantation.

Further, if shelterbelt plantations are established close to the high tide line, they can potentially block the supply of sand to littoral currents, because of sand holding by *Casuarina* roots, while to compensate for this, currents and waves would remove large amounts of sand from other areas, leading to erosion and subduction in those areas (MSSRF, n.d.). Massive plantations may restrict sand dune formation, which is an integral part of seashore topography and beach ecosystems. Manmade bioshields, though perhaps better than sea walls and groynes, are not the last word in protection measures. Sand dunes, the coast's natural system, have a great protective value and should be conserved. In Tamil Nadu, South Poigainallur is well known for its sand dunes along the seashore which have attained heights of up to 30 to 40 feet. Local communities believe that these sand dunes have protected them from cyclones and high tides. The dunes in fact are believed to have minimized deaths in the village during the 2004 tsunami (Balakrishnan 2007).

Being an exotic, *Casuarina* may not support local biodiversity. Once established, the shade and the thick litter layer under the trees prevent germination and growth of native vegetation (Schmid *et al.* 2008). Exotics such as *Casuarina equisetifolia* can exclude native species in coastal areas (Nelson 1994) and can displace native dune and beach vegetation through shading and/or chemical inhibition.

Specialized organisms like sea turtles which nest on sandy beaches may not be able to adapt to such changes. When plantations are established very close to the high tide line, there is loss of habitat for fauna such as sea turtles, shore crabs, etc. (Selvam 2006). *Casuarina* plantations in Orissa are believed to have had negative impacts on nesting beaches and nesting (Pandav 2005). Witherington (1999) defines threats to nesting habitats as any action or process that can alter the sand substrate of the nesting beach, injure or kill sea turtles or their eggs, and/or cause the disruption of normal behavioral patterns. Since all coastal plantations are taken up on either side of the sand dune berm, there is significant loss of sea turtle nesting habitat. Dense new vegetation shades nests, potentially altering natural hatchling sex ratios.

The effect of *Casuarina* on the nesting of loggerhead turtles has been demonstrated (Schmelz & Mezich 1988). *Casuarina* dominated areas had greater instances of turtle aborting nests; thus *Casuarina* also affects nest site selection in loggerhead turtles. Incubation temperature for the nests which were under the shade of *Casuarina* plants was lower than natural areas. The nests laid in the shaded areas of the pines are subjected to cooler incubation temperatures and, subsequently, longer incubation periods. These conditions may produce a higher percentage of male hatchlings. Over a period of time, this selection process could artificially alter the natural sex ratio of turtles (Schmelz & Mezich 1988).

When *Casuarina* plants fall, they create a barrier to sea turtles searching for nest sites on beaches (Schmelz & Mezich 1988; LeBuff 1990; Schmid 2003). Thick root masses can also entangle eggs and hatchlings. Alien vegetation with its superficial root growth and thick litter fall renders the beach unsuitable for turtles to nest. Dense vegetation along coastal sand dunes provides shelter for both natural predators (jackal, hyena, monitor lizard, wild pig, crabs, etc.) and subsidized predators (pigs and dogs) to breed, creating additional predation pressure on nesting females, eggs and hatchlings (Shanker 2003).

The lack of wide beaches might result in significant differences in nest placement from the high tide line and the supra littoral vegetation line, which also determines incubation temperature. This can greatly hamper ecological processes along the coastal system. Thus, further changes in an already limited nesting habitat will prove detrimental for the olive ridley and other fauna.

# 3. Objectives

Several research papers and articles have suggested that *Casuarina* plantations might have detrimental effects on sea turtle nesting (Choudhury *et al.* 2002; Mohanty 2002; Shanker *et al.* 2003). Many non government organizations have also shown concern over this issue (Narayanan 2008; Oppili 2008). However, this has not been demonstrated with empirical evidence for olive ridley turtles on the coast of India. This study addresses the following questions with regard to the impact of *Casuarina* plantations on olive ridley turtles:

1) Is there any difference in the average nesting under *Casuarina*, vegetated and non vegetated beaches?

2) Is there a significant difference in beach parameters such as slope and beach width for *Casuarina*, vegetated and non vegetated beaches?

3) Is there significant difference in the temperature of sand under *Casuarina* plantations, native vegetation and open sandy beaches? How much does it vary from pivotal temperatures for olive ridley turtles?

4) Is there a significant impact on the regeneration of native sand dune vegetation under *Casuarina* plantations?

# 4. Study area

The study was focused on the impact of *Casuarina* plantations on olive ridley turtles. Beach characteristics in terms of slope, beach width, proximity from nearby human settlements and degree of disturbance play a vital role in nest site selection by sea turtles. A preliminary survey was conducted to identify beaches for the study. This involved extensive beach surveys and interviews along the coastal district of Kanchipuram, Tamil Nadu. On the basis of information from interviews, coastal areas reported to have nesting were rapidly visited to check general beach profile, dominant vegetation type and beach composition. On the basis of this information, three field sites i.e. three beach types based on vegetation type, were selected.

All the three sites lie along the northern Tamil Nadu coast (Fig. 4), roughly covering 40 km of coastline. The average daily temperature ranges from 20 $^0$C to 32 $^0$C during summer and is lower in subsequent seasons. The average rainfall is 1215 mm. There are scanty showers between the end of winter and early summer.
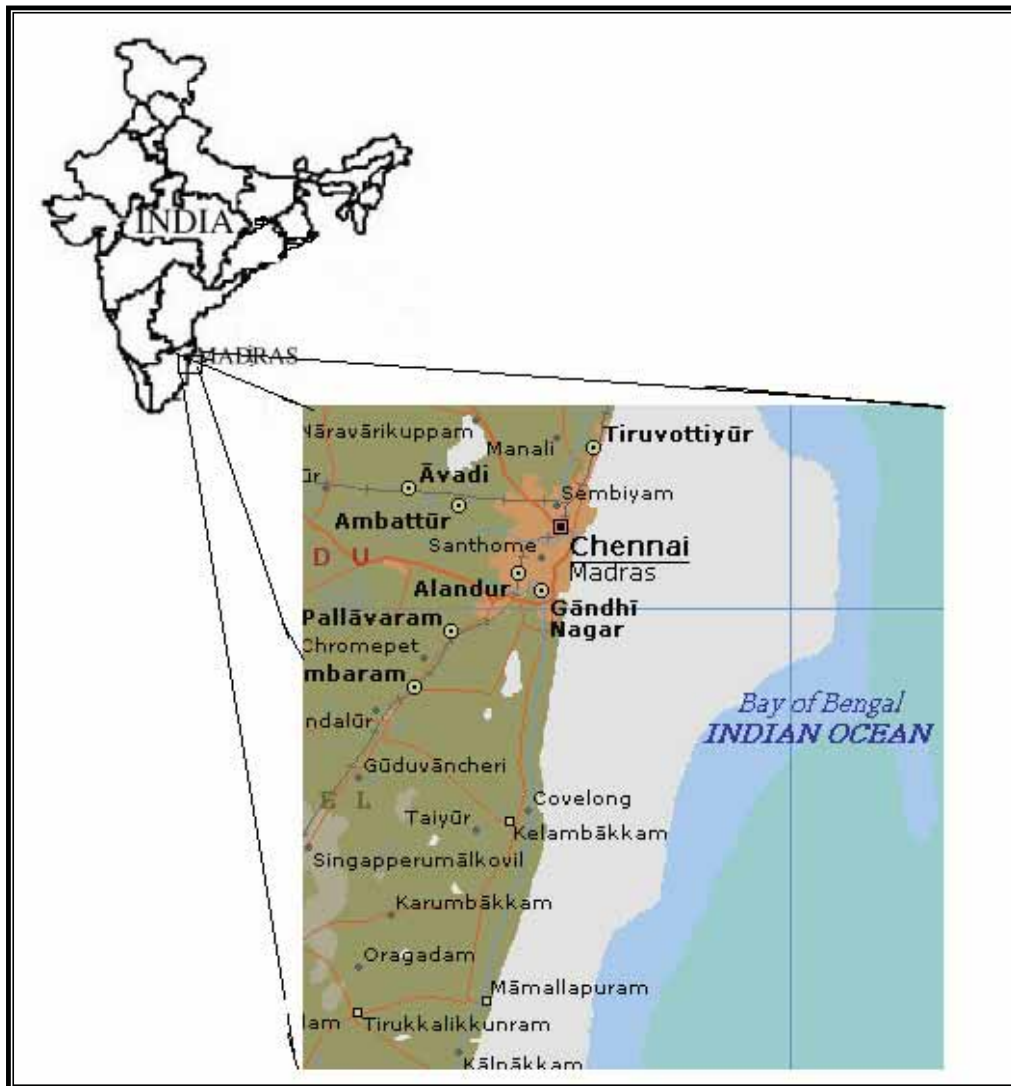


**Figure 4.** Map of study area covering beach from Chennai till Mamallapuram.

## 4.1. Open beach

This type predominantly consists of open sandy beaches, mostly devoid of any vegetation. This includes beaches from Adyar estuary up to Neelankarai, which includes the villages of Palavakkam, Kotivakkam and Neelankarai. The length of beach is approximately 7.5 km ($13^0 00'$ 46.51" N $80^0 16' 34.98"$ E to $12^0 56' 57.06"$ N $80^0 15' 43.05"$ E).

## 4.2. Vegetated beach

This beach type starts from Injumbakkam and stretches till Reddikuppam, covering approximately 7.2 km. This beach includes four fishing hamlets namely Injumbakkam, Panayur, Nainarkuppam, and Reddikuppam ($12^0 55' 09.40"$N $80^0 15' 22.54"$E to $12^0 51' 17.49"$N $80^0 14' 59.53"$ E). The vegetation mostly consists of *Ipomea pes-caprae, Spinifix littoreus* and *Pandanus tectornis.*

## 4.3. *Casuarina* beach

This beach type starts from Kovalam to Madras Crocodile Bank, roughly covering 6 km of continuous beach ($12^0 48' 07.99"$N $80^0 14' 56.80"$E to $12^0 43' 56.57"$N $80^0 14' 16.66"$E). The Madras Crocodile Bank Trust (MCBT) has been active in monitoring this beach for turtle nesting along with local villagers and fishermen. MCBT has been maintaining hatcheries with 10 to 20 nests/season (Devi & Mundoli 2004; Devi 2005). This stretch has both fishing and non-fishing villages, including Kovalam, Chemmenjerry, Thirkapattu, Tiruvanindathai and Vadanemmeli. Almost 90% of this stretch is backed with plantations. Starting from Chemmenjery, crocodile bank and further south, the forest department of Tamil Nadu has established plantations of *Casuarina equisetifolia* under the ETRP shelter belt project. This plantation was established in the month of December, 2006.

# 5. Methods

The methodology was adapted from similar work by Sivasundar and Devi Prasad (1996).

## 5.1. Nesting

Selected study sites were patrolled on foot. Night patrolling of study sites started in mid January and data collection was completed by the first week of March, covering a total of 43 nights (17 *Casuarina*, 14 open, 12 vegetated).

Each site was patrolled twice a week on successive days from 10 pm onwards. Each beach type was patrolled to determine the minimum number of nests by direct sighting or through tracks. The following parameters were recorded for each nest encountered during the walk:

- Time at which the nest was encountered and name of closest village.

- The GPS location of the nest, false tracks and aborted nests with average accuracy ranging from 5 to 7 meters.

- Distance of the nest from current high tide line (DHTL) and distance from highest high tide line or Spring Tide line (DSTL) along the slope of the beach, which was measured with flexible measuring tape.

- Distance from vegetation line (DVL), also measured with tape.

- Number of nesting attempts made by the turtle.

- Beach width at the point of nest (BW).

- Slope of the beach at the point of nest measured by procedure described (5.2.).

- Type of vegetation in and around the nest area.

## 5.2. Slope and beach width

To examine the impact of *Casuarina* plantations on beach profile with regard to slope and width, eight points were selected at each of the three sites. The first point was placed arbitrarily, and the remaining points were placed 200 meters apart along the beach. In the *Casuarina* beach type, *Casuarina* plants at each of the eight points were marked using enamel paint, while physical features were used in the other beach types to locate the exact point each time. At these points, slope and beach width (BW) were measured once a week. Slope was measured by the procedure described below.

Slope was measured using two vertical PVC poles, 5 meters apart, on the sea-to-vegetation line. The vertical difference (V meters) between the two poles was measured using a laser pointer fitted at 30 cm height of one pole and focusing it on the other pole which was marked with measurement counts (Fig. 5). The angle was then calculated as $\tan^{-1}(V/5)$; the exact horizontal placement of the laser was ensured using spirit level, and vertical placement of the poles was also ensured using spirit level.
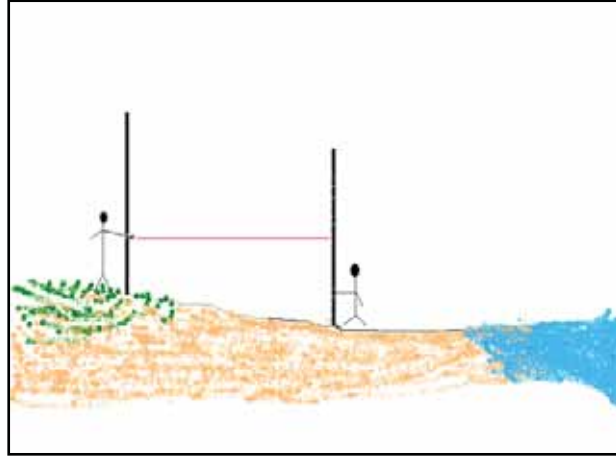
**Figure 5.** Slope measurement using two scale marked poles and laser pointer.

## 5.3. Temperature

The temperature during the incubation of eggs determines hatchling sex. At each of the above points, the temperature was measured perpendicular to the beach i.e. at 3 m, 6 m, 9 m and 12 m from the high tide line. Temperatures at all the points were recorded at 6:00 am, 4:00 pm and 10:00 pm once a week, over the course of one month.

All temperatures were measured in degrees Celsius using a digital thermometer, Model CHY 700 (Fig. 6). The instrument is a portable 3 ½ digit, compact sized digital thermometer designed to use external K-type thermocouple as a temperature sensor. The thermocouple consists of a probe 24" length and 0.5 cm diameter with a 4" handle. Temperature indication follows Reference Temperature/Voltage Tables N.I.S.T. Monograph 175 Revised to ITS-90 for K-type thermocouples.
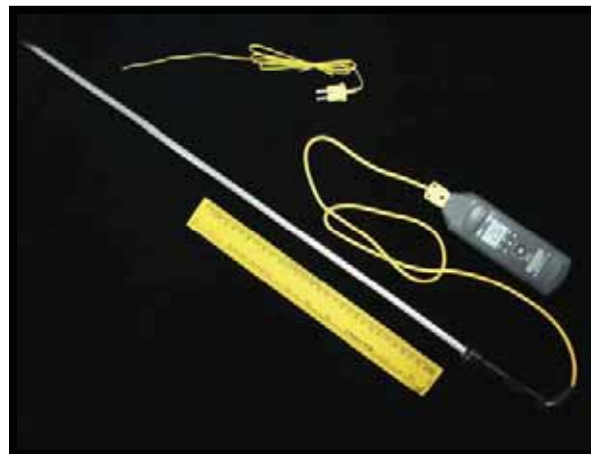


**Figure 6.** Digital thermometer along with Thermocouple devices.

## 5.4. Vegetation

The study of vegetation under the shade of *Casuarina* was done by placing four transects; three quadrats of 4 × 4 m were laid across each of the four transects at every 15 meters. The procedure was repeated in the following habitats:

1. Three year old plantation

2. One year old plantation

3. Non-*Casuarina* beach

In every quadrat, the following parameters were recorded:

- Number of individuals of *Casuarina*

- Total number of native species

- Total number of individuals of each species

- Light intensity inside the quadrat and light intensity outside the quadrat using a Lux meter. This was measured twice a day once at 10:00 am and once at 3:00 pm.

### 5.4.1. Litter biomass

In a separate experiment, within every 4 × 4 m quadrat, one 25 × 25 cm quadrat was laid and biomass was collected. The samples adhering to soil particles were carefully removed at the sorting stage and hence positive errors arising from various sources were avoided. The samples were transported to the laboratory in polythene bags.

Within the same 25 × 25 cm quadrat, the number of species and individuals of each species was counted. Later, collected biomass was dried in an oven at $80^{0}$C for 48 hours. After oven drying, the weight of dried biomass was measured using an electronic weighing machine.

## 5.5. Analysis

Before applying any tests, exploratory data analysis was performed for all the datasets. This included tests of homogeneity of variances. Null hypothesis was tested for normality, by *Kolmogorov-Smirnov* (N>50) (a) and *Shapiro-Wilk* (N<50) tests at 95% confidence levels. Then parametric and non-parametric tests were applied (Zar 2005). Almost all the data, namely slope, beach width, average temperature and temperature at different times of the day, were normally distributed, except for temperature samples at 10:00 pm, which were not normal, and hence non - parametric statistics were applied.

### 5.5.1. Nesting

Since the sample sizes were too small, alternatives to the chi-square or G test were required. Randomization test of goodness of fit was used to check for differences in observed and expected number of nests across the beach types. This test uses the spreadsheet available at http://udel.edu/~mcdonald/statrand.xls, to calculate the chi-square statistic for the data (McDonald 2008). It then draws 200 random samples from a population with the expected

proportions and calculates chi-square for each replicate sample. The proportion of replicates with chi-square values equal to or greater than the observed value is the P-value.

To see if the nesting of olive ridleys at a site is the result of certain beach characteristics like slope, beach width, etc., available data of beach width and slope for each nest was graphically plotted as a frequency distribution histogram. This was done using data for all 47 nests.

## 5.5.2. Beach characteristics

### 5.5.2.1 Slope

The graph of mean slope was plotted for each of the beach types. To test the hypothesis of difference in the slopes between beach types, one way ANOVA with 99% confidence level was performed. Since the variances were not homogeneous, multiple comparisons were done by *Games-Howell* statistic to see which beach type is different from the other.

### 5.5.2.2 Beach width

One way ANOVA with 99% confidence level was performed, but the *Levenes* statistic showed that the variances were significantly different. To test with greater precision, *Welch* and *Brown-Forsythe* statistics were used as a robust test of equality of means. Student t-test was performed to test the significant difference in beach width between *Casuarina* beach type and vegetated beach type. Paired sample t-test was used to test the null hypothesis that the beach width at *Casuarina* beaches did not significantly differ after two weeks.

## 5.5.3. Temperature

Graphs describing the temperature profile of all beach types was plotted to show the temperature pattern with respect to the distance from the high tide line. The graph of temperature at different time intervals between beach types was plotted. Box plots were drawn to represent the difference in the average temperature between beach types.

For checking the significance in difference in mean temperature, One Way Analysis of variance (ANOVA) with 95 % confidence level was used for testing the null hypotheses that mean temperature of the day and mean temperature at 6:00 am, 4:00 pm, and 10:00 pm did not differ between beach types. *Kruskal-Wallis* test and *Mann-Whitney U* non-parametric tests were performed to test the null hypothesis that temperature at 10:00 pm does not differ between beach types.

## 5.5.4. Vegetation

Vegetation data was compared using means. Species richness S and evenness was calculated using *Shannon diversity Index*, H. Litter biomass was calculated per square meter. Light intensity was taken as a proportion of that in the open to that inside the quadrat to nullify the error of cloud cover and different time intervals. Box plots were also drawn to show light intensity difference between beach types.

# 6. Results

## 6.1. Nesting

During the study period, 3 nests in the *Casuarina* beach type, 21 nests on open beaches and 23 nests on vegetated beaches were found. Nesting was considerably lower on *Casuarina* beach types than the others. The number of nests/day/km at the *Casuarina* beach was 0.03, while in the open and vegetated beaches, it was 0.24 and 0.27 respectively (Table 1). Randomization tests for goodness of fit (Table 2) indicated that there was a significant difference in the number of nest at the three sites ($x^2=15.489$, $p<0.05$).

**Table 1.** Average nesting at three beach types for respective lengths of beach and number of days walked.

| Beach types | Length (km) | Nest | Days | Average nesting | Nesting/day/km |
|---|---|---|---|---|---|
| *Casuarina* | 6 | 3 | 17 | 0.18 | 0.03 |
| Open Beach | 7.35 | 21 | 12 | 1.75 | 0.24 |
| Vegetated | 7.2 | 23 | 12 | 1.92 | 0.27 |

*Average nesting= no. of nest found/ no. of days walked

**Table 2**. Randomization test for goodness of fit to check the statistical significance in nesting at the three beach types

| Nest | Observed | Expected proportion | N | Observed $x^2$ | P value for 200 replicates |
|---|---|---|---|---|---|
| Open | 21 | 1 | 47 | 15.489 | 0.00 |
| Vegetated | 23 | 1 | | | |
| *Casuarina* | 3 | 1 | | | |

Out of the total nests recorded, most of them were at beaches with a slope of 2 to 8 degrees (Fig. 7). Turtles seemed to prefer to nest at beaches with a gradual slope, though the difference was not statistically significant. Likewise, maximum nests which were found at beach widths of 5 to 25 m. (Fig. 8).

**Frequency of Nesting at Different Slopes**
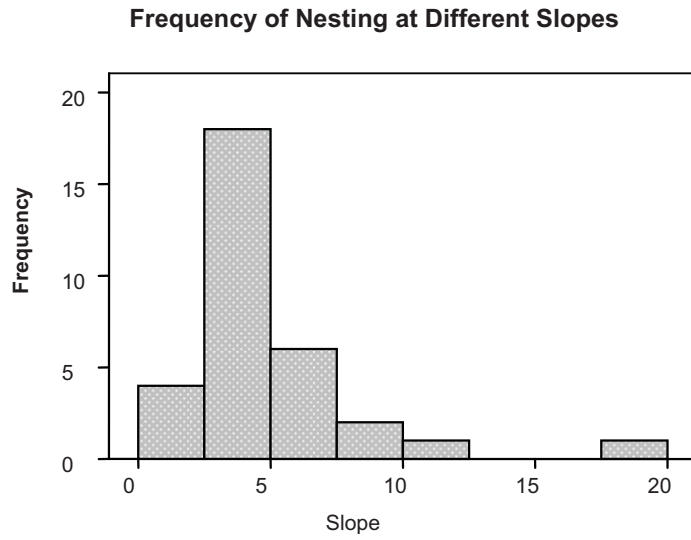


**Figure 7.** Frequency distribution histogram for slope measured at each of 47 nests encountered

**Frequency of nesting with Beach Width**
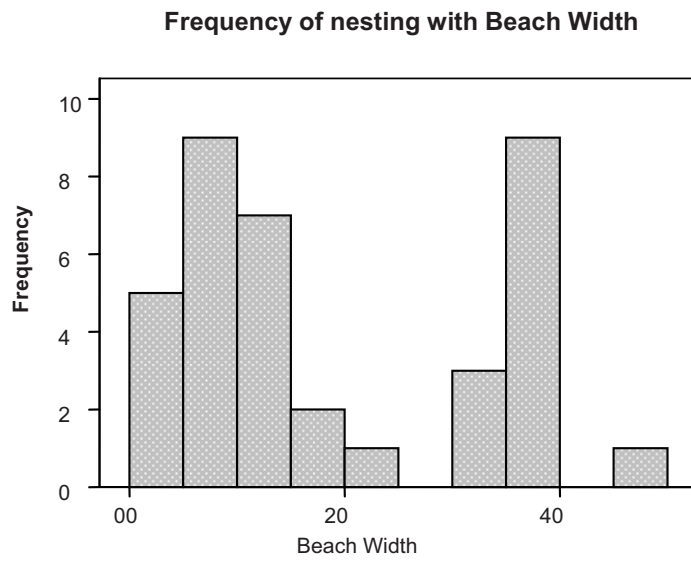


**Figure 8.** Frequency distribution histogram for beach width at each of 47 nests encountered

## 6.2. Beach characteristics

### 6.2.1. Slope

An independent study of beach characteristics showed that the slope of the beach with *Casuarina* is very steep, with a mean of 19.12 ± 6.38 (Fig. 9). There is significant difference in the slope of the beach between the three beach types (Table 3), $F_{(2, 21)} = 50.05, p<0.01$.

It is important to note that there is no significant difference (*Games-Howell* tests of multiple comparisons) between the slopes at open and vegetated beaches. But the slope at *Casuarina* beaches is significantly different from the other two (Table 4).

### 6.2.2. Beach width

The beach width at the three beach types is significantly different ($F_{(2, 21)} = 18.9, p<0.01$) (Table 3). However, since the variances are significantly different $W_{(2, 21)} = 4.41, p<0.05$, the results of the *Welch* and *Brown-Forsythe* statistic was examined; the significance value of these are both <.01, so we still reject the null hypothesis.

The *Games-Howell* tests of multiple comparisons between the beach width at the three beach types showed that beach width at *Casuarina* beaches 4.51 ± 3.13 is significantly different from open beaches 27.49 ± 8.54, while there is no significant difference in beach width between vegetated 13.13 ± 9.39 and *Casuarina* beaches (Table 4) (Fig. 10).

**Table 3.** Results: One way ANOVA for differences in the slope and beach width between beach types.

| Effects | | SS | df | MS | *F* | *P* |
|---|---|---|---|---|---|---|
| Slope | Between Groups | 1488.84 | 2 | 744.42 | 50.1 | 0.00 |
| | Within Groups | 312.33 | 21 | 14.87 | | |
| Beach width | Between Groups | 2155.87 | 2 | 1077.94 | 18.9 | 0.00 |
| | Within Groups | 1197.09 | 21 | 57.00 | | |

**Table 4.** Multiple comparisons done by *Games-Howell* statistic to see the difference between beach types for slope and beach width.

| Test statistics | Multiple comparison | (I) beach types | (J) beach types | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|---|---|
| *Games-Howell* | Slope | Open | Vegetated | -0.42 | 0.71 | 0.8 |
| | | | *Casuarina* | -16.91 (*) | 2.28 | 0 |
| | | Vegetated | Open | 0.42 | 0.71 | 0.8 |
| | | | *Casuarina* | -16.49(*) | 2.34 | 0 |
| | | *Casuarina* | Open | 16.91(*) | 2.28 | 0 |
| | | | Vegetated | 16.49(*) | 2.38 | 0 |
| *Games-Howell* | Beach width | Open | Vegetated | 14.36(*) | 4.49 | 0 |
| | | | *Casuarina* | 22.98(*) | 3.22 | 0 |
| | | Vegetated | Open | -14.38(*) | 4.49 | 0 |
| | | | *Casuarina* | 8.6 | 3.5 | 0.1 |
| | | *Casuarina* | Open | -22.98(*) | 3.22 | 0 |
| | | | Vegetated | -8.6 | 3.5 | 0.1 |

\* The mean difference is significant at the .05 level.

Student t test results showed that there is a significant difference in the beach width of vegetated and *Casuarina* beaches ($t_{14} = 2.457$, *p<0.05 two tailed*). (Table 5 *left*).

**Table 5.** Results of student t test for differences in the mean beach width of vegetated to *Casuarina* beach (*left table*) and paired t test (*right table*) for difference in the mean beach width before and after two weeks.

| T | df | sig (two tail) | Variable | mean | df | t | t crit one tail | t crit two tail |
|---|---|---|---|---|---|---|---|---|
| 2.46 | 14 | 0.028 | BW before | 4.51 | 7 | 1.16 | 1.9 | 2.37 |
| 2.46 | 8.54 | 0.038 | BW after | 4.44 | | | | |
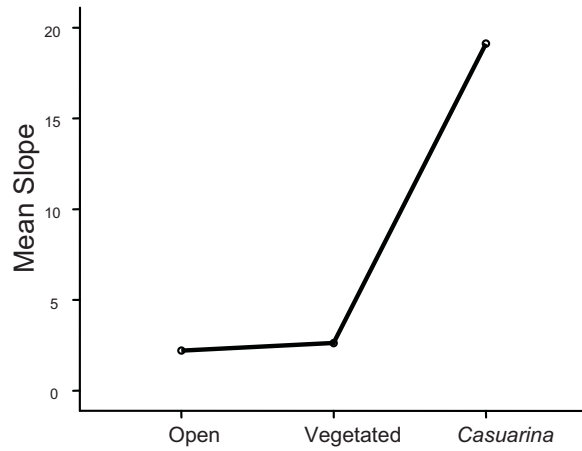
**Figure 9.** Graph plotted for mean slopes taken from eight replicates at each of the three beach types
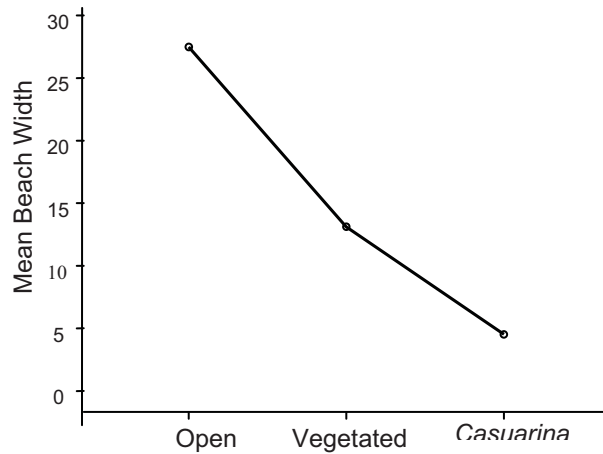


**Figure 10.** Graph plotted for mean beach width taken from eight replicates for each of the three beach types

The beach width for the same point after two weeks was also compared by paired t-test, (Table 5, *right)* to see if there was any difference in beach width. Results showed no significant difference after two weeks (*t $_{(7)}$ = 1.99, p>0.05 one tailed*).

**Figure 11.** Steep slope at the *Casuarina* beach type, dead debris and swash mark showing the high tide level.



**Figure 12.** *Casuarina* plants till the high tide line of beach with very less dune vegetation.

## 6.3. Temperature

### 6.3.1. Mean temperature

Box plots revealed that the mean temperature is different at all three beach types; average temperature at *Casuarina* beaches (28.91 $^0$C ± 0.28) is lower than the open beach (29.33 °C ± 0.39) and vegetated beach (29.72 °C ± 0.33) (Fig. 13). (One way ANOVA $F_{(2, 9)} = 5.722, p<0.05$).
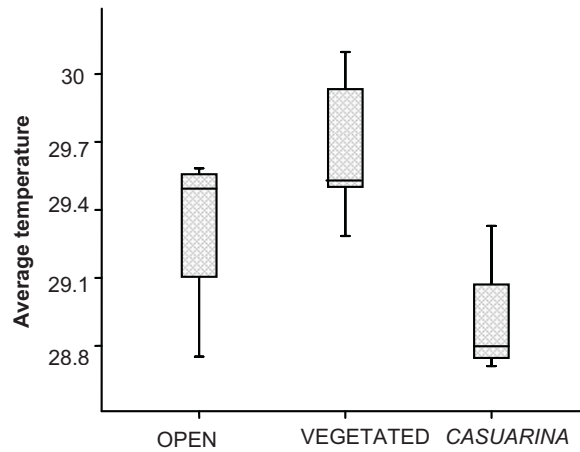


**Figure 13**. Box plots drawn for average day temperatures; taken from measurements done three times a day at each beach type and pooled data of study period.

*Tukey HSD* multiple comparison tests showed that there is no difference in the mean temperature of *Casuarina* and open beaches, but there is a significant difference in the mean temperature of *Casuarina* and vegetated beaches. Temperature readings showed that the average temperature at all three beach types is significantly different.

**Table 6.** Results of One way ANOVA for differences in the temperature between beach types

| Effects | | SS | df | MS | *F* | *P* |
|---|---|---|---|---|---|---|
| Average temperature | Between Groups | 1.31 | 2 | 0.655 | 5.72 | 0.025 |
| | Within Groups | 1.03 | 9 | 0.114 | | |
| 4:00 pm | Between Groups | 3.043 | 2 | 1.522 | 3.07 | 0.097 |
| | Within Groups | 4.468 | 9 | 0.496 | | |
| 6:00 am | Between Groups | 5.517 | 2 | 2.758 | 57.4 | 0.000 |
| | Within Groups | 0.432 | 9 | 0.048 | | |

### 6.3.2. Temperature at different times of the day

Temperature graphs plotted at different times of the day showed that the temperature under *Casuarina* is lower in the early hours of the day till the afternoon, but is higher at night (Fig. 14). Variances were significantly different between the beach types at 4:00 pm ($W_{(2, 9)} = 4.87, p<0.05$). ANOVA showed no significant difference in temperature between beach types at 4:00 pm ($F_{(2, 9)} = 3.07, p>0.05$). Even using the *Welch* and *Brown-Forsythe* statistics, the significance value of these are both > .05, so the null hypothesis is accepted. But there is a significant difference in the temperature between beach types at 6:00 am ($F_{(2, 9)} = 57.42, p<<0.05$) and at 10:00 pm ($x^2_{(2)} = 7.25, p>0.05$) with similar variances (Table 6). *Tukey HSD* multiple comparison tests showed that there is a significant difference in the mean temperature between *Casuarina* and the other two beach types at 6:00 am (Table 7). Temperature graphs were also plotted for the three beach types at different distances from the high tide line (Fig. 15).

**Table 7.** Multiple comparisons to see the difference between the beach types for average temperature and temperature at 6:00 am.

| Test statistics | Multiple comparison | (I) beach types | (J) beach types | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|---|---|
| *Tukey HSD* | Average temperature | Open | Vegetated | -0.39 | 0.24 | 0.288 |
| | | | *Casuarina* | 0.42 | 0.24 | 0.235 |
| | | Vegetated | Open | 0.39 | 0.24 | 0.288 |
| | | | *Casuarina* | 0.81(*) | 0.24 | 0.020 |
| | | *Casuarina* | Open | -0.42 | 0.24 | 0.235 |
| | | | Vegetated | -0.81(*) | 0.24 | 0.020 |
| *Tukey HSD* | 6:00 AM | Open | Vegetated | -1.07(*) | 0.16 | 0.000 |
| | | | *Casuarina* | 0.56(*) | 0.16 | 0.013 |
| | | Vegetated | Open | 1.07(*) | 0.16 | 0.000 |
| | | | *Casuarina* | 1.64(*) | 0.16 | 0.000 |
| | | *Casuarina* | Open | -0.56(*) | 0.16 | 0.013 |
| | | | Vegetated | -1.64(*) | 0.16 | 0.000 |

* The mean difference is significant at the .05 level.

**Table 8.** *Krusakal-Wallis* ANOVA for temperature difference between the beach types at 10:00 pm.

| Effect | $X^2$ | df | *P* |
|---|---|---|---|
| 10:00 pm | 7.27 | 2 | 0.03 |

At 10:00 pm there is a significant difference in the temperatures (Table 8) ($x^2_{(2)}$ = 7.27, p< 0.05).  *Mann-Whitney U* Test showed a significant difference in the temperature between open and *Casuarina* beaches (*U=1, p<0.05* two tailed) (Table 9), while there is no difference in the temperature between vegetated and *Casuarina* beaches (*U=4, p>0.04,* two tailed).

**Table 9.** *Mann-Whitney U* test for differences in mean temperature between open and *Casuarina*; vegetated and *Casuarina* beach types.

| Variables | *Mann-Whitney* U | *Wilcoxon* W | Z | Asymp. Sig. (2-tailed) |
|---|---|---|---|---|
| Open- *Casuarina* | 1 | 11 | -2.021 | 0.043 |
| Vegetated-*Casuarina* | 4 | 14 | -1.155 | 0.248 |



| | 6:00 AM | 4:00 PM | 10:00 PM |
|---|---|---|---|
| CASUARINA | 25.96378676 | 32.3962963 | 32.25384615 |
| VEGETATED | 27.59891304 | 32.86449176 | 28.68888889 |
| OPEN | 26.52857143 | 33.61875 | 27.84545455 |
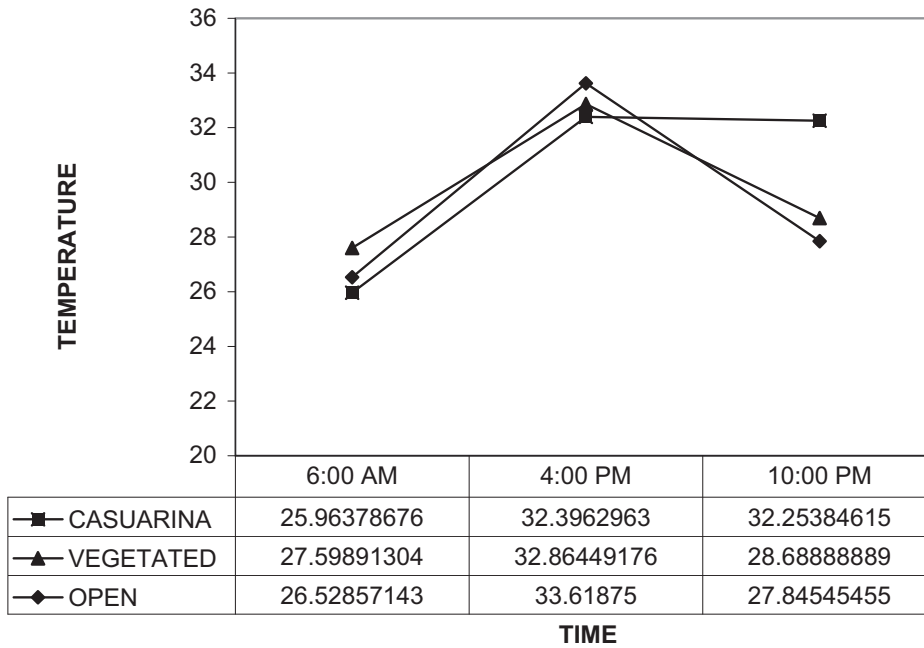
**Figure 14.** Temperature at different times of the day at each beach type.

| DISTANCE FROM HTL | 3 m | 6m | 9 m | 12 m |
|---|---|---|---|---|
| CASUARINA | 29.32854031 | 28.7828976 | 28.81219136 | 28.71018519 |
| VEGETATED | 30.09727398 | 29.77025535 | 29.71759259 | 29.284603 |
| OPEN BEACH | 29.45673701 | 28.75213745 | 29.58400974 | 29.5308171 |
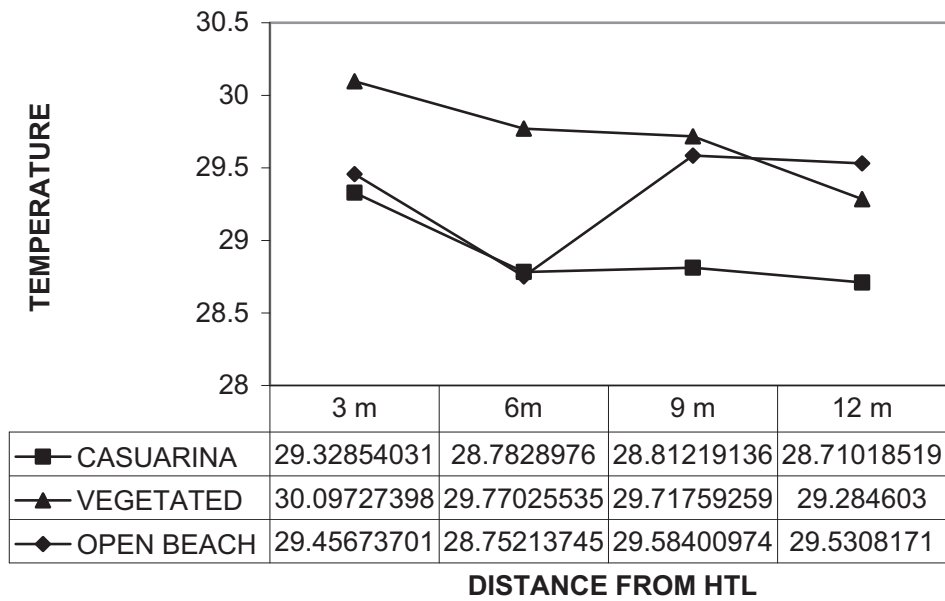
**Figure 15.** Pattern of temperature at different distances from high tide line for each beach type.

## 6.4. Vegetation

### 6.4.1. Species diversity and evenness

Vegetation analysis showed the following results:

- The number of native species recorded (S) at 3 year old plantations, 1 year old plantations and non-*Casuarina* areas are 3, 4 and 12 respectively. *Shannon diversity Indices, H* for 3 year old *Casuarina*, 1 year old *Casuarina* and non-*Casuarina* beach is 0.35, 0.93 and 1.26 respectively, while the *Evenness, $E_H$* is 0.32, 0.67 and 0.51 respectively. The evenness in 3 year old *Casuarina* plantations is lower than the other two beach types, and though the diversity in non-*Casuarina* areas is higher, evenness at 1 year old *Casuarina* plantations is higher than the non-*Casuarina* areas.

- The total number of individuals of native species was recorded to be 335 in 3 year old *Casuarina* (6.9 individuals/m$^2$), 2777 in 1 year old *Casuarina* (57.85 individuals/m$^2$) and 3175 in non-*Casuarina* (66.15 individuals/m$^2$).

### 6.4.2. Light intensity

Box plots drawn for the proportionate light intensity under *Casuarina* plantations and non-*Casuarina* beaches shows that light intensity is much lower under *Casuarina* (Fig. 16). This might be a reason for finding fewer species under *Casuarina*.
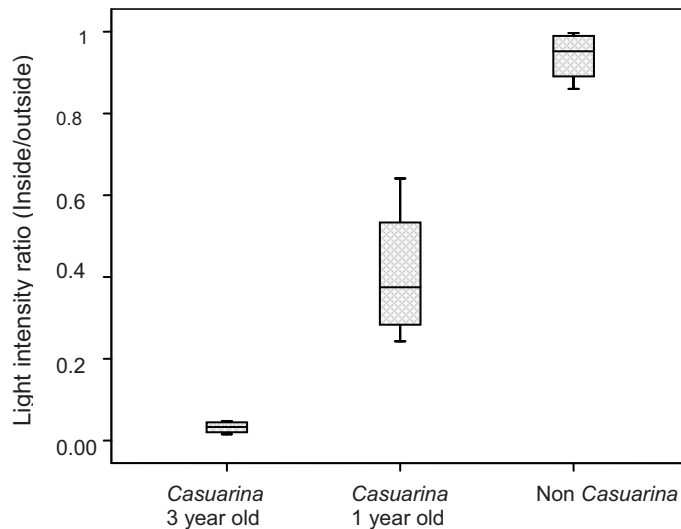


**Figure 16.** Box plot for proportionate light intensity measured as a ratio of LUX reading inside the quadrat to open area outside to transact (values inside / outside).

# 7. Discussion

## 7.1. Nesting

During the previous year, SSTCN and TREE foundation recorded 60 and 66 nests, which is similar to that found during the study period. While there was little change in the nesting intensity between seasons, nesting at the *Casuarina* beach type for current season is low compared to previous records wherein Madras Crocodile Bank Trust documented 20 nests per season in the same area (Subramanean 2001; Devi & Mundoli 2004). The overall nesting intensity recorded earlier for the stretch from Mamallapuram to Chennai is 3.25 nests/night/10 km (Bhupathy & Saravanan 2001). Nesting is also low compared to the other two beach types. The beach has relatively remained the same at the *Casuarina* beach type; there has not been any developmental activity at the beach apart from the establishment of *Casuarina* plantations. The plantation is relatively young but still seems to have a considerable impact on nesting.

The histogram plotted shows that most of the nesting occurred in the slope range of 2 to 8 degrees. Irrespective of beach types, nesting occurs more in beaches that have gentle slopes presumably because access is easier. Similarly, most of the nesting happened at a beach width of 5 to 25 m. This demonstrates that the greater the beach width, the more likely it is that there is suitable nesting habitat. Earlier studies have shown that olive ridleys nest at an average of 17.2 m from the high tide line on this coast (Bhupathy *et al.* 2007).

## 7.2. Beach characteristics

### 7.2.1. Slope

The slope of the beach at *Casuarina* beach types is steeper than the other two beach types. This is primarily because of sand blockage by roots of *Casuarina* trees. Beach sand is constantly subjected to wind and wave born erosion, which is a natural process of a healthy beach. In *Casuarina* planted beaches, these dynamics and transport of sand has been retarded. Thousands of individual trees obstruct the flow and transport of sand. This obstruction in transport results in the erosion of fore dune sand where the influence of *Casuarina* is absent, while sand gets piled up at the lateral margin of the plantation. As olive ridleys prefer to nest on beaches with a gentle slope, steep *Casuarina* beaches are not conducive for turtle nesting.

### 7.2.2. Beach width

Much of the nesting occurred where the beach width was 5 to 25 m, showing a preference for wider beaches. This was case at the open and vegetated beach types. The results also showed that the beach width available at *Casuarina* for turtles to nest is less than in open and vegetated beaches. Thus, *Casuarina* also impacts beach width, further reducing the space available to nest. All the nests in this area are vulnerable to flooding by sea water. The beach width might be narrow because of erosion of sand at the fore dune side of beach, with *Casuarina* roots holding sand and obstructing their transport. Secondly, the forest department may have planted *Casuarina* too close to the high tide line at some sites.

The comparison of beach width at the same point after two weeks revealed that there is no change in beach width, indicating that there is no fresh flux of sand enriching the beach. As a result the natural beach nourishment might have been stalled.

## 7.3. Temperature

Mean temperature in the morning was different from the evening. This shift in temperature can be attributed to the ecology of plants, which retain heat during the night. Sand absorbs and releases heat faster, which is the exact opposite of what happens under *Casuarina* plantations. Thus the pattern in temperature fluctuation is quite different at *Casuarina* and open and vegetated beaches.

The pivotal temperature, in which equal numbers of males and females are produced, is 29.5°C for olive ridley sea turtles in Orissa (Dimond & Mohanty-Hejmadi 1983, 1986; Mohanty-Hejmadi *et al.* 1985). Considering this, average temperature at *Casuarina* beaches 28.91 °C $\pm$ 0.28, is lower than the pivotal temperature of olive ridley turtles. So even if nesting occurs at *Casuarina* planted beaches, temperatures are likely to be lower and might result in male biased hatchling sex ratios.

There was a significant variation in the mean temperature between the three beach types at different distances from high tide line. It follows a pattern in which there is gradual decrease in the mean temperature away from the high tide line.

## 7.4. Vegetation

The richness is lower in the quadrats laid at 3 year old and 1 year old *Casuarina* plantations in comparison to non-*Casuarina* beaches. Similarly, the total number of individuals, N, of all native species is less in both *Casuarina* beach than the non-*Casuarina* beach.

Biomass also varies between beach types. Older *Casuarina* shades more leaves covering the whole floor with a thick mat of litter. Similarly, the light available under *Casuarina* is very low; the older the plantation, the more it shades, and this reduces the availability of light for native ground vegetation. Most of the native vegetation is creepers, which absorb nutrients and water from the ground, and are adapted to dunes. Under the thick canopy cover of *Casuarina*, these creepers are unable to survive.

The absence of native vegetation prevents the formation of dunes. The faunal community, including ghost crabs, lizards, sand dune skinks and other invertebrates, might be affected over time. In the long run, the loss of native species will prove detrimental for beach dynamics, which relies on the enrichment of new sand from littoral current and system flows can stagnate.

# 8. Conclusions

The plantation of *Casuarina equisetifolia* in areas where it was not found before has dramatically changed the habitat and may have resulted in lower nesting of olive ridley turtles in these areas. Thus it is important to balance ecological needs with human requirements, to ensure that ecosystem processes in natural systems are maintained.

Numerous studies have now questioned the protective value of bioshields, especially exotics such as *Casuarina*. Such plantations might have negative impacts on coastal systems, while having few positive benefits in terms of coastal protection. In fact, in many instances, the plantations are not even established in front of fishing villages because fisherfolk insist on having direct access to the sea. The plantations are established beside the villages where they can play no protective role and community support for the plantations therefore has been questionable (Rodriguez *et al.* 2008).

Any permanent structure built in close proximity to the beach is always prone to erosion, and thus any developmental initiative near sand dunes or turtle nesting beaches should adhere to conservative set back requirements. Based on the study, most of the nesting occurred at a distance of 5 to 50 meters from high tide line. A setback distance of 50 meters should be fixed as a no activity zone; this has to be made mandatory to ensure natural sand dynamics. This set back distance should be greater at shorelines with more dynamic cycles of erosion and accretion. If property and lives are threatened by erosion or storms they should be moved away from the sea if at all possible; armoring and shelterbelt development, which are expensive and have uncalculated ecological damages, should be the last priority.

Sea turtles have been around for millennia; they have seen many drastic changes throughout their ancient history, and although their numbers may have declined on many occasions they have managed to survive. They have adapted to these dynamic systems which often change from year to year. The human need to impose stability on these fundamentally unstable ecosystems may destroy both the system itself and the fauna that depend on it, such as sea turtles. It is necessary to develop policy and management strategies that can cope with the inherent dynamic nature and instability of these crucial coastal habitats.

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## Appendix 1

**Table I:** Checklist of plant species recorded across three study site using 4 × 4 quadrats.

| Sr No | Species | Family |
|---|---|---|
| 1 | *Ipomoea pes-capre* | Convolvulaceae |
| 2 | *Ipomoea carnea* | Convolvulaceae |
| 3 | *Spinifex littoreus* | Poaceae |
| 4 | *Launea sarmentosa* | Asteraceae |
| 5 | *Cyperus arenarius* | Cyperaceae |
| 6 | *Oldenlandia umbellata* | Ribiaceae |
| 7 | *Pupalia lappacea* | Amaranthacease |
| 8 | *Mollugo pentaphylla* | Mulluginaceae |
| 9 | *Alysicarpus rugosus* | Papilionaceae |
| 10 | *Glinus oppositifolius* | Molluginaceae |
| 11 | *Fimbrystilis miliacea* | Cyperaceae |
| 12 | *Calotropis gigantia* | Asclepidiaceae |
| 13 | *Vinca rosea* | Apocynaceae |
| 14 | *Sida cordifolia* | Malvaceae |
| 15 | *Sida acuta* | Malvaceae |
| 16 | *Pergularia daemia* | Asclepiadaceae |
| 17 | *Lucas aspera* | Labiatae |
| 18 | *Tephrosia pumila* | Fabaceae |
| 19 | *Pandanus tectorius* | Pandanaceae |

**Table II:** Diversity indices of native vegetation in different areas.

| No | Indices | CP3 | CP 1 | NC |
|---|---|---|---|---|
| 1 | Richness S | 3 | 4 | 12 |
| 2 | N | 335 | 2777 | 3175 |
| 3 | Shannon's diversity Index, H | 0.35 | 0.93 | 1.26 |
| 4 | Evenness $E_H$ | 0.32 | 0.67 | 0.51 |
| 5 | Litter Biomass(gm/m$^2$) | 159.65 | 70.69 | 0 |

CP3: *Casuarina* Plantation 3 year old; CP1: *Casuarina* plantation 1 year old; NC : Non-*Casuarina* area

## Appendix 2

**Table I:** Descriptive statistic; mean and standard deviation for average temperature, temperature at 6:00 am, 4:00 pm and 10:00 pm.

| Effects | Beach type | N | Mean | Std Dev |
|---|---|---|---|---|
| Average temperature | Open | 4 | 29.33 | 0.39 |
| | Vegetated | 4 | 29.72 | 0.33 |
| | *Casuarina* | 4 | 28.91 | 0.28 |
| 6:00 am | Open | 4 | 26.53 | 0.06 |
| | Vegetated | 4 | 27.6 | 0.32 |
| | *Casuarina* | 4 | 25.96 | 0.19 |
| 4:00 pm | Open | 4 | 33.62 | 1.15 |
| | Vegetated | 4 | 32.87 | 0.39 |
| | *Casuarina* | 4 | 32.4 | 0.07 |
| 10:00 pm | Open | 4 | 27.85 | 0.1 |
| | Vegetated | 4 | 28.69 | 0.47 |
| | *Casuarina* | 4 | 32.25 | 0.72 |
| Beach Width | Open | 8 | 27.49 | 8.54 |
| | Vegetated | 8 | 13.11 | 9.39 |
| | *Casuarina* | 8 | 4.51 | 3.13 |

**Table II:** Test of normality for temperatures at different time of the day with *Kolmogorov-Smirnov(a)* and *Shapiro-Wilk*.

| Effect | *Kolmogorov-Smirnov(a)* | | | *Shapiro-Wilk* | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| 4:00 pm | .217 | 12 | .123 | .886 | 12 | .104 |
| 6:00 am | .215 | 12 | .130 | .913 | 12 | .233 |
| 10:00 pm | .240 | 12 | .054 | .826 | 12 | .019 |

**Table III:** Test of normality for Slope by *Kolmogorov-Smirnov* and *Shapiro-Wilk*.

| | Kolmogorov-Smirnov(a) | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Open | .253 | 7 | .196 | .916 | 7 | 0.442 |
| Vegetated | .247 | 8 | .162 | .736 | 8 | 0.006 |
| *Casuarina* | .273 | 8 | .081 | .850 | 8 | 0.095 |

**Table IV:** Test of normality for beach width by *Kolmogorov-Smirnov* and *Shapiro-Wilk*.

| BEACH TYPE | Kolmogorov-Smirnov(a) | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Open | .185 | 8 | .200(*) | .933 | 8 | 0.540 |
| Vegetated | .263 | 8 | .110 | .827 | 8 | 0.055 |
| *Casuarina* | .237 | 8 | .200(*) | .886 | 8 | 0.216 |

* This is a lower bound of the true significance

**Table V:** *Levene* statistic to test the homogeneity of variances.

| Effect | Levene Statistic W | df1 | df2 | Sig. |
|---|---|---|---|---|
| Slope | 7.887 | 2 | 21 | 0.003 |
| Beach width | 4.410 | 2 | 21 | 0.025 |
| Average temperature | .211 | 2 | 9 | 0.813 |
| 6:00 am | 2.433 | 2 | 9 | 0.143 |
| 4:00 pm | 4.871 | 2 | 9 | 0.037 |