

A REVIEW OF THE ADVERSE EFFECTS OF CASUARINA SPP. ON COASTAL ECOSYSTEMS AND SEA TURTLE NESTING BEACHES

DIPA AWALE & ANDREA D PHILLOTT

Asian University for Women, Chittagong, Bangladesh

andrea.phillott@auw.edu.bd

Introduction

Casuarina spp. are extensively cultivated worldwide for beach establishment, erosion control, wind breaking, coastal sand dune stabilization, and as ornamental trees (NRC, 1984). Throughout Asia, bioshields of *Casuarina* spp. are also recommended for construction (Danielsen *et al.*, 2005; Kesavan & Swaminathan, 2006; De Zoysa, 2008; Mattsson *et al.*, 2009) or reinforcement (Tanaka, 2009; Samarakoon *et al.*, 2013) to mitigate the impacts of future tsunamis and other natural disasters.

However, *Casuarina* spp. reduce biological diversity and beach integrity, and *C. equisetifolia* has been reported as a serious invasive species in many coastal regions of the world, including Florida and Hawaii in the USA, countries throughout the Caribbean Sea (Wheeler *et al.*, 2011), and the Republic of Palau in the Pacific Ocean (Space *et al.*, 2003). Eight of 33 countries at the 2012 IOSEA Marine Turtle Memorandum of Understanding meeting described the planting of *Casuarina* spp. as a current conservation activity, yet six countries identified it as a problem on their nesting beaches (see <http://iosea-reporting.org/test/reporting/Test.asp>).

Natural growth of *Casuarina* spp. and effect on beach ecosystems

The Genus *Casuarina*, of the Family Casuarinaceae, contains 17 species. *Casuarina equisetifolia*, commonly known as the beach she-oak, beef wood, or Australian pine, has the widest distribution of all *Casuarina* species and is native from Australia eastward to Melanesia and westward to coastal Southeast Asia (Whistler & Elevitch, 2006). *Casuarina* spp. are capable of very fast growth, require little attention, and thrive in sandy and saline conditions. The natural habitat is semi-arid to sub-humid, with a mean annual temperature of 10-35°C and mean annual rainfall of 200-3,500mm. *Casuarina* spp. grow best in well-drained and coarse-textured soils, such as sands and sandy loams, occur naturally

on sand dunes, in sands alongside estuaries and behind fore-dunes, and on gentle slopes near the sea, and persist at the leading edge of dune vegetation where plants are subject to salt spray and inundation with seawater at extremely high tides (Hanum & van der Maesen, 1997).

Although very little is known about the effects of salinity on its physiology and biochemistry, basic metabolic adaptations such as the accumulation of osmolytes (e.g. proline), as occurs in other saline-tolerant plants, may ensure adaptability to the saline stress (Desingh, 2002; Tani & Sasakawa, 2006). The accumulation of antioxidant enzymes may also contribute to the tolerance of *Casuarina* spp. to salinity (Desingh, 2002). Tolerance to adverse environmental conditions allows *Casuarina* spp. to easily colonise new environments, after which it can often outcompete other species due to its mode of reproduction. *Casuarina* spp. are both monoecious and dioecious; the genera reproduces sexually, via seed, and vegetatively through the sprouting of new clonal trunks from existing rootstock (Hanum & van der Maesen, 1997) or by rooting along branches that touch the ground (Whistler & Elevitch, 2006). Some *Casuarina* spp. are capable of flowering year long, so individual trees can produce thousands of seeds in a year, with each seed remaining viable for up to a year and germinating within 4-8 days under suitable conditions (Hanum & van der Maesen, 1997). Wind pollination aids in rapid seed dispersal over a large area (Whistler & Elevitch, 2006). These characteristics contribute to the production of a large number of seedlings in a short period of time.

Stands of *Casuarina* spp. compete easily with native vegetation, as actinorhizal root nodules that form with a bacterial symbiont of the genus Frankia allow the trees to fix nitrogen (Potgieter *et al.*, 2014). Once established, they displace native vegetation by producing heavy shade and a thick layer of leaf litter; the genera can accumulate up to 120 t/ha of litter (Bernhard-Reversat & Loumeto, 2002). Such thick accumulation of leaf litter, and the production of phytotoxic allelopathic

compounds, inhibits the germination and seedling growth of understorey vegetation (Batish & Singh, 1998; Batish *et al.*, 2001). Thus, these species can form monocultures and alter soil chemistry to further inhibit competitors (Batish *et al.*, 2001).

The high primary production of *Casuarina* spp. may be aided by strategies that reduce the decomposition rate of leaf litter and improving the synchrony between mineralization and uptake. Although leaf decomposition rate is affected by both litter type and the forest type of invaded sites (Hata *et al.*, 2012), the tannin concentration of *Casuarina* spp. leaves inhibit decomposition of litter and soil organic matter, form tannin-protein complexes relatively resistant to decomposition, induce toxicity to microbial populations, and inhibit microbial enzyme activities (Zhang *et al.*, 2013). The ecological consequences of elevated tannin levels may include allelopathic responses, changes in soil quality and reduced ecosystem productivity. These effects may also alter or control succession pathways of natural vegetation (Kraus *et al.*, 2003) and, therefore, beach structure.

Impacts of *Casuarina* spp. on beach structure

Beaches are not rigid or permanent structures; they are maintained by seasonal weather and wave action. Coastal dunes are formed by the aeolian (wind) transport of sand from the near-shore to the back-beach. The first plant colonisers of the bare sand, usually grasses or small shrubs (Martinez *et al.*, 2001), reduce wind velocity and the capacity for aeolian transport and trap sand (reviewed by Sloss *et al.*, 2012). Growth of the pioneer species is stimulated by sand entrapment and accumulation, and the roots begin to bind the surface sand layers together. As the substrate becomes more stable and suitable for successive plant species to colonise, humus formed from the decomposition of fallen vegetation increases substrate nutrition, cohesion, and water retention (reviewed by Pye, 1982; Martinez *et al.*, 2001) and promotes further growth.

Abundant native vegetation on the dunes traps sand and aids in progressive widening of the beach; an annual addition of up to 10,000 cubic meters of sand per kilometer of beach is possible on a well vegetated dune (see Sealey, 2006). Introduced *Casuarina* spp. out-competes or inhibits native vegetation and destabilizes the beach as sand is deposited between the *Casuarina* trees instead of accumulating vertically in front of dune-stabilising grasses. The beach subsequently becomes flattened and can be more easily stripped of sand by waves during severe storms to create a steep beach, which further erodes to become a narrow beach (see Gordon, 1998; Burroughs & Tebbens, 2008; Schmid *et*

al., 2008). With each successive storm, the beach shrinks to the *Casuarina* tree line (Schmid *et al.*, 2008). Beach destruction may eventually occur if the erosion continues and there is insufficient sand in the longshore currents to rebuild the beach by normal processes (Samsuddin & Suchindan, 1987). *Casuarina* trees are also prone to falling because of their height and shallow root system (Sealey, 2006; Schmid *et al.*, 2008) so erosion continues as the front trees are uprooted and washed away (Sealey, 2006).

Impacts of *Casuarina* spp. on sea turtles and their nests

Casuarina spp. are often planted on sea turtle nesting beaches (Figure 1) as a physical shield between urban areas and the ocean so as to reduce light levels and create suitable photic conditions for nesting (Salmon *et al.*, 1995) or as shade during adaptive practices to manage the effect of rising ambient temperatures resulting from global climate change on sea turtle nests (Wood *et al.*, 2014). However, if *Casuarina* spp. are allowed to alter beach structure, nesting and hatching success may be reduced and natural hatchling sex ratios altered.

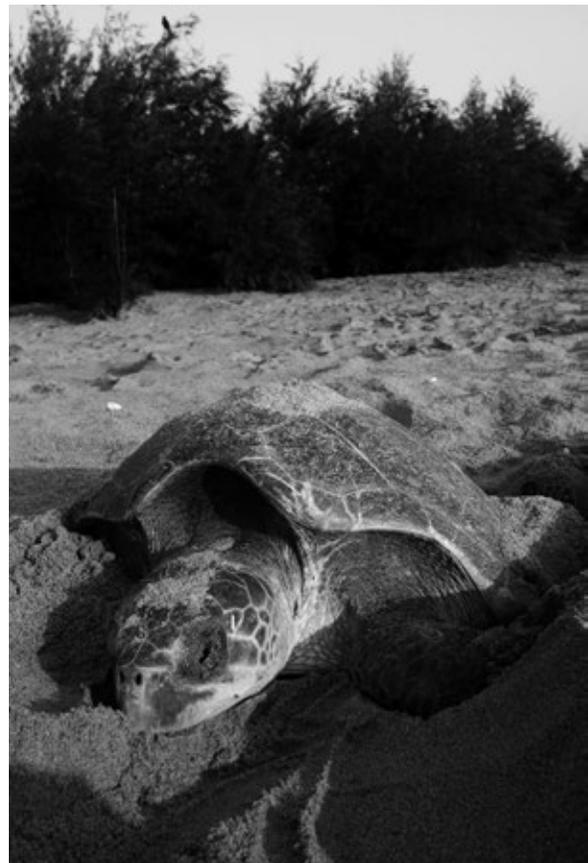


Figure 1. Olive ridley nesting in front of *Casuarina* trees at Rushikulya, Odisha, India.

Photo credit: Kartik Shanker

Stands of *Casuarina* spp. are only likely to be a moderate impediment to nesting sea turtles that can maneuver around them to nest (Witherington *et al.*, 2011), but fallen trees can create physical obstacles for nesting females to navigate (NRC, 1984) and result in abandoned nesting attempts or nesting in sub-optimal areas. The dense, shallow roots of *Casuarina* spp. may interfere with nest construction so females abandon their nesting attempts (NRC, 1984; Wood *et al.*, 2014) or penetrate the nest and destroy eggs during incubation (Hays and Speakman, 1993; Leslie *et al.*, 1996). Hatchlings emerging from nests laid within dense forests are at risk of entanglement in roots during emergence or disorientation into supralittoral vegetation (Godfrey and Baretto, 1995).

The formation of significantly steeper and narrower beaches in the presence of dense stands of *Casuarina* spp. may impact hatchling survival as nests laid close to the sea are at risk of egg loss due to erosion and mortality due to salt water inundation (Foley *et al.*, 2006; Caut *et al.*, 2010). Nest temperatures during incubation may be lowered by *Casuarina* spp. shading nests (Morreale *et al.*, 1982; Spotila *et al.*, 1987; Kamel, 2013), lowering the water table and exhausting soil moisture (NRC, 1984), or blanketing the beach surface with a thick layer of leaf litter (NBII & ISSG, 2010). Lower nest temperatures can skew hatchling sex ratios to result in more males and reduce hatchling swimming performance (e.g. Burgess *et al.*, 2006). The relationship between the primary sex ratios of hatchlings, hatchling fitness, and the operating sex ratios of adult populations is currently unknown, but the resulting population demographics may influence the capacity of a species to persist during global climate change (Stewart & Dutton, 2014).

Recommendations

Beach vegetation initiatives should be carefully planned to ensure dune preservation and stability (see comments by Mascarenhas, 2006) and utilise indigenous plant species instead of exotics or invasives such as *Casuarina* spp. Natural forests in relatively undisturbed areas can be examined to determine the species most likely to grow in different localities, and can possibly be sourced from local NGOs or communities. If little natural forest remains, then local botanists may be able to suggest the most suitable species. The removal of existing stands of *Casuarina* trees can be expensive and time consuming, but a priority in areas where nesting and hatching success is low. Careful, physical removal is likely to have less effect on the environment, and sea turtle nests, than methods of chemical or biological control (see Conrad *et al.*, 2011; Wheeler *et al.*, 2011).

The problems experienced on beaches planted with

Casuarina spp. should be remembered when plans to introduce exotic species or interfere with natural beach processes are considered. Other methods of stabilization, including groin construction, beach dewatering, beach nourishment (Grain *et al.*, 1995), piling installation (Bouchard *et al.*, 1998), and artificial reef construction also change beach dynamics and have an adverse impact on sea turtles; it should be remembered that beaches are dynamic structures and local development should be prepared to cope with a changing environment.

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