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Short Communication: Survival and growth of monoculture and mixed-species plantations on the Coromandel coast of India

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Abstract. *Anbarashan M, Padmavathy A, Alexandar R. 2017. Short Communication: Survival and growth of monoculture and mixed-species plantations on the Coromandel coast of India. Asian J For 1: 70-76.* There exists very little information on the growth of autochthonous tree species in the tropics, and when it is compared to monoculture plantations. The aim of this study was to compare the variation in growth parameters between the mixed-species plantation and mono species plantation. The survival and growth in terms of height and girth of 82 autochthonous mixed-species plantations were compared with *Casuarina equisetifolia,* an exotic species broadly planted in this region after over a decade (2006 to 2016). In the mixed-species plantation, seven species showed 100% survival rate and 19 species were not survived after 10-year intervals. In the mono species plantation, *Casuarina equisetifolia* had 92% survival rate. When it is compared to the monoculture plantation, the growth rate of mixed-species plantation showed highly significant differences (P < 0: 05) values. Simple linear regression between annual girth increment and height produced very strong positive relations (R^2 0.759). Plantations of *Casuarina equisetifolia* seem to be well adapted to the coastal region, especially in the Coromandel coast of India. On the other hand, mixed plantations with autochthonous species would contribute more to sustainable management because they provide a greater range of ecological goods and ecosystem services than single-species plantations.

Keywords: Exotic species, growth, mortality, autochthonous tree species, plantation, survival

INTRODUCTION

In tropical countries, there is an increasing interest in establishing mixed autochthonous species plantations for a wide range of economic, silvicultural and sustainability objectives (Nguyen et al. 2016). This is in contrast to the dominance of monoculture plantation at an industrial scale practiced in the sub-tropics and temperate regions, largely because of the association with economic benefits. Mixed plantation systems provide a broader range of options for the restoration of degraded areas, protection and biodiversity conservation (Montagnini et al. 1995; Keenan et al. 1995; Guariguata et al. 1995; Parrotta and Knowles 1999). For example, Vietnam, China, and the Philippines encourage landholders to plant a mixture of tree species in their national reforestation programs (Lamb et al. 2005; Herbohn et al. 2014).

In certain situations, mixed species plantations are found to be more successful in terms of biomass production and carbon sequestration (Lawson and Michler 2014; Puettmann and Tappeiner 2014), improved nutrient cycling (Forrester et al 2010; le Maire et al 2013), reduced damage from pest or disease (Nichols et al 2006; Hung et al 2011), than monocultures. Ecological disturbance and climate change impacts can be mitigated and more resilient forests can be developed when mixtures of different species with different traits are established (Rodrigues et al. 2011). Lamb and Lawrence (1993) stated that the complete utilization of soil and water resources, as well as different soil strata, could be attained by roots of different species during plantation. Plantation of different species tends to observe more solar energy, and the light requirements are broadly distributed in the vertical plane (Guariguata et al. 1995).

The primary goal of ecological research in tropical forests is about comprehending the patterns of highly dynamic plant growth. Forest growth function is important for determining the size and multitude in ecological management and applications (Vivek et al. 2016). Providing practical and meaningful classification of tropical forest species is needed by foresters in modeling the growth and yield factors, whereas the ecologists explain the life history of tropical forests and their diversity (Vivek et al. 2016).

In the prediction of forest dynamics, tree mortality is inevitable, and its center to any long-term dynamics of woody plants as their biomass is regulated by the difference between gains through individual growth and losses through mortality (Scherer-Lorenzen et al. 2005). The growth and mortality of saplings of trees are dependent on impacts of various factors such as species-specific, tree vigor and size, and environmental conditions on the interactions and processes in stands (Scherer-Lorenzen et al. 2005; Radosevich et al. 2006). Differences in mortality rates among species are the major determinants of ecological succession (Schneider et al. 2014) and forest stand structure (Semwal et al. 2013). Performance of a tree species is indicated by its vigor and size, as it partially reflects the competitive ability of a tree (Nakashizuka 2001). Growth-mortality trade-off can also be predicted by their relationship to plant functional traits (Baker et al. 2004; Nguyen et al. 2016).

However, the success of the establishment of mixed-species plantations depends on plantation design and an appropriate definition of the species to be used, taking into consideration ecological and silvicultural aspects (Wormald 1992). There is very little information on the growth of autochthonous tree species in the tropics, and on the comparison between mono and mixed-species plantations. Therefore, this study aimed to determine the growth and survival of 82 autochthonous species in the mixed plantations in the coastal sand dunes compared with *Casuarina equisetifolia* monoculture plantation after over a decade (2006-2016). The hypotheses tested were: there is variation in growth and survival among species, and the growth and survival of autochthonous species are higher in mixed-species plantations than that in mono-species plantations.

MATERIALS AND METHODS

Study site

The study plots were developed in 2006 in Koonimedu Coastal village on the Coromandel Coast of southern India. The mean annual maximum and minimum temperatures are 33ºC and 24.5ºC. The mean annual rainfall is 1282 mm year with a six-month dry period (2006 to 2016). In general, coastal sandy soils with poor nutrients prevail in the region.

Preparation of plant materials

The saplings were produced in the onsite nursery, under a standard white polyethylene nursery bag system. Seeds were collected from the local Tropical Dry Evergreen forests in the region. Weeding became the primary maintenance activity after field planting of trees, and pruning of secondary apical shoots was conducted in the first year.

Research design

A total of 2055 individuals of 82 autochthonous tree species and 1500 individuals of *Casuarina equisetifolia* were planted on two hectares in 2006. Table 1 shows the list of species, families, and ecological importance. Species choice was based on growth rate, timber, ecological significance. In each one-hectare plot, diameter at breast height (dbh) and total height were measured for each tree after over a decade (2016). The averages of total height, dbh, basal area, and survival and mortality were calculated for each one-hectare plot in each species. The differences in diameter distribution of trees between the two inventories (2006-2016) were tested using Kolmogorov-Smirnov two-sample test (Zarr 2006), and we used paired t-tests to test the significant differences in tree variables in two different plantations using SPSS software.

Table 1. List of species observed in this study with families and ecological importance

Species	Family	Ecological values
Mixed species		
Aegle marmelos (L.) Correa	Rutaceae	Medicinal, economic
Aglaia elaeagnoidea (Juss.) Benth.	Meliaceae	Ecological
Alangium salvifolium (L.f.) Wangerin	Alangiaceae	Medicinal
Albizia amara (Roxb.) Boivin	Mimosaceae	Medicinal, commercial
Atalantia monophylla (L.) Correa	Rutaceae	Medicinal, ecological
Azadirachta indica A. Juss.	Meliaceae	Medicinal, cultural
Barringtonia acutangula (L.) Gaertner	Barringtoniaceae	Ecological
Bauhinia purpurea Lam.	Leguminosae	Medicinal
Bauhinia racemosa Lam.	Leguminosae	Timber, ecological
Benkara malabarica (Lam.) Tirven.	Rubiaceae	Ecological
Calophyllum inophyllum L.	Calophyllaceae	Medicinal
Calotropis gigantea L.	Apocynaceae	Medicinal, cultural
Carmona retusa (Vahl) Masm	Boraginaceae	Ecological
Canthium dicoccum (Gaertn.) Merr.	Rubiaceae	Medicinal
Cassia auriculata L.	Fabaceae	Medicinal
Cassia fistula L.	Fabaceae	Ecological
Cassine glauca Rottb. Kuntze.	Celastraceae	Ecological
Chloroxylon swietenia DC.	Rutaceae	Timber
Coccoloba uvifera L.	Polygonaceae	Fruit, ecological
Commiphora berryi (Arn.) Engl.	Burseraceae	Ecological
Dalbergia latifolia Roxb.	Fabaceae	Timber
Delonix elata Gamble.	Fabaceae	Medicinal, aesthetic
Diospyros ebenum J. Koenig ex Retz.	Ebenaceae	Timber

Diospyros ferrea (Willd.) Bakh.	Ebenaceae	Ecological
Diospyros montana Roxb.	Ebenaceae	Ecological
Dolichandrone falcata Seem.	Bignoniaceae	Ecological
Drypetes sepiaria (Wight and Arn.) Pax and Hoffm.	Euphorbiaceae	Ecological
Ehretia pubescens Benth.	Boraginaceae	Ecological
Erythrina indica L.	Fabaceae	Medicinal
Eugenia bracteata (Willd.) Roxb. ex DC.	Myrtaceae	Ecological
Ficus benghalensis L.	Moraceae	Cultural, medicinal
Ficus hispida Lf.	Moraceae	Medicinal
Ficus religiosa L.	Moraceae	Cultural, medicinal
Garcinia spicata (Wight and Arn.) J.D. Hook.	Clusiaceae	Ecological
Glycosmis mauritiana (Lam.) Tanaka	Rutaceae	Fruit, ecological
Gliricidia sepium (Jacq.) Kunth ex Walp.	Fabaceae	Medicinal
Gmelina asiatica L.	Verbenaceae	Medicinal, aesthetic
Helicteres isora L.	Malvaceae	Medicinal, aesthetic
Holoptelea integrifolia Planch.	Ulmaceae	Timber
Ixora pavetta T. Anderson	Rubiaceae	Cultural, aesthetic
Lawsonia inermis L.	Lythraceae	Cultural, medicinal
Lepisanthes tetraphylla (Vahl.) Radlk.	Anacardiaceae	Cultural
Limonia acidissima L.	Rutaceae	Cultural, medicinal
Madhuca longifolia (L.) Macbr.	Sapotaceae	Oil, cultural
Maerua oblongifolia Forssk.	Capparaceae	Ecological
Mallotus rhamnifolius Muell.-Arg.	Euphorbiaceae	Cultural, aesthetic
Manilkara hexandra (Roxb.) Dubard	Sapotaceae	Fruit, ecological
Melia azedarach L.	Meliaceae	Medicinal
Memecylon umbellatum Burm.f.	Melastomataceae	Ecological, aesthetic
Mimusops elengi L.	Sapotaceae	Medicinal, cultural
Mitragyna parviflora (Roxb.)Korth.	Rubiaceae	Timber
Murraya paniculata (L) Jack	Rutaceae	Aesthetic
Ochna obtusata DC.	Ochnaceae	Ecological, aesthetic
Ormocarpum sennoides (Willd.)DC.	Leguminosae	Medicinal
Pamburus missionis (Wight) Swingle	Rutaceae	Ecological
Pandanus oddaratissimus L.f.	Pandanaceae	*Ecological*
Phyllanthus reticulatus Poir.	Euphorbiaceae	Ecological, medicinal
Pleiospermium alatum (Wall. ex Wight. & Arn.) Swingle	Rutaceae	Ecological, medicinal
Polyalthia suberosa (Dunal) Thw.	Annonaceae	Ecological, aesthetic
Pongamia pinnata (L.) Pierre	Fabaceae	Oil, cultural
Pterocarpus marsupium Roxb.	Combretaceae	Timber, medicinal
Pterospermum canescens Roxb.	Sterculiaceae	Ecological
Pterospermum xylocarpum (Gaertn.) Sant. & Wagh.	Sterculiaceae	Ecological
Salacia chinensis L.	Celastraceae	Medicinal
Salvadora persica L.	Salvadoraceae	Medicinal, economic
Sapindus emarginatus Vahl	Sapindaceae	Medicinal, economic
Streblus asper Lour.	Moraceae	Ecological
Strychnos nux-vomica L.	Loganiaceae	Medicinal
Strychnos potatorum Lf.	Loganiaceae	Ecological, medicinal
Suregada angustifolia (Baill. ex. Muell-Arg.) Airy Shaw	Meliaceae	Ecological
Syzygium cumini (L.) Skeels	Myrtaceae	Medicinal, fruit
Tarenna asiatica (L.) Kuntze.	Rubiaceae	Medicinal, cultural
Terminalia arjuna (DC.) Wight & Arn.	Combretaceae	Medicinal, timber
Terminalia bellirica (Gaertner) Roxb.	Combretaceae	Medicinal, timber
Terminalia catappa L.	Combretaceae	Ecological, fruit
Thespesia populnea (L.)Sol.	Malvaceae	Timber, cultural
Tricalysia sphaerocarpa (Dalz.) Gamble	Rubiaceae	Timber, cultural
Vitex leucoxylon Lf.	Lamiaceae	Timber, ecological
Vitex negundo L.	Lamiaceae	Medicinal, cultural
Walsura trifolia (A..Juss.) Harms	Rubiaceae	Ecological
Wrightia tinctoria (Roxb.) R.Br.	Apocynaceae	Medicinal
Ziziphus mauritina Lam.	Rhamnaceae	Ecological
Monoculture plantation		
Casuarina equisetifolia L.	Casuarinaceae	Fuel wood

RESULTS AND DISCUSSION

Measurements in the mixed-species plantation at 10 years of age showed that *Albizia amara*, *Lepisanthes tetraphylla*, *Diospyros ferrea*, *Eugenia bracteata*, *Mimusops elengi*, *Sapindus emarginata*, and *Terminalia bellerica* exhibited the highest rate of survival (100%), followed by *Wrightia tinctoria*, *Mitragyna parviflora*, *Streblus asper*, *Pleiospermium alatum*, *Gmelina asiatica*, *Ixora pavetta* and *Coccoloba uvifera* showing 99% of the survival rate (Table 2). In total, 19 species were not survived for over a decade. No species exhibited significant differences ($P < 0.05$) in survival between the mixed species and monoculture plantation plots. Species such as *Bauhinia purpurea*, *Benkara malabarica*, *Calophyllum inophyllum*, *Limonia acidissima*, *Polyalthia suberosa*, *Pterospermum xylocarpum*, *Strychnos potatorum*, *Terminalia catappa* and *Thespesia populnea* did not survive any single sapling in the two-hectare plots. *Barringtonia acutangula*, *Cassia fistula*, *Chloroxylon swietenia*, *Pamburus missionis* and *Pterocarpus marsupium* demonstrated less than 20% survival rates. Comparing monoculture to mixed-species plantations, in general, species in the monoculture plantation demonstrated better survival rates. Notably, in the single species plot, *Casuarina equisetifolia* exhibited high survival and growth rates. Introducing new species, however, is not without risks. Many reforestation projects fail due to inappropriate species choice, a consequence of inadequate knowledge about the potential of species and their growth and survival rates under different site and environmental conditions (Corlett 1999; Wuethrich 2007; Rodrigues et al. 2009).

The use of a wider variety of autochthonous species in reforestation may enhance the recovery of ecosystems, decrease sensitivity to pests and diseases, and increase functional diversity (Hooper et al. 2005; Benayas et al. 2009; Rodrigues et al. 2009). Creation of forests in the tropics takes place across a wide variety of non-climatic and climatic conditions. Different reforestation experiments have elucidated that environmental conditions may have strong effects on species growth and survival (Butterfield 1996; Calvo-Alvarado et al. 2007; Park et al. 2010). On the other hand, the finding that 23 % of the species may have high initial mortality and unsatisfactory early growth is critical information in avoiding early failure of reforestation projects. Several species showed poor performance and seemed to be unsuitable for large-scale planting in open plantation sites. Ashton et al. (2001) reported that some of these species might do better when they were planted later after some pioneer plants or extant nurse trees.

In the mixed-species plantation, the measurements taken at 10 years intervals showed that *Ficus benghalensis* and *Bauhinia racemosa* have the best growth in terms of height, followed by *A. amara* and *Azadirachta indica*, with no statistically significant differences ($P < 0.05$) between monoculture and mixed autochthonous species plantations. In the monoculture plantation, *C. equisetifolia* showed moderate growth of height and girth. Simple linear regression between annual girth increment and height produced very strong positive relation (R^2 0.759) (Figure 1).

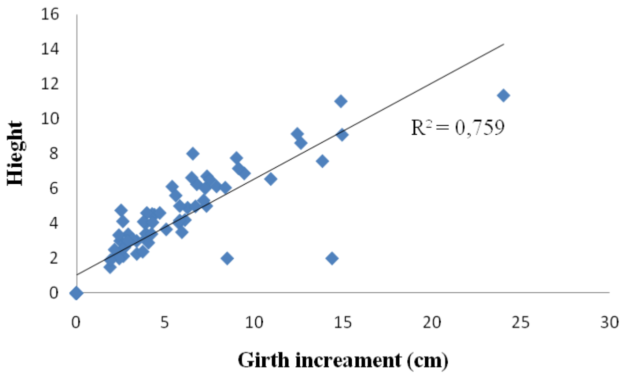

Figure 1. Simple linear regression between annual girth increment and average height of mixed-species plantation (2 ha).

Table 2. Number of individuals of each species with survival and growth rate after 10 year period of intervals

Species	Planted in 2006	Survived in 2016	Mean annual girth increment (cm)
Mono plantation			
Casuarina equisetifolia L.	1500	1380	14.564±0.478
Mixed species			
Aegle marmelos (L.) Correa	10	8	2.337±0.678
Aglaia elaeagnoidea (Juss.) Benth.	4	4	2.774±0.478
Alangium salvifolium (L.f.) Wangerin	26	22	2.945±1.317
Albizia amara (Roxb.) Boivin	40	40	14.978±9.127
Atalantia monophylla (L.) Correa	50	31	2.464±0.863
Azadirachta indica A. Juss.	20	18	12.65±4.608
Barringtonia acutangula (L.) Gaertner	10	1	14.4
Bauhinia purpurea Lam.	25	0	0
Bauhinia racemosa Lam.	150	145	12.458±5.055
Benkara malabarica (Lam.) Tirven.	20	0	0
Calophyllum inophyllum L.	15	0	0
Calotropis gigantea L.	10	4	2.525±0.853
Carmona retusa (Vahl) Masm	35	29	2.658±0.797

Canthium dicoccum (Gaertn.) Merr.	10	10	3.95±2.204
Cassia auriculata L.	20	13	7.36±3.509
Cassia fistula L.	10	2	1.9±0.707
Cassine glauca Rottb. Kuntze.	30	28	6.275±3.750
Chloroxylon swietenia DC.	10	2	4.4±1.414
Coccoloba uvifera L.	30	29	5.786±4.142
Commiphora berryi (Arn.) Engl.	100	81	7.907±3.142
Dalbergia latifolia Roxb.	5	4	5.4±1.914
Delonix elata Gamble.	15	12	5.608±3.538
Diospyros ebenum J. Koenig ex Retz.	70	69	4.066±2.681
Diospyros ferrea (Willd.) Bakh.	70	70	4.271±2.534
Diospyros montana Roxb.	20	18	2.927±1.143
Dolichandrone falcata Seem.	50	45	6.122±4.170
Drypetes sepiaria (Wight and Arn.) Pax and Hoffm.	28	26	3.419±1.808
Ehretia pubescens Benth.	10	0	0
Erythrina indica L.	10	0	0
Eugenia bracteata (Willd.) Roxb. ex DC.	20	20	2.425±2.009
Ficus benghalensis L.	5	3	24.066±9.928
Ficus hispida Lf.	10	0	0
Ficus religiosa L.	1	1	14.9
Garcinia spicata (Wight and Arn.) J.D. Hook.	15	13	3.746±1.983
Glycosmis mauritiana (Lam.) Tanaka	20	16	1.931±0.618
Gliricidia sepium (Jacq.) Kunth ex Walp.	5	0	0
Gmelina asiatica L.	25	24	6.796±3.175
Helicteres isora L.	30	28	3.978±2.404
Holoptelea integrifolia Planch.	90	82	7.332±4.175
Ixora pavetta T. Anderson	20	19	3.924±1.219
Lawsonia inermis L.	5	4	3.9±1.732
Lepisanthes tetraphylla (Vahl.) Radlk.	101	101	7.172±4.037
Limonia acidissima L.	5	0	0
Madhuca longofolia (L.) Macbr.	5	3	5.066±4.618
Maerua oblongifolia Forssk.	5	0	0
Mallotus rhamnifolius Muell.-Arg.	5	0	0
Manilkara hexandra (Roxb.) Dubard	85	83	6.719±3.075
Melia azedarach L.	5	3	6.566±5.107
Memecylon umbellatum Burm.f.	5	2	2.15±0.535
Mimusops elengi L.	35	35	5.82±3.083
Mitragyna parviflora (Roxb.)Korth.	15	15	4.233±2.135
Murraya paniculata (L) Jack	10	7	2.471±0.449
Ochna obtusata DC.	10	7	7.525±3.224
Ormocarpum sennoides (Willd.)DC.	10	1	3.4
Pamburus missionis (Wight) Swingle	5	0	0
Pandanus oddaratissimus L.f.	10	9	3.177±0.440
Phyllanthus reticulatus Poir.	20	0	0
Pleiospermium alatum (Wall. ex Wight. & Arn.) Swingle	100	88	8.396±5.134
Polyalthia suberosa (Dunal) Thw.	5	0	0
Pongamia pinnata (L.) Pierre	5	0	0
Pterocarpus marsupium Roxb.	5	1	8.5
Pterospermum canescens Roxb.	50	42	7.269±4.281
Pterospermum xylocarpum (Gaertn.) Sant. & Wagh.	10	0	0
Salacia chinensis L.	5	5	4.7±3.383
Salvadora persica L.	20	16	2.622±1.617
Sapindus emarginatus Vahl	40	40	6.5±4.071
Streblus asper Lour.	30	29	3.796±2.114
Strychnos nux-vomica L.	35	31	2.722±1.235
Strychnos potatorum Lf.	10	0	0
Suregada angustifolia (Baill. ex. Muell-Arg.) Airy Shaw	10	8	5.837±3.580
Syzygium cumini (L.) Skeels	10	8	9.462±4.617
Tarenna asiatica (L.) Kuntze.	5	2	2.9±1.414
Terminalia arjuna (DC.) Wight & Arn.	10	9	10.955±4.126
Terminalia bellirica (Gaertner) Roxb.	10	10	5.95±4.126
Terminalia catappa L.	30	0	0
Thespesia populnea (L.) Sol.	25	0	0
Tricalysia sphaerocarpa (Dalz.) Gamble	5	3	2.4±0.866
Vitex leucoxylon Lf.	15	14	13.864±5.607
Vitex negundo L.	10	8	9.025±2.100
Walsura trifolia (A..Juss.) Harms	50	48	4.29±4.16
Wrightia tinctoria (Roxb.) R.Br.	70	69	9.146±3.860
Ziziphus mauritina Lam.	10	0	0
Total	2055	1616	

The growth in diameter of *Ficus benghalensis* was the highest in the mixed autochthonous species plantation plot, followed by *A. amara*, *Vitex leucoxylon*, and *A. indica* with no statistically significant differences (P <0.05) with that in the mixed-species plots. When compared to the monoculture plantation, it showed highly significant differences (P < 0.05) values. In the monoculture plantation, *Casuarina equisetifolia* showed a greater diameter increment in the last 10 years when compared to the mixed-species plantation. *Tricalysia sphaerocarpa*, *Tarenna asiatica*, *Strychnos nux-vomica*, *Salvadora persica*, *Murraya paniculata*, *Glycosmis mauritiana*, *Cassia fistula*, and *Aegle marmelos* showed the slowest growth rates, with no significant differences in the mixed plantation. *Casuarina equisetifolia* had the highest basal area, showing significant differences (P < 0.05) compared to all species and the mixture of autochthonous species plantations. The present study revealed that the variation in GBH increment was also found on trees from similar species. This might be due to the response of each species to the growth process, which was different among species as well as among trees of similar species. Many studies showed that the internal and external factors had affected tree growth and development (Breugel et al. 2011). The internal factors comprised genetic factors, plant growth process, internal growth property, and physiological process. On the other hand, the soil parameters, microclimatic factors, and response plants to the environment could be the external factors. Miya et al. (2009) reported that variation in diameter growth of different saplings of different species in an uneven-aged mixed stand was influenced by individual growth conditions, but it was negatively related to the wood density (Keeling et al. 2008).

In conclusion, the present study shows that both monoculture and mixed autochthonous species can perform well in the plantation sites. Although the plantations are still young and it may be too soon to determine the behavior of the species studied, there is evidence that the best growth for these species was demonstrated in mixed autochthonous species systems. The higher mortality of shade-intolerant species appears to be the result due to the high intensity of light in coastal dune ecosystem. Management practices such as pruning and thinning could favor the development of these species in mixed plantations and provide revenues at earlier ages when an appropriate group of species is used. Plantations of *Casuarina equisetifolia* seem to be well adapted to the coastal region and are certainly commercially important trees. On the other hand, mixed species plantations with autochthonous species would contribute more to sustainable management because they provide a greater range of ecological goods and ecosystem services than monoculture plantations.

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