GROWTH AND SURVIVAL OF TREES PLANTED IN AN OIL PALM PLANTATION: IMPLICATIONS FOR RESTORATION OF BIODIVERSITY

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YAMADA T, WATANABE K, OKUDA T, SUGIMOTO T & NOOR AZLIN Y. 2016. Growth and survival of trees planted in an oil palm plantation: implications for restoration of biodiversity. Oil palm production is rapidly expanding across the tropics. Expanding oil palm plantations is an important driver of tropical deforestation and thus species loss. Oil palm plantations can be made more hospitable to biodiversity by planting indigenous trees inside the plantations. However, because planting trees in cleared lands involves many complex and sometimes difficult silvicultural activities, suitability of the tree species chosen must be determined prior to planting. To examine the feasibility of planting for biodiversity restoration, 351 seedlings of various species (< 1 m tall) were planted along a river in an oil palm plantation in Peninsular Malaysia in 2003. Survival rate over the study period was very high (> 90% year^{-1}). The planted species thrived in wet riverbank soil. Both survival and growth of planted trees suggested that biodiversity restoration planting was highly silviculturally feasible.

Keywords: Biomass, demographic trade-off, biodiversity restoration planting, Peninsular Malaysia

INTRODUCTION

The planting of new oil palm plantations has been rapidly increasing across the tropics since the 1990s largely because of high profitability of producing palm oil and its products (Wilcove & Koh 2010). The use of palm oil for vegetable oil production in 2013 reached 50 million tonnes, making it the world's leading source of vegetable oil (RSPO 2014). Two countries, Indonesia (33.0 million tonnes) and Malaysia (19.4 million tonnes) produced around 85% of this oil in 2013 (USDA 2014a, b). That year, Malaysia had 5.2 million ha of oil palm plantations that occupied 15.7% of its total land area (Malaysian Palm Oil Board 2014).

Monoculture oil palm plantations have great impact on biodiversity because oil palm plantations often support far fewer species than do other forested areas (Fitzherbert et al. 2008). The expansion of oil palm plantations has been regarded as a major factor driving the loss of biodiversity in tropical countries (Wilcove & Koh 2010). Although rich in biodiversity, Malaysia has several imperilled biodiversity hotspots (Sodhi et al. 2004). Malaysia had the highest number of IUCN Red List Threatened Species among the top eight palm oil producing countries (Turner et al. 2008). This country needs to mitigate negative effects of oil palm plantations on biodiversity.

The best way to protect Malaysia's biodiversity will be to ban deforestation of primary as well as secondary forests for the development of new oil palm plantations, because most of the biodiversity loss caused by oil palm plantations is due to deforestation (Fitzherbert et al. 2008, Koh & Wilcove 2008, Wilcove & Koh 2010). Other steps available that are designed to protect riparian forests within oil palm plantations include creating forested buffers around oil palm plantations and leaving natural forest patches within oil palm

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plantations (Koh 2008b). All these steps can be implemented when new oil palm plantations are established. Since extensive areas in Malaysia are already covered by oil palm plantations, upgrading the biodiversity within established oil palm plantations is also essential. This may include planting woody tree species and/or enhancing flowering plants in the understorey of oil palm plantations to make these sites more hospitable for broader diversity of plants and animals (Koh 2008a, b, Wilcove & Koh 2010).

Oil palm growers usually straighten natural rivers within plantations to make it easy to plant oil palm trees. The growers do not plant oil palm trees in the areas near the straightened rivers. These unused spaces can be filled by planting indigenous trees to increase biodiversity within the plantation. Aside from enhancing biodiversity, this type of buffer-zone planting can yield many benefits such as improving water quality, protecting oil palm from insect pests, providing habitats for insect pollinators and enabling financial incentives such as REDD+ and/or carbon offset mechanisms.

In 2003, 351 trees were planted along a river in an oil palm plantation in Peninsular Malaysia in an attempt to enhance biodiversity in the area. In this paper, we discuss the silvicultural feasibility of biodiversity restoration through planting other species in an oil palm plantation by monitoring the planted trees for 11 years.

MATERIALS AND METHODS

In 2003, several organisations (Japan International Cooperation Agency, Forest Research Institute of Malaysia, National Institute for Environmental Studies of Japan, Organization for Industrial, Spiritual and Cultural Advancement International, Federal Land Development Agency of Malaysia as well as local schools from Pasoh Dua, Negeri Sembilan, Malaysia) participated in this tree-planting project. Trees were planted along a river flowing within an oil palm plantation adjacent to the Pasoh Forest Reserve (2° 57' N, 102° 17' E), located in the state of Negeri Sembilan, about 70 km south-east of Kuala Lumpur, Malaysia (Figure 1). The oil palm plantation was established in 1985 and has a mean annual rainfall of 1842 mm year^{-1} (Yamada et al. 2014). At the time of study, the oil palm trees averaged 13 m tall. The original objective of this restoration planting was to create a 5-km greenway link connecting two forest reserves, Pasoh and Serting Forest Reserves. Palm oil plantations have separated these reserves and

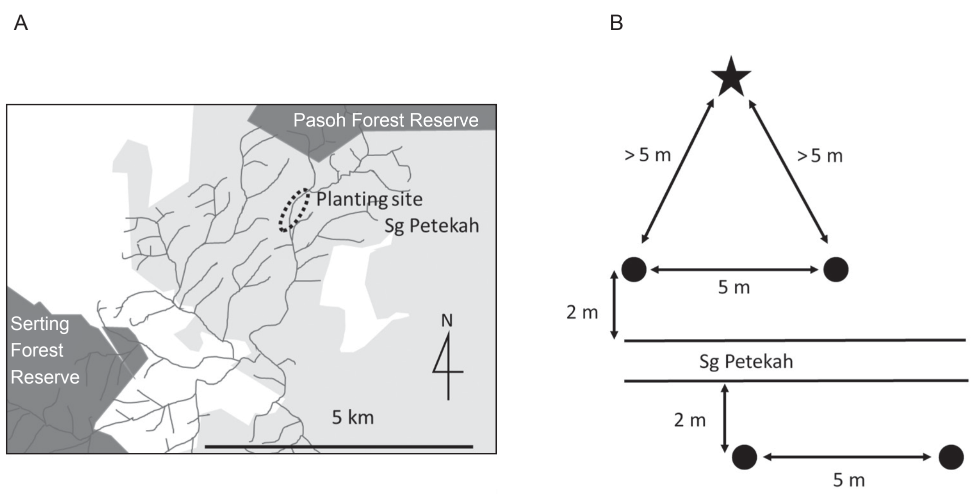

Figure 1 (a) Site map showing the two forest reserves, Pasoh and Serting Forest Reserves, separated by an oil palm plantation (light grey area); Sungai (Sg) Petekah River (solid line) and the planting site (dotted circle) are also shown; the 50-ha plot was set in Pasoh Forest Reserve, (b) schematic diagram showing a location of the trees planted; closed circles show trees planted and the star shows oil palm tree

a narrow green belt consisting of planted tree species has not yet connected them. Local junior high school students planted the trees along both sides of Sungai Petekah River, which is only 2 m wide in this area, as part of an environmental education programme.

A total of 351 trees comprising eight (*Dipterocarpus oblongifolius*, *Dryobalanops oblongifolia*, *Calophyllum wallichiana*, *Intsia palembanica*, *Sindora coriacea*, *Heritiera javanica*, *Artocarpus hispidus*, *Pometia pinnata* var. *alnifolia*) indigenous species and one species (*Artocarpus altilis*) native to New Guinea were planted. These nine species were expected to grow into medium to large trees and were chosen because of the availability of seedlings and these species were adapted to the local climate. The planted species included two fruit trees (*A. altilis* and *A. hispidus*) that were selected to encourage local people living near or working in the plantation to support the project. The young trees were about 50 to 100 cm tall and were planted in a 4 m × 900 m area along the river (Table 1) on 22 February 2003. A total of 171 trees were planted on one side of the river and 180 trees on the other. The trees were planted within 2 m of the river and spaced 5 m apart. The planted trees were at least 5 m and usually more than 10 m from the nearest oil palm tree. Weeding was carried out using the usual management applied for the oil palm plantation.

Survival rates of the planted trees were recorded on 19 June 2004, 17 June 2011, 15 March 2012, 19 March 2013 and 8 March 2014. Visually, at planting, seedlings within a particular species varied little in size. We selected two trees per species and measured their growth in height on 22 February 2003, 19 January 2004, 20 May 2005 and 18 February 2006. All surviving trees were tagged with plastic number tape. Diameter at breast height (dbh), was measured on 17 June, 19 September and 12 December in 2011 as well as 15 March, 15 June and 18 September in 2012 and on 19 March 2013 and 8 March 2014.

Of the nine species, five (*C. wallichiana, I. palembanica, S. coriacea, H. javanica, P. pinnata* var. *alnifolia*) were also found in a 50-ha plot in a pristine forest at the Pasoh Forest Reserve, located approximately 4 km from the planting site. Trees over 1 cm in dbh inside this plot had been monitored since 1985 (Condit 1998). Their dbh growth rates for 10 years from 1995 till 2005, which were the closest periods to our monitoring period, were compared with those of planted trees in the plantation. Tree diameter growth is typically non-linearly related to initial diameter (Zuidema & Boot 2002), thus, growth rates were plotted against initial dbh.

The annual survival rate of each species was calculated following Sheil et al. (1995). Tree height for each species was converted into the corresponding tree aboveground biomass by allometric relationships derived from data for a tropical rainforest in Borneo (Lee et al. 1997). Then we calculated the average biomass of each species. By multiplying the species average biomass by the number of surviving trees of the species for all the species, we determined the total aboveground biomass of the planted trees. We did not record survival of trees from 2004

Table 1 Trees planted along a river in an oil palm plantation in Peninsular Malaysia

Species	Attainable size	No. of trees planted	Presence in 50 ha plot
Dipterocarpus oblongifolius	Large trees*	50	●
Dryobalanops oblongifolia	Medium to large trees*	40	●
Calophyllum wallichiana	Big trees‡	50	○
Intsia palembanica	Big to very big trees†	52	●
Sindora coriacea	Big to very big trees†	22	○
Heritiera javanica	Large trees‡	24	○
Artocarpus altilis	Medium to large trees§	100	●
Artocarpus hispidus	Medium to large trees§	10	●
Pometia pinnata var. *alnifolia*	Medium to large trees♯	3	○

Sources: *Ashton (1964), †Whitmore (1972), ‡Whitmore (1973), §Ng (1978), ♯Ng (1989); open and closed circles denote presence and absence respectively of trees in a 50-ha plot in a pristine forest at the Pasoh Forest Reserve till 2006. Therefore, we assumed that all trees that survived in 2004 did not die by 2006. Our biomass calculation in 2005 and 2006 would result in a slight overestimation of the biomass because annual survival rate from 2004 till 2011 was fairly high (93.2% $year^{-1}$) and, even for the first year, the rate was over 90%. Likewise, dbhs of trees were converted into corresponding tree aboveground biomass using allometric equations by Kato et al. (1978).

RESULTS

Of the 351 trees planted, 162 (46.2%) trees survived for 11 years. Survival rates for the 1st, 2nd to 8th, 9th, 10th and 11th years were 90.6, 93.2, 98.8, 98.8 and 99.4% $year^{-1}$ respectively (results not shown). Survival in the first year was lower than the rest of the years. During this year, *A. hispidus* had the lowest survival rate (40%), while all trees of *D. oblongifolius, S. coriacea, P. pinnata* var. *alnifolia* survived. The annual survival rate eventually increased with time and in the 11th year, it reached 99.4% $year^{-1}$. The species-specific 1st year annual survival rate was significantly and positively correlated with that of the 11th year ($r = 0.67$, $p < 0.05$, Figure 2). This implied that a species which had higher mortality rate in the first year also had higher mortality rate in the last year. Trees generally showed rapid increases in height with *P. pinnata* var. *alnifolia*, *A. altilis* and *A. hispidus* among the fastest-growing species (Figure 3). These species attained heights over 350 cm three years after planting. *Dryobalanops oblongifolia* was the slowest-growing species, reaching about 130 cm in height in the third year after planting.

Dbh growth rates also showed rapid growth of the planted trees, surpassing those of nearby pristine forest (Figure 4). *Artocarpus altilis* had the largest dbh, i.e. > 50 cm at 11 years after planting.

Species-specific annual survival rate (average of 11 years) was significantly and negatively correlated with the species-specific annual dbh growth rate ($r = -0.81$, $p < 0.005$, Figure 5). High survival and rapid growth rate will ensure planted trees have rapid increase in biomass over time. At the 11th year, total aboveground biomass was estimated to be 41 Mg (Kato et al. 1978, Figure 6).

DISCUSSION

Feasibility of biodiversity restoration planting in terms of silviculture

The survival rates of trees analysed in this study were much higher than the rates reported in previous studies discussing planted trees in open lands. For example 0–40% of seedlings planted in a grassland survived for 81 months in Sarawak, Malaysia (Hattori et al. 2013), 6–78% of seedlings planted in an area of abandoned shifting cultivation survived for 26 months in south Kalimantan (Adjers et al. 1996) and 20–40% survived for 22 months in south China (Li et al. 2011). Studies of planted trees in open lands in Peninsular Malaysia (Ang & Maruyama 1995) and south Kalimantan (Otasmo et al. 1997) showed that while some species had good survivorship of over 80%, others did very poorly, with some survival rates reported to be under 20% for the initial 24 months after planting.

The main cause of high mortality in previous studies was the combination of high light intensity, high temperature and desiccation. Despite the fact that our study was conducted at a site drier than study sites in other parts of Malaysia, i.e. with only about 1850 mm rain $year^{-1}$, many trees survived. This may be the advantage of planting along a river. Similarly, in the case of grassland planting in Sarawak (Hattori et al. 2013), seedlings planted near a stream had higher survival rate compared with trees at the rest of the sites, indicating planting trees along rivers is good practice.

In this study, trees planted along the river showed more rapid growth compared with trees in the nearby pristine forest even though some trees in canopy gaps received plenty of light. Their growth rates were even greater than trees planted in open land sites (Primack et al. 1988). For trees in open land areas, factors other than light often limit tree growth. Soil nutrients are most likely to affect growth of trees in this study. It has been reported that soil nitrogen content in oil palm plantation was higher than that in Pasoh Forest Reserve, possibly due to effect of fertiliser (Adachi et al. 2006). Planted trees may show faster growth rate by exploiting nutrient-rich soil in the oil palm plantation.

Trees planted exhibited an interspecific demographic trade-off between two strategies

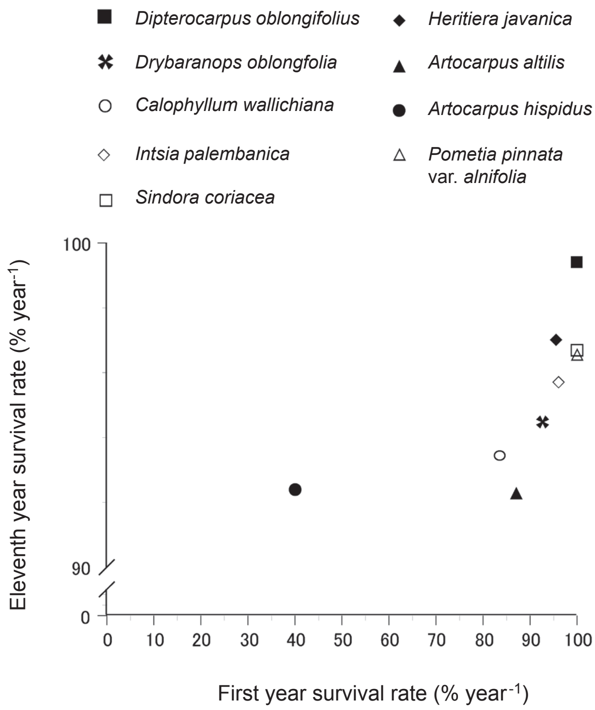

Figure 2 Relationship between the first and the final (11th) years survival rates between eight planted species; these were significantly positively correlated ($r = 0.67$, $p < 0.05$)

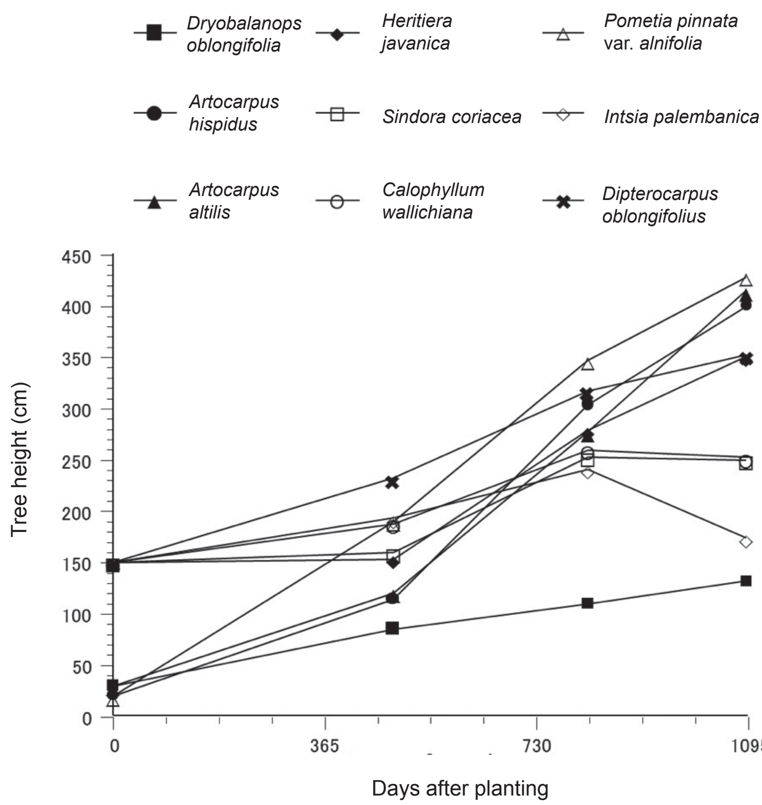

Figure 3 Height growth of planted trees for 3 years after planting in an oil palm plantation in Peninsular Malaysia

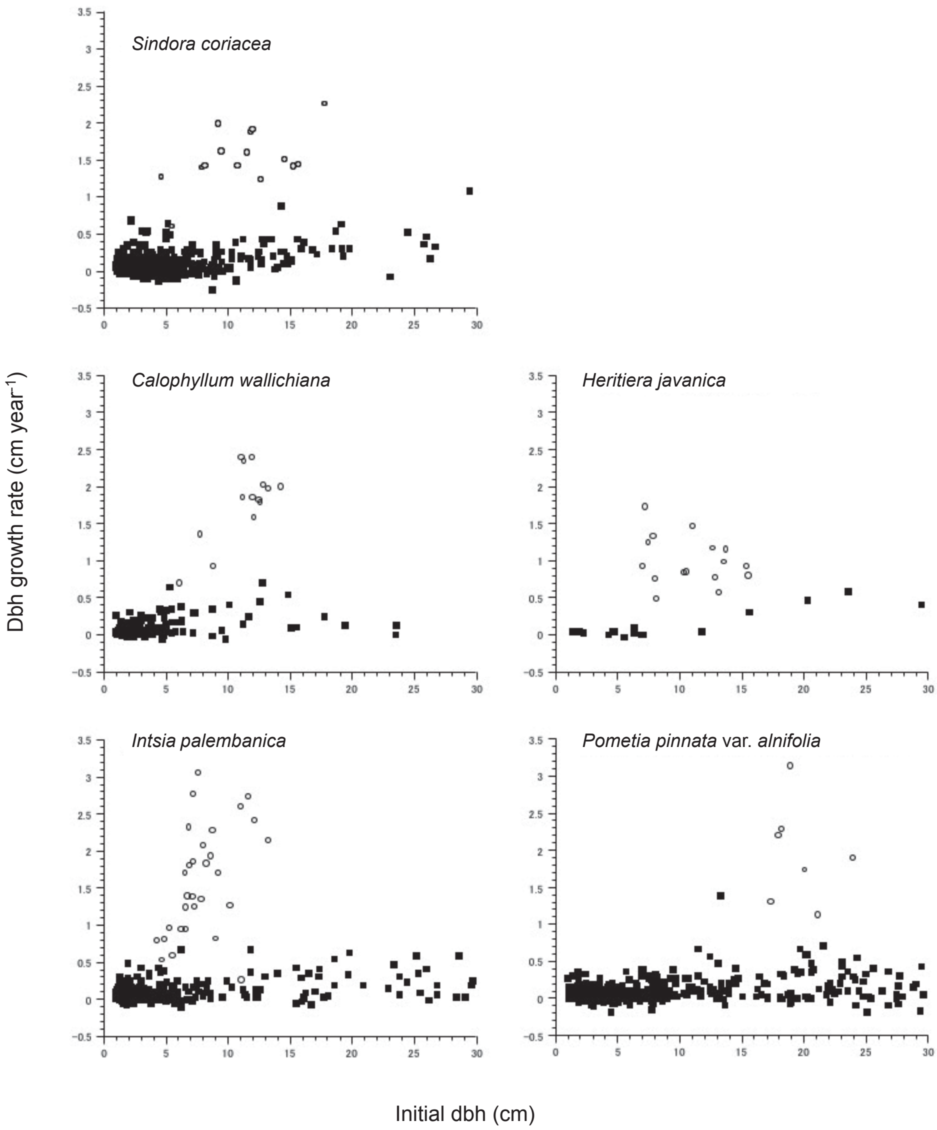

Figure 4 Dbh growth as a function of initial dbh of planted trees in an oil palm plantation in Peninsular Malaysia (open circles); dbh growth for trees in a 50-ha forest monitoring plot in a nearby pristine forest are also shown (closed squares)

(high survival versus rapid growth). This trade-off has often been believed to between carbon allocation to traits that enhance growth and increased survival (Kitajima 1994). The success of tree planting in open land area largely relies on proper selection of species (Otasmo et al. 1997, Hattori et al. 2013). Our data suggested that fast-growing species had lower survival rates than slow-growing species. This proves that selection of planted species is important to achieve success in plantation. If emphasis is placed on rapid increase in biomass, greater numbers of fast-growing species should be planted to compensate for the low survival rate.

Survival and growth rates of trees in this trial planting suggested that planting with the goal of restoring biodiversity for animals and plants in oil palm plantations is silviculturally very feasible. However, the contribution of the planting to biodiversity is still obscure. Direct evidence of such contribution may be difficult to obtain from this type of small-scale planting of young trees. To adequately evaluate the effects on biodiversity we need to establish a larger-scale study and wait for the planted trees to grow larger. A study of bird and butterfly diversity in oil palm plantations suggested that adding more natural vegetation such as riparian buffers and natural forest patches

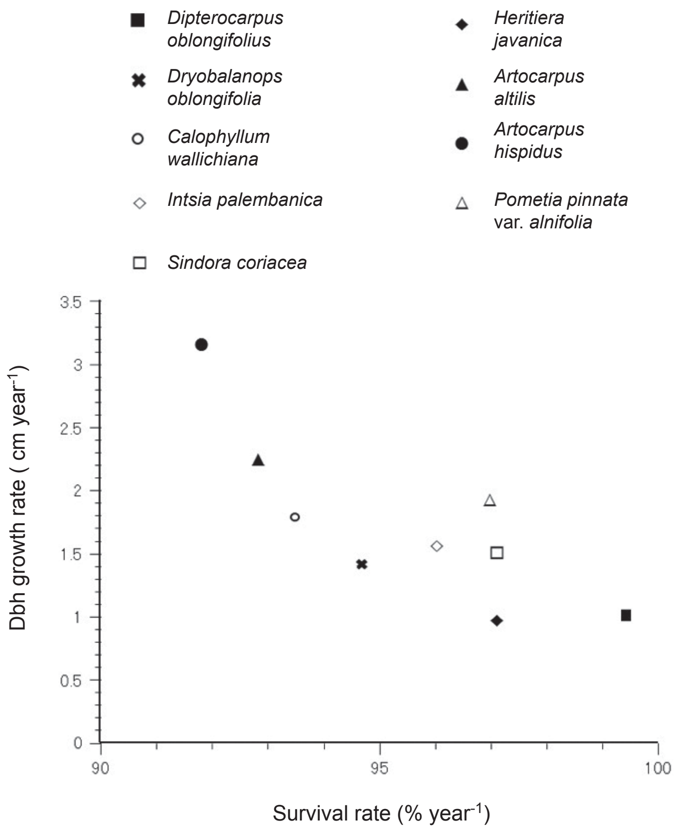

Figure 5 Relationship between species-specific annual survival rate and annual dbh growth rate between nine species planted; these were significantly negatively correlated ($r = -0.81$, $p < 0.005$)

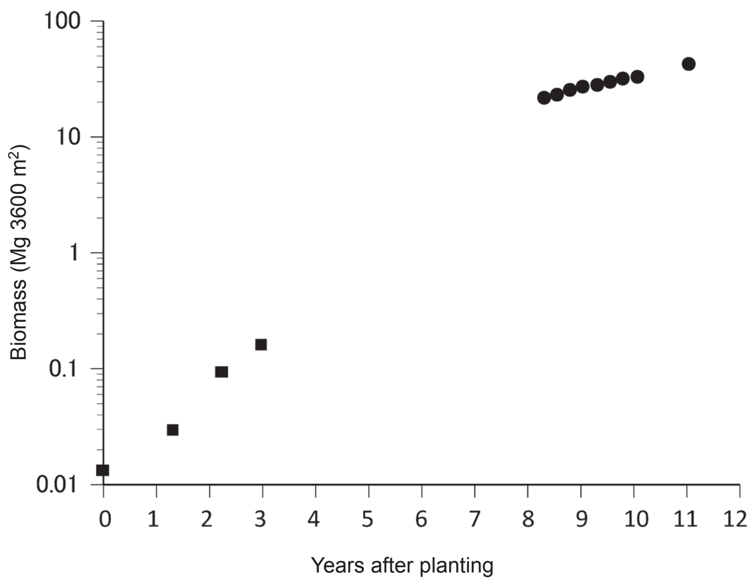

Figure 6 Growth trajectory of biomass after tree planting in an oil palm plantation in Peninsular Malaysia; for the initial 3 years tree biomass was estimated based on tree height following Lee et al. (1997; closed squares), after 8 years tree biomass was estimated using allometric equations of Kato et al. (1978, closed circles)

in oil palm plantations had positive effects on biodiversity (Koh 2008a, b). This means leaving natural vegetation inside the oil palm plantation had weaker effects on biodiversity than did forest cover in the area surrounding the plantation (Koh 2008b). Planting with the goal of restoring biodiversity will be more effective if planted trees connect two forest reserves that are separated by oil palm plantation.

Social and financial feasibility of biodiversity enhancement planting

Oil palm growers could be given incentives to practice biodiversity-restoration planting. However, social and financial hurdles must first be cleared. Initially, the implementation of this type of planting will totally depend on the decision by oil palm growers and the planting will be practiced only if oil palm growers understand the importance of the restoration of biodiversity. This may be attainable because some growers and/or companies wish to enhance their images of business to satisfy environmentally conscious consumers (Koh & Wilcove 2007).

Planting needs to be attractive to maintain the interest of oil palm growers in biodiversity restoration over the long term. Fruit trees should be included in the mix of planted trees and the fruit should be made available to plantation owners to encourage them to support this type of project. Additionally, the biodiversity restoration planting may deliver many additional benefits such as improving water quality, protecting oil palms from insect pests (Koh 2008a), providing habitats to insect pollinators for oil palms and perches to raptors that prey on rats because rats are the main animal pest of oil palm productions.

Financial hurdles may be more difficult to overcome. Planting costs will discourage people from planting a diverse array of species. Some oil palm companies are very interested in conserving biodiversity and may fund planting to restore biodiversity (Koh & Wilcove 2007). Financial subsidies from oil palm companies for biodiversity restoration planting may strongly encourage oil palm growers who desire to plant for ecological reasons.

Financial incentives for biodiversity restoration planting may provide another way to clear financial hurdles. At a minimum, this potentially includes involvement of the Roundtable on Sustainable Palm Oil Certification Programme (Fitzherbert et al. 2008, Laurance et al. 2010) and funding planting from reducing carbon emissions from deforestation and forest degradation (REDD+) (Miles & Kapos 2008), because planted trees gain biomass very rapidly.

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