The Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Project*

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Palm oil is among the most important vegetable oils worldwide. With increasing use as a feedstock for biofuel, its global demand is set to increase. Forest conversion to oil palm has severe impacts on biodiversity. However, little research has focussed either on methods that can be employed to maximise biodiversity within plantations or on the role this biodiversity plays in ecosystem functioning and crop production.

Taking an experimental approach, the Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Project aims to quantify the effect of habitat complexity within oil palm plantations on biodiversity and the role of this biodiversity in ecosystem functioning and productivity. As a collaborative project between ecology, conservation and industry researchers, BEFTA links ecological and agronomic expertise to identify management techniques that benefit biodiversity and ecosystem functioning with no cost to productivity.

The project is now in its second year: we have established study plots, collected data on habitat structure, carried out surveys of a range of taxonomic groups, measured ecosystem functioning, and recorded palm oil yield. We describe the methods used in this project and discuss its likely implications and the importance of collaborations between research organisations and industry in pioneering biofriendly oil palm production.

Keywords: *Biodiversity, collaboration, ecosystem function, ecosystem service, oil palm, production, SMARTRI.*

Agriculture is expanding dramatically in the tropics (Foley *et al*., 2005; Phalan *et al*., 2013), contributing to the high rate of forest loss catalogued worldwide (Hansen *et al*., 2013). An area of particular concern is Southeast Asia, as it is a biodiversity hotspot (Myers, 2000)

* This paper was first presented at the Fourth International Conference on Oil Palm and Environment (ICOPE) 2014, Bali, Indonesia.

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suffering from rapid deforestation, largely owing to the expansion of oil palm plantations (Koh & Wilcove, 2008). Oil palm is among the most important tropical crops and represents a major source of vegetable oil (Corley, 2009). With an increasing range of potential uses (Henderson & Osborne, 2000), particularly as a feedstock for biofuel production (Koh, 2007), global demand for palm oil is likely to increase (Koh & Ghazoul, 2008). Expansion of oil palm has come at a cost to species diversity (Fitzherbert *et al.*, 2008; Foster *et al.*, 2011), and there is an urgent need to mitigate biodiversity loss through developing agricultural landscapes that minimise forest loss and maximise sustainability.

Studies comparing forest and oil palm have found a much lower biodiversity in plantations across a wide range of different taxa (Fitzherbert *et al.*, 2008; Foster *et al.*, 2011). This reduction in biodiversity is of concern, not least because of the role different species can play in supporting important ecosystem functions within agricultural areas (Schmid *et al.*, 2009), such as pollination, pest control, decomposition, and carbon sequestration. However, remaining natural vegetation within oil palm, such as understory plants, areas of natural habitat (Maddox *et al.*, 2007) or epiphytes growing on palm trunks (Fayle *et al.*, 2010), can support significant levels of biodiversity. Research in other crops has shown that areas of natural vegetation within the agricultural matrix can increase the diversity of important guilds such as biological control agents and pollinators, and thereby increase productivity through enhanced ecosystem functioning (e.g. Bianchi *et al.*, 2006; Ricketts *et al.*, 2004).

Very little research has investigated management methods, which can be employed to increase biodiversity within oil palm habitats (Turner *et al.*, 2011), nor the potential role of this biodiversity in maintaining ecosystem functioning and crop productivity. Due to its longevity and the range of understory and epiphytic plants that are found in oil palm plantations (Foster *et al.*, 2011), there is considerable potential for within-plantation management that can benefit both biodiversity and ecosystem services. Management for ecosystem functioning may be particularly relevant in systems such as plantations, which have already lost much of their endemic wildlife, yet rely on services such as pollination, decomposition and pest control provided by the natural world (Hobbs *et al.*, 2009). Any management that enhances this component of diversity has the potential to increase the stability of these important functions as well as benefit crop yield and reduce management costs.

The Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Project aims to experimentally investigate the role of local habitat complexity in supporting biodiversity, ecosystem functioning and crop productivity within oil palm plantations. By working alongside Sinar Mas Agro Resources and Technology Research Institute (SMARTRI), BEFTA is manipulating the understory complexity within the oil palm landscape to assess the potential for biodiversity-friendly management to enhance ecosystem services and crop production.

METHODS

Study site

All of the fieldwork for the BEFTA Project takes place within plantations owned and managed by SMARTRI, particularly Ujung Tanjung (UTNE) and Kandista (KNDE) Estates in Riau Province, Sumatra, Indonesia

(N0 55.559, E101 11.619; *Figure 1*). The area surrounding the estates is mainly mature oil palm, with varying amounts of other crops.

Number and location of the treatments and replicates.

The core experimental set-up for the project is 18 plots, each with one of three different levels of habitat complexity:

i. *Normal complexity*: this represents standard industry practice and includes an intermediate level of herbicide spraying of the understory plants
ii. *Reduced complexity*: this represents highly destructive management and includes the spraying of all understory vegetation with herbicides
iii. *Enhanced complexity*: this represents reduced-input management/conservation treatment and includes no herbicide input and only limited understory cutting. Understory growth will therefore be maximised as far as possible, while still allowing access to the palms for harvest.

The plots are arranged at six locations across the estates in triplets with each of the three treatments represented at each location and assigned to plots at random. Replicate locations were chosen to be within flat areas of between 10-30 m height above sea level, to not be adjacent to habitation, and to be of a similar age (planting date 1987-1993). Each plot is 150 m x 150 m (2.25 ha) in area, with a central 50 m x 50 m (0.25 ha) area where most of the sampling takes place (*Figure 1 & Figure 2*).

Data collection

A comprehensive set of measurements has been taken in each of the sample plots since October 2012 to quantify aspects of biodiversity, ecosystem functioning and crop production, allowing functional links across the oil palm landscape to be assessed (*Figure 3*). Measurements began more than 12 months before the experimental treatments were implemented in February 2014. It is therefore possible to quantify the level of change as a result of the experiment, rather than assuming similar values prior to treatment.

Environmental measures

At the same time as plots were established in October 2012, a number of environmental factors were measured to assess the homogeneity of plots. These include: slope, understory vegetation cover, canopy openness and the distribution of termite mounds. The presence of streams and their GPS locations were also recorded and anything unusual about the plots noted.

Dataloggers (*ibutton*), buried ten centimeters below the ground, were established in April 2013 at three locations in each plot. These are set to record temperature at three-hourly intervals throughout the timeframe of the project.

Soil cores have also been collected at replicate locations in each of the plots in September 2013, using established industry protocols. At the same locations, penetration and infiltration rates have also been measured. Soil samples are currently being analysed for a range of nutrients in the labs at SMARTRI.

Biodiversity data

A number of different collection methods have been employed to quantify aspects of biodiversity in the survey areas, where possible

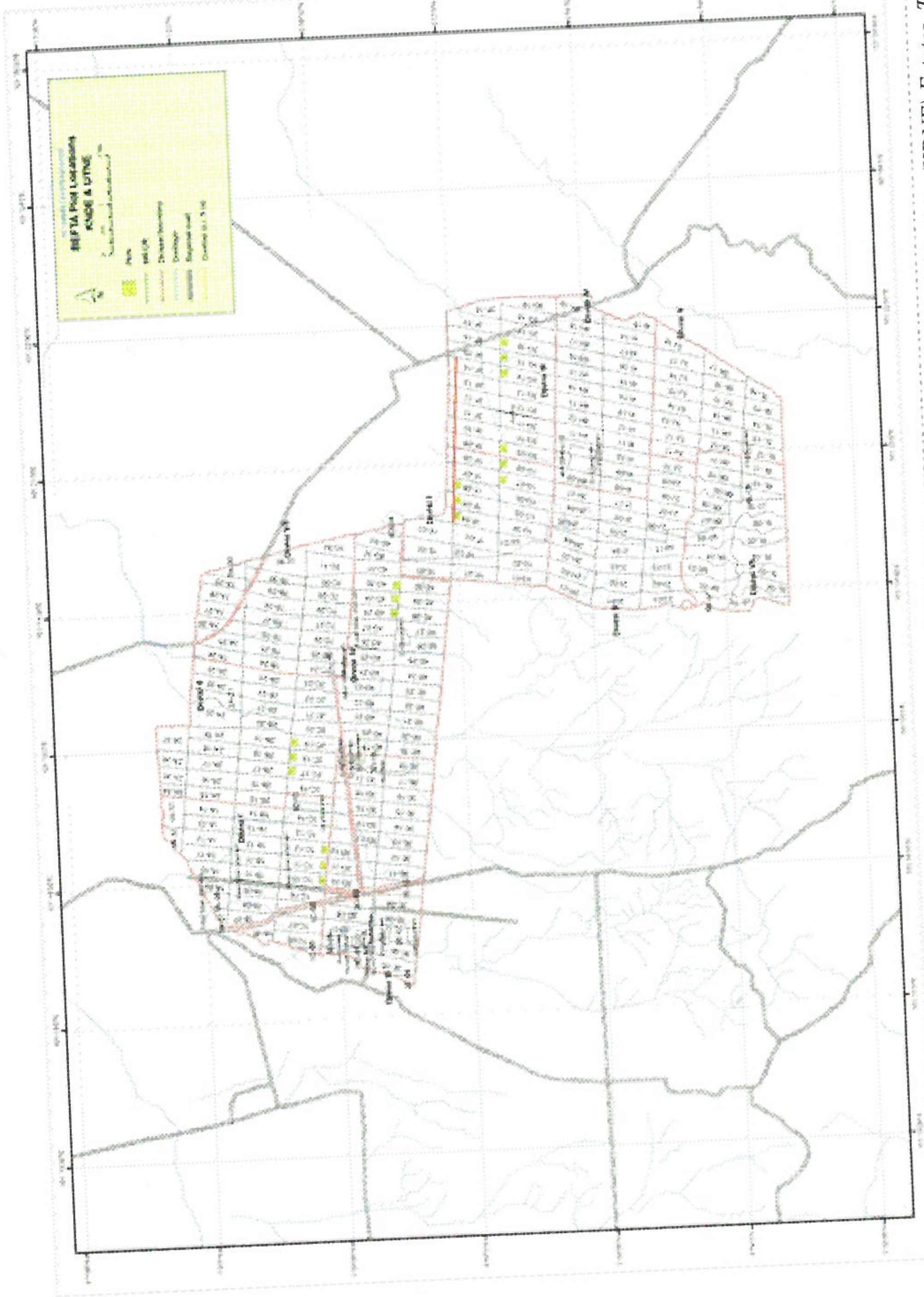

Figure 1 Locations for the six replicates of the three treatment plots within Ujung Tanjung (UTNE) and Kandista (KDNE) Estates. The areas surrounding the marked estates on the maps are predominately mature oil palm

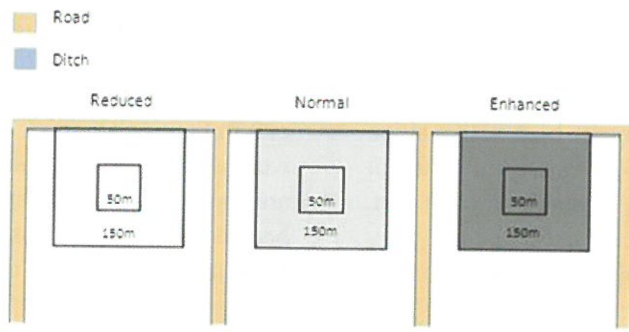

Figure 2 *One replicate within the BEFTA Project, consisting of the three different treatment plots of: reduced, normal and enhanced understory complexity*

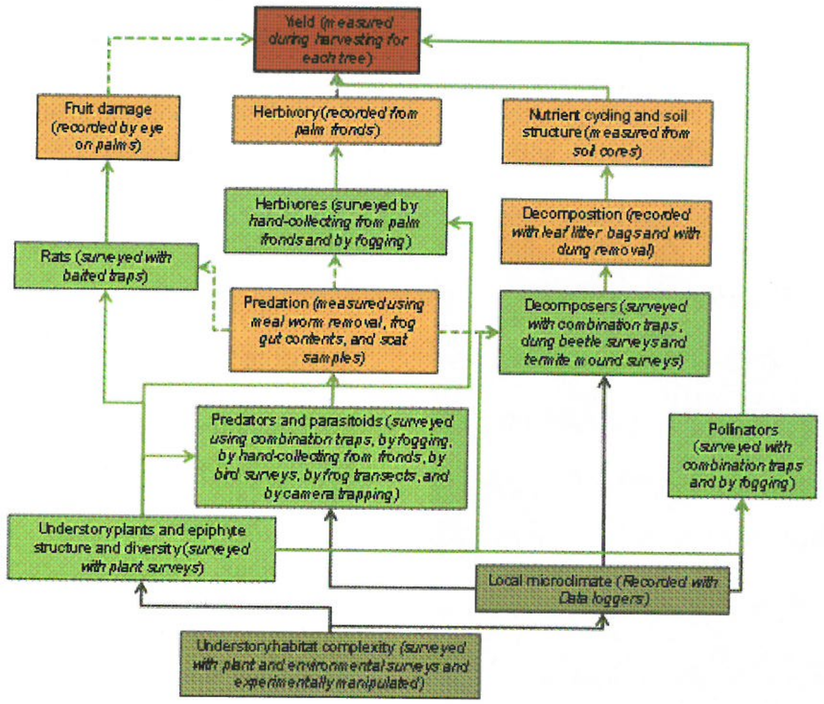

Figure 3 *An overview of biodiversity and ecosystem function data being collected as part of the BEFTA Project. Dark green boxes show habitat complexity and environmental factors; light green boxes show plant and animal taxa (biodiversity); orange boxes show ecosystem functions and red box shows ecosystem services. Brown arrows show non-ecosystem function links within the ecosystem and green arrows ecosystem function links, with dashed lines illustrating a negative relationship and un-dashed a positive relationship between different components of the oil palm ecosystem*

following standard sampling protocols.

Ground-active insects: Combination (pitfall, flight intercept and Malaise) insect traps (*Figure 4*) have been set biannually since March 2013 to sample a variety of different insect groups at three locations in each plot. These traps have been used successfully before in related projects in Malaysia (see www.safeproject.net; Ewers *et al.*, 2011), ensuring that results are comparable with other studies. All insects are in the process of being identified to order and counted, but it is already clear that these traps have been successful, with a mean of 230 individual arthropods being caught in each trap, representing a range of taxonomic groups.

Canopy insects: A canopy fogging machine (Pulsefog K-10 fogging machine, containing synthetic pyrethroid insecticide - Rolidor 25 EC: lambda cyhalotrin 25 g/l) was used to sample insects from a single palm at the centre of each plot in September 2013. Canopy fogging is a well-established technique for sampling canopy arthropods (e.g. Paarmann & Stork, 1987), has been used before successfully in studies of oil palm fauna (Turner & Foster, 2009), and was successful in this project, with an average of 250 individual arthropods being collected from each fog.

Figure 4 An insect combination trap being set in one of the BEFTA plots. Inset - insects being collected from the trap

Butterflies and dragonflies: Combined butterfly and dragonfly transects have been set up at all of the plots, with routes around the edge of the central 50 m and also along the adjacent road. To record butterflies and dragonflies, researchers slowly walk these routes, following standard butterfly monitoring methods (Pollard & Yates 1993), and record all individual butterflies and dragonflies that fly into the 5 m by 5 m area in front of the recorder. Transects have been walked biannually since March 2013. Where it is not possible to identify species in the field, specimens are collected for later identification. As well as butterflies and dragonflies, the presence of *Nephila* spp. spiders on webs and the two main species of beneficial predatory assassin bugs (*Cosmolestes picticeps* and *Sycanus dichotomus*) along the transect route are also recorded. We are now in the process of producing identification guides for the sites, which will simplify future identification and monitoring in the field (*Figure 5*).

Dung beetles: Dung beetles and associated dung removal were measured in September 2013 and February 2014, following standardised protocols (e.g. Slade *et al.*, 2011; Gray *et al.*, 2014). These involved pitfall-trapping together with quantified removal of fresh cattle dung.

Aquatic insects: Aquatic insects were collected between November 2013 and

Figure 5 Some of the range of dragonfly and damselfly species found within the BEFTA plots. Images of all species recorded have been taken, facilitating the production of area-specific identification guides

January 2014 along a subset of ditches in the plots by placing mesh bags containing 4 g of oil palm leaf litter within the ditch, recollecting after a standard time-period and hand-removing any insects. Dry weight of the leaf material was also recorded, allowing the rate of leaf litter decomposition in the ditches to be calculated.

Frogs: Frogs were collected along a transect that followed the central 50 m box at each site in February-March 2014. Frogs observed along each transect were identified to species and their resting position noted. A sub-set of frogs within the plots were then stomach-flushed, enabling an assessment of dietary preference, following established protocols (Solé *et al.*, 2005).

Mammals: Rats have been surveyed in the plots using traps baited with palm fruits biannually since February 2013. Mark-Release-Recapture methods are used to estimate rat population density and the presence of fruits damaged by rats in each tree is also recorded at each survey.

Surveys of small carnivores were carried out using camera traps deployed in 12 out of the 18 plots between January and December 2013. All of the plots were also searched for small carnivore scats over the same time period. These were later dissected to determine the diet and level of rat predation for each species (see Naim *et al.*, 2014 for full details).

Birds: Point counts were used to survey for birds over a ten minute period at the central location in each plot in September 2013, with bird abundance and species richness being recorded. Birds are important biocontrol agents for oil palm herbivores (Koh, 2008).

Understory plants and epiphytes: Plant surveys were carried out in each of the BEFTA plots following existing methods developed by SMARTRI (Purnomo & Caliman, 2012), between May and July 2013. These are based on 1m² quadrats, set at ten replicate locations within the plots as well as at five locations along the road and on five oil palm trunks. The percentage cover of each species in the quadrat is recorded and all the above-ground growth in each quadrat cut and oven-dried to calculate species-specific biomass.

Ecosystem functioning

Herbivory: Herbivory levels in the plots have been measured every three months since March 2013. At each survey, three trees in each plot are randomly selected and a frond cut from each. The herbivory damage on each frond is then estimated by eye and a subset of leaflets cut and photographed to allow digital analysis of damage, using the processing software, *ImageJ* (see: http://rsbweb.nih.gov/ij/). In addition, any lepidopteron larvae on the fronds are collected for identification, and the number of ants on the frond is estimated by eye and a subset of individuals collected for later identification to species.

Additional decomposition and nutrient cycling measurements: The rate of leaf litter decomposition in the plots has been measured annually since March 2013, following established methods (e.g. Didham, 1998). At three locations in each plot, four litter bags of fine mesh (<1 mm wide - excluding invertebrates), coarse mesh (2 mm - allowing small invertebrates access) and open mesh (fine mesh with 1cm holes cut in it - access to all but the largest invertebrates) containing 4 g of oven-dried palm leaves are placed on the soil surface. These are collected after 10 days, 30 days, 60 days and 120 days. Following collection, litter is oven dried to 50°C, brushed clean of mud and weighed, allowing mass loss to be calculated. Dung removal is also being measured across the plots and this will be linked to nutrient cycling measured from soil core data.

Soil fauna feeding activity has been assessed in each plot using bait lamina sticks (Terra Protecta GmbH, Berlin, Germany). Bait lamina sticks are plastic strips (1 mm x 6 mm x 120 mm) containing sixteen apertures of 1.5 mm diameter, cut at 5 mm intervals (Kratz, 1998). The apertures are filled with a bait mix of cellulose powder, bran flakes and active carbon (in the ratio - 70:27:3). At three locations in each plot, six bait lamina sticks were inserted vertically into the soil, with the top aperture positioned just below the soil surface. The sticks were collected after 6 days and feeding activity was assessed by noting the number of perforated apertures in each stick (Tao *et al.*, 2013).

Predation: Meal worms were used to measure predation in the understory and canopy in each plot in February and March 2014. A standard set of six meal worms, glued to small pieces of cut fronds were suspended in the understory or the canopy at three locations in each plot. Each of the canopy and understory locations contained a set of six exposed mealworms and a set enclosed within cages (gauge approximately 2 cm). These were left for 24 hours and the number of mealworms

remaining recorded. This provides a measure of predation in the plots, with open fronds representing all predation and caged fronds representing predation without vertebrate predators.

Palms and oil palm yield: Within each of the 50 m plots all palms were labeled with an individual number and the Diameter Breast Height (DBH) at 1.2 m and the height of each tree recorded, following standard industry practice. Oil palm yield (number and weight of bunches) from each individual palm has been recorded on a monthly basis since January 2013.

RESULTS AND DISCUSSION

The BEFTA Project has already collected comprehensive pre-treatment data that describes the habitat structure, biodiversity, ecosystem functioning and yield of the experimental plots. This will allow future work on the project, following experimental manipulation, to assess the impacts of habitat management on oil palm ecosystems. Results from this project have potentially far-reaching impacts on oil palm management from both a conservation and agronomic perspective. In particular, management within plantations that can increase or maintain understorey heterogeneity may benefit within-plantation biodiversity. Similarly, identifying the potential importance of invertebrate decomposers in nutrient recycling may pave the way for management that favours these beneficial groups and the functions they perform within the plantation.

More generally, as a result of a long-term, in depth focus on a wide range of taxa, we will be able to produce the most comprehensive account of the biodiversity housed within an oil palm estate to date. This baseline information adds greatly to our knowledge of this important novel ecosystem and will facilitate the design and implementation of replicable survey methods and tools in other areas. Such descriptive work is particularly necessary at the moment, with the implementation of sustainability criteria that require robust, oil palm-appropriate ecological survey methods.

Given the increasing importance of palm oil as a source of vegetable oil and revenue both within Indonesia and globally, the results from this project may help to inform more sustainable and more productive palm oil cultivation worldwide. The wide range of data already collected as part of this project as well as the successful establishment of the plots themselves demonstrates the importance and strength of collaborations between industry and research institutions, which can bring together different groups of people with complementary skills. We propose that initiatives like the BEFTA Project represent a new paradigm for conservation research in tropical agricultural landscapes: one in which conservation practices take place outside as well as inside forest reserves, through collaboration with the agricultural industry.

CONCLUSION

Although still in its early stages the BEFTA Project is already yielding important results on biodiversity and ecosystem functioning within oil palm plantation habitats. It is hoped that this will facilitate the development of more biofriendy oil palm cultivation with both productivity and sustainability at its heart.

ACKNOWLEDGEMENT

We would like to thank the researchers and staff at SMART for all their hard work and help with data collection and RISTEK for research permission. PT SMART Research Institute and the Isaac Newton Trust, Cambridge funded ECT and WAF.

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