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What drives the success of reforestation projects in tropical developing countries? The case of the Philippines

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ABSTRACT

In response to substantial deforestation over many decades, large scale reforestation programs are being implemented across many tropical developing countries. Examples include the United Nations Billion Trees Campaign, the National Greening Program in the Philippines, and the 5 million ha reforestation program in Vietnam. However, while substantial investments are being made in reforestation, little information exists on the drivers influencing reforestation success and how these interact to determine environmental and socio-economic outcomes. In this study we surveyed 43 reforestation projects on Leyte Island, The Philippines to identify the drivers that most influence reforestation success as measured by key indicators drawn from the literature, including interactions between drivers and between drivers and indicators. We investigated 98 potential success drivers, including technical and biophysical factors; socio-economic factors; institutional, policy and management factors; and reforestation project characteristics. We also measured 12 success indicators, including forest establishment, forest growth, environmental and socio-economic success indicators. Stepwise multiple regressions were used to identify significant relationships among drivers and indicators and this analysis was used to develop a system of driver and indicator relationships. Based on this we found that revegetation method, funding source, education and awareness campaigns, the dependence of local people on forests, reforestation incentives, project objectives, forest protection mechanisms and the condition of road infrastructure were highly connected drivers that influenced multiple success indicators either directly or indirectly. We conclude that policies targeting revegetation methods, socioeconomic incentives, forest protection mechanisms, sustainable livelihoods, diversification of funding and partnerships, technical support, and infrastructure development are likely to have a broad systemic and beneficial effect on the success of reforestation programs in tropical developing countries.

1. Introduction

While tropical deforestation continues at alarmingly high rates, the net loss of forest area globally has slowed from 8.3 million ha per year between 1990 and 2000 to 5.2 million ha per year between 2000 and 2010 (FAO, 2010). This reduction in net loss is mainly due to an increase in afforestation, reforestation, and natural forest regrowth. It appears that a number of tropical countries have recently been through a forest transition, whereby there has been a shift from deforestation to net reforestation (Meyfroidt and Lambin, 2011).

Reforestation through planting trees on cleared land is an important mechanism that leads to tree cover establishment as reported in the forest transition literature, however reforestation is not a straightforward process that leads invariably to tree cover increase (de Jong, 2010). Rather, the outcome of forest rehabilitation itself is influenced by many factors (Chokkalingam et al., 2005; Le et al., 2012). If forest rehabilitation outcomes can be appropriately assessed, and these outcomes linked to forest cover increases, the study of forest rehabilitation could shed light on some of the many complex processes that ultimately result in forest transition (de Jong, 2010).

Little information exists to indicate the success of reforestation projects in achieving ecological or socio-economic benefits. Unfortunately, many existing reforestation projects have partially or completely failed, often because the trees that were planted have not survived or have been rapidly destroyed by the same pressures that caused forest loss in the first place. Even when planted trees have survived to maturity, they have not necessarily

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been welcomed by local communities. Dudley et al. (2005:6) observed that, 'too many restoration projects do not bother to find out what local people really want'. This is a particular problem in the rural areas of developing countries because if reforestation projects do not meet community livelihood needs, then the planted trees will not be respected and will most likely be removed and replaced with agricultural land uses.

A number of problems with past reforestation projects can be identified. Reforestation projects have often sought to encourage and sometimes impose tree planting without understanding why the trees disappeared in the first place and without attempting to address the immediate or underlying causes of forest loss (Eckholm, 1979). There has also often been a mismatch between social and ecological goals of reforestation; either reforestation has aimed to fulfil social or economic needs without reference to ecological goals, or it has had a narrow conservation aim without taking into account the social and economic needs of people. For foresters, reforestation traditionally meant establishing trees for a number of functions (wood or pulp production, soil protection). For many conservationists, reforestation is either about restoring original forest cover on degraded areas or about planting corridors of forest to link protected areas. For many interested in social development, the emphasis of reforestation is on establishing trees that are useful for fuel-wood, fruit, or as windbreaks and livestock enclosures.

Until now, most reforestation practitioners and ecologists have tended to see their jobs as strictly technical. In reality, however, reforestation is as much a cultural activity as any other human endeavour. As Higgs (1997) has compellingly argued, good reforestation requires a view expanded beyond the technical to include historical, social, cultural, political, aesthetic and moral aspects. Otherwise conflicts may arise when reforestation programs are introduced (Light and Higgs, 1996; Swart et al., 2001).

Based on a variety of case studies, the most important socio-economic requirements for reforestation success appear to be a stable land-use pattern, equitable land-tenure systems, homogeneous human populations (with respect to ethnicity, economics, and so forth), local public involvement, and strong local leadership and participation by government institutions (Karki, 1991; Lamb, 1988). However, the success or failure of reforestation projects cannot be explained by either a single technical or a socio-economic factor (Aronson et al., 1993; Le et al., 2012; Sayer et al., 2004). Little quantitative research has been conducted on reforestation success drivers and their interactions.

Through a comprehensive review of the literature we have identified a list of potential success drivers and grouped these into technical/biophysical drivers; socio-economic drivers; institutional, policy and management drivers; and reforestation project characteristics (Le et al., 2012). In that study, we also identified a large set of indicators that have been used to measure the success of reforestation projects (Fig. 1). A critical shortcoming in our current understanding concerns the relationships between the drivers of reforestation success and the indicators. In some cases these links are relatively clear, for example weed control and grazing management are logical drivers that would affect seedling survival rate (a key indicator of reforestation success). However in many other cases, the links are not clear and there may be many drivers that affect the outcomes of reforestation in unknown or unexpected ways. We also do not know the relative importance of the many potential drivers, nor their impact on one or more indicators of success. In addition, we do not know what the interactions are between drivers and/or indicators. The aim of this paper is to gain a deeper understanding of these relationships by investigating the drivers that have determined reforestation success in the Philippines. We do this by surveying 43 reforestation projects on Leyte Island, covering 98 potential drivers and 12 success indicators.

2. Methods

2.1. Study region and reforestation programs

The Philippines is one of world's seventeen mega-diverse countries (Mittermeier et al., 1997) and is one of the world's most threatened biodiversity hotspots. Like many other Asian countries, the Philippines lost its forest cover rapidly through heavy logging, upland migration and agricultural expansion over the last century. Up to 59% (9.3 million ha) of the country's official forest lands are not forested at present and are either grass or shrub land, or under cultivation (Chokkalingam et al., 2006). There is approximately 1 million ha of primary forest remaining, which represents less than 3% of the original primary forest cover (Agoncillo et al., 2011).

Reforestation efforts in the Philippines started almost a century ago and were meant to restore forest cover, provide environmental services, supply timber, and more recently contribute to local livelihoods. The common perception is that the efforts were largely a failure, with little to show on the ground and logging and livelihood pressures continuing to degrade remaining forests (Chokkalingam et al., 2006). Although the reforestation effort in the Philippines planted approximately 1.7 million ha of forest between 1960 and 2002, only 50% was estimated to have survived (FMB, 2002).

Given the current state of the Philippines' forest lands and the demands placed on them, reforestation still continues to remain high on the national environmental policy agenda (Lasco, 2008). Reforestation was one of the major programmes in the 'General Program of Actions for the Forestry Sector from 2005–2010' (Chokkalingam et al., 2006). In 2011, President Benigno S. Aquino III issued Executive Order No. 26, ordering the implementation of a National Greening Program as a government priority (NGP, 2011). The programme aims to plant some 1.5 billion trees covering 1.5 million ha over a period of six years from 2011 to 2016. Understanding reforestation success drivers will be central to the success of the programme and others like it around the world.

Our study was conducted on Leyte Island (Fig. 2), which is the eighth largest island in the Philippines (Wernstedt and Spencer, 1967), with a total land area of 750,000 ha (Groetschel, 2001). Leyte is located in the Eastern Visayas region (Region 8), at about 9°55′N–11°48′N latitude and 124°17′–125°18′E longitude, with an extension of 214 km from north to south (Langenberger et al., 2006), and about 65 km at its widest point. The island is divided into two provinces: Leyte and Southern Leyte. Based on the Corona system of classifying climatic conditions, the island has two climate types (Coronas, 1920). The eastern part of the island has a Type II climate characterised by a pronounced rainfall from November to January, while the western part has a Type IV climate with a rainfall more or less uniformly distributed throughout the year. This climatic difference is due to a mountain range that bisects the island (Emtage, 2004; Groetschel, 2001). The average annual precipitation is relatively high, at about 2900 mm (Kucharski, 2010).

Leyte province is home to 1,724,240 people of which 390,847 live in Southern Leyte province (NSO, 2008). The island has relatively flat lands around the coastline and mountainous terrain towards the centre, rising up to 1,150 m above sea level at the top of Mt. Pangasugan (Vilei, 2010). The average annual family income of the Eastern Visayas Region was approximately 3606 USD as in 2011 (NSCB, 2011). Fifty-five per cent of the households on Leyte depend on agriculture and fishing for their living (Vilei, 2010).

As in most parts of the Philippines, forests were the major natural resource on Leyte in the early 1900s. Large-scale logging

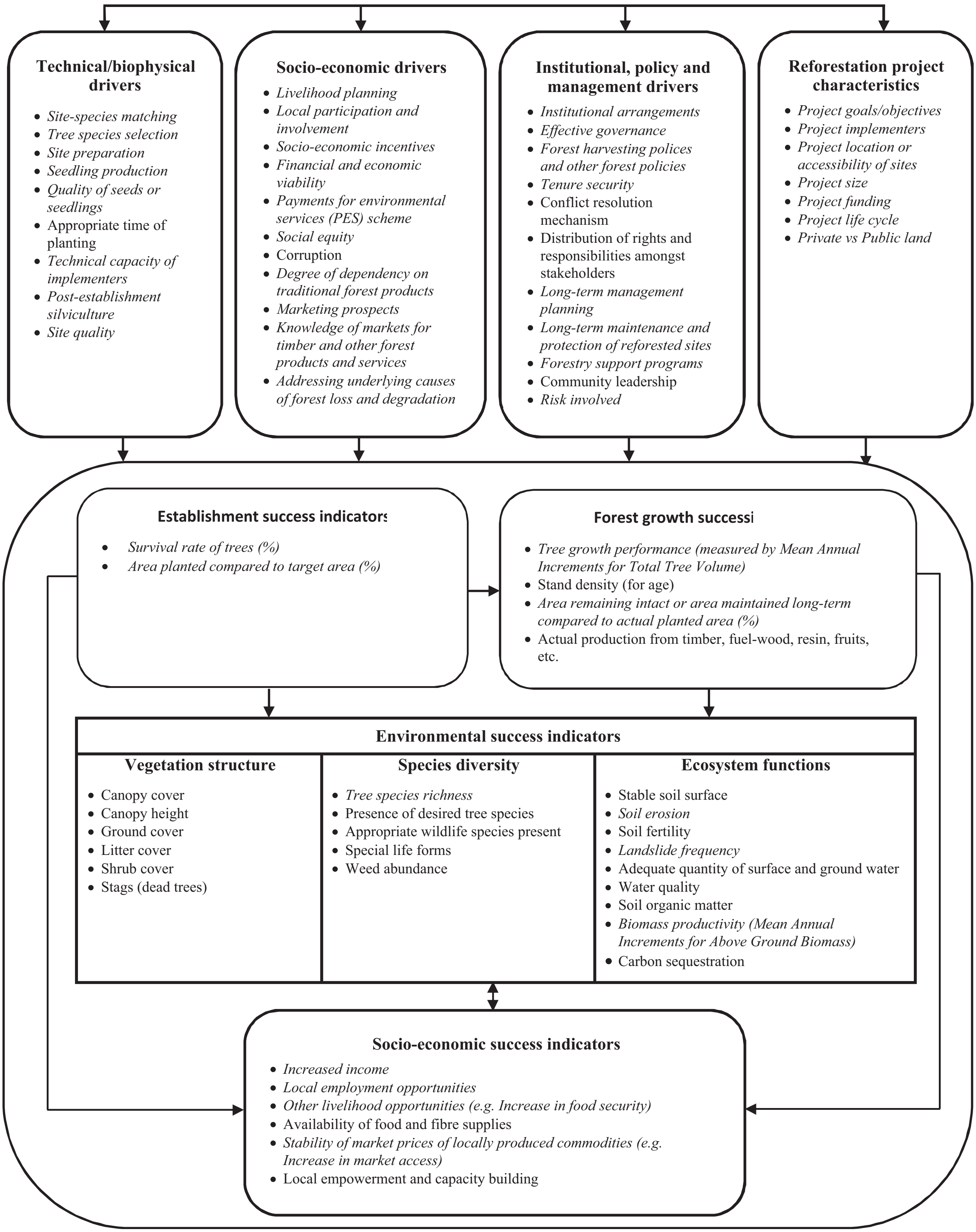

Fig. 1. Conceptual modelused for assessing reforestation success on Leyte Island, the Philippines (Adapted from Le et al., 2012). Drivers and indicators in italics were used in the current study.

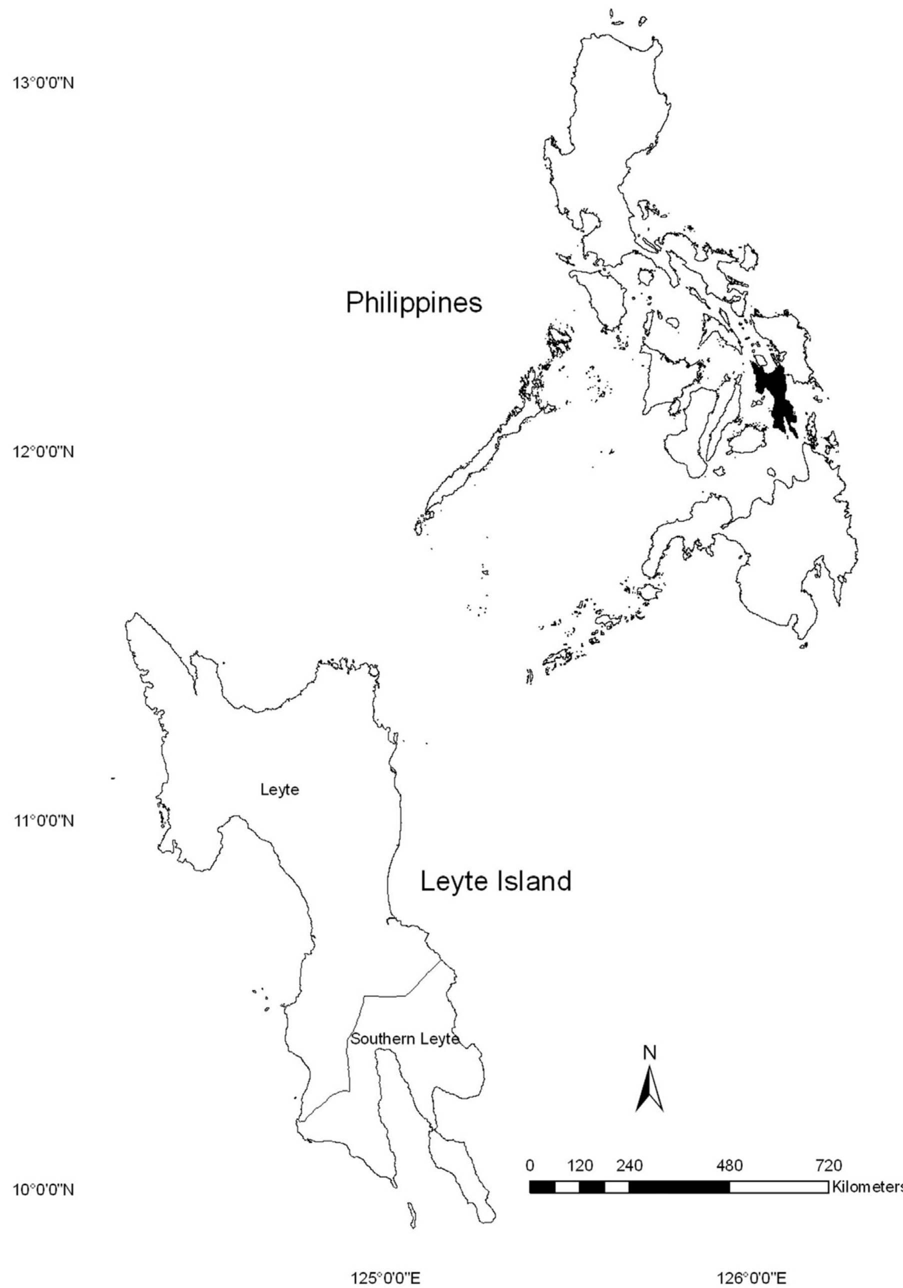

Fig. 2. Study location (Leyte and Southern Leyte Provinces, the Philippines).

operations, and conversion of forest into agriculture, has resulted in a massive decline of forest cover (Groetschel, 2001). Records show that the island had a forest cover of about 42% in 1939, which had declined to 12% by 1987, a loss of around 240,000 ha (Dargantes, 1996). In 1994 only 2% of the island's area was estimated to be primary forest (Dargantes and Koch, 1994). More recent data show that about 40% of Leyte is covered by grassland and barren land as a result of abandoned cultivation and grazing land that became unproductive due to soil erosion and leaching (DENR, 1998). A further 40% of the island is under coconut plantations. The remaining 20% of the island is composed of settlements, agricultural land and forest.

We chose Leyte Island as our study site because there has been substantial reforestation on the island as part of many past projects and the types of reforestation projects and socio-economic setting in this region is characteristic of most other parts of the Philippines. As such it is an ideal location to assess the factors affecting reforestation success.

2.2. Data collection methods

We adopted the following definition of reforestation: "Reforestation is the process by which trees are returned to areas from which they have been previously cleared. Reforestation can take many forms, ranging from establishing timber plantations of fast-growing exotic species through to attempting to recreate the original forest type and structure using native species" (Le et al., 2012). Hence the focus of our study was on reforestation projects that aimed to establish trees on formerly forested land.

Out of a total of 62 current or completed reforestation projects recorded on Leyte Island by Department of Environment and Natural Resources, we selected 43 for survey according to the criteria in Table A.1. These comprised a mix of monoculture, mixed native species and mixed introduced species. The attributes of the selected reforestation projects are summarised in Table A.2.

The reforestation project survey was based on the conceptual model for assessing reforestation success developed by Le et al. (2012) (Fig. 1). The survey covered a subset of the both success indicators and drivers from Le et al. (2012) (identified in italics in Fig. 1), and was broken into two components: an 'interview' component and a 'field survey' component. The 'interview' component comprised of a questionnaire designed to collect data on general project characteristics, project reforestation process, technical aspects of site management, project socio-economic aspects, and project institutional aspects. A copy of the questionnaire is available on request. The questionnaire was administered face-to-face with a key informant associated with each project, usually the president of the people's organisation for the community based forest management agreement projects or the property or business manager for private reforestation projects. If the key informant did not have information for a particular question, then data for that question was sort from official government records, usually Department of Environment and Natural Resources.

The 'field survey' component was designed to collect data on project site biophysical characteristics, tree establishment success, forest growth performance and forest environmental success. The field survey design was the same as used by Herbohn et al. (in press) and Le (2013), with some of the data collected from 43 sites in the current study forming a subset of the larger data sets reported in those studies. For each reforestation project site, three 5 m radius circular plots were surveyed: a site centre plot, a plot within the site boundary but more than 10 m from the site boundary (inside plot), and a plot within the site boundary but butting against the site boundary (edge plot). The centre plot was located at the centroid of the site and the inside and edge plots were located randomly within the site. For each plot, canopy cover (%), understorey and ground cover (%), diameter at breast height (cm) of trees with diameter at breast height $\geq$5 cm, total height (m) of trees with diameter at breast height $\geq$5 cm, height of tallest tree (m) and tree species were recorded. Canopy cover was measured as projective foliage cover at the centre of each plot using digital photos (Kanowski et al., 2008) and included vegetation >2 m above ground level. Tree diameter at breast height was measured using a diameter at breast height tape and tree heights were measured using a digital hypsometer (LaserAce 150 Hypsometer). Understorey, shrub, vine and scrambler, coarse woody debris and litter cover was measured at three 1 × 1 m quadrats within each plot, located at the centre of the plot and 4 m either side of the centre along a randomly oriented transect. All sites were surveyed between September 2010 and March 2011.

2.3. Data analysis methods

IBM SPSS Statistics 20 (2011) was used for data analysis. The basis for calculating the indicators used to measure reforestation success are described in Table A.3. Bivariate analysis was used to identify association between success drivers (independent variables) and success indicators (dependent variables) (see Table A.4 for a full list of drivers included in the analysis). Indicators were also compared against indicators in this analysis. For binary indicators (0 or 1), the Student's t test was used to explore associations with continuous drivers and the Pearson's χ^2 test was used to explore associations with categorical drivers. For continuous indicators, linear regression was used to explore associations with continuous drivers and the Student's t test was used to explore associations with categorical drivers. Drivers found to be significantly associated with indicators in the bivariate analyses ($p < 0.05$) were considered as candidates in stepwise multiple regressions with indicators.

Before conducting stepwise multiple regressions, preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity among the variables. For continuous indicators, standard stepwise multiple linear regression was used. For binary indicators, forward stepwise binary logistic regression was used. Drivers were entered into the stepwise regressions if the significance of their relationship with an indicator was $p < 0.05$ and removed from the stepwise regressions if the significance of their relationship with an indicator became $p \geq 0.10$. Drivers were entered into the stepwise regressions in order of their correlation with an indicator, from most strongly (lowest p value) to least strongly correlated (highest p value) (Brace et al., 2006; Ho, 2006).

A set of significant drivers for each indicator was the result of the stepwise regressions. Relationships among these significant drivers were then tested for using Pearson's correlation. The end result was a set of significant driver-indicator, indicator-indicator and driver-driver relationships that was used to identify a system of relationships that affect reforestation success.

3. Results and discussion

3.1. Reforestation project success

3.1.1. Establishment success

The mean short-term tree survival rate of reforestation projects was quite high (77%) and most projects (86%) meet the 80% tree survival rate required by the Philippines Government for payment under the contract reforestation scheme. It is, however, important to note that survival rates reported in our study were not 'measured' and were simply those 'reported' by key informants. Given that communities were only paid if they achieved survival rates higher than 80%, there may be some natural bias towards reporting rates that met this minimum, hence a reported survival rate greater than the actual rate. It is possible that this bias could have resulted in the failure to identify some additional important drivers affecting the survival of seedlings. However, the survival rates in our study are consistent with previous research carried out by Centre for International Forestry Research (CIFOR) in the Philippines, which reported a short-term tree survival rate for Forest Sector Loan I projects (contract reforestation projects) of 64–68% and for forest sector loan II projects (community based forest management agreement projects) of 71–93% (Chokkalingam et al., 2006).

3.1.2. Forest growth performance

Compared to the actual area planted, most reforestation projects (83.7%) achieved an intact forested area of >70% of the actual planted area, the mean intact forested area being 88% of the actual area planted. Mixed introduced species plantations had the best growth performance, with a significantly higher mean annual increment for Total Volume of 21.3 m^3 ha^{-1} $year^{-1}$ compared to mixed native species plantations (11.6 m^3 ha^{-1} $year^{-1}$) and a higher, but not significantly different, mean annual increment for total volume compared to monoculture plantations (13.9 m^3 ha^{-1} $year^{-1}$). These results are similar to those reported by ERDS (1998), i.e. mean annual increment for total volume of 20–30 m^3 ha^{-1} $year^{-1}$ for well-managed exotic species plantations, ranging from 5 m^3 ha^{-1} $year^{-1}$ in poor sites to 40 m^3 ha^{-1} $year^{-1}$ in good sites.

3.1.3. Environmental success

Overall, mixed introduced species plantations produced the most biomass, with a significantly higher mean annual increment for above ground biomass of 10.9 Mg ha^{-1} $year^{-1}$ of compared to monoculture plantations (6.4 Mg ha^{-1} $year^{-1}$) and a higher, but not significantly different, mean annual increment for above ground biomass compared to mixed native species plantations (6.9 Mg ha^{-1} $year^{-1}$). These results are consistent with Lasco and Pulhin (2003) who reported a mean annual increment for above ground biomass of 9.1 Mg ha^{-1} $year^{-1}$ for tree plantations in the Philippines. Mixed native species plantations were the most diverse, with a significantly higher Simpson's diversity index (0.71) compared to monoculture plantations (0.39) and a higher, but not significantly different, Simpson's diversity index compared to mixed introduced species plantations (0.55).

Nearly 50% of projects reported a decrease in soil erosion and landslide frequency as a result of the project. Mixed species plantations (mixed introduced species and mixed native species) were significantly more likely to report a decrease in soil erosion compared to monoculture plantation ($\chi^2(1, 43) = 5.969$, $p < 0.05$). Mixed species plantations were also significantly more likely to report a decrease in landslide frequency compared to monoculture plantation ($\chi^2(1, 43) = 3.305$, $p < 0.10$), which is consistent with those reported from Indonesia (Nawir et al., 2007).

3.2. Key drivers affecting reforestation project success

3.2.1. Survival rate of trees

Three variables (grazing management applied, weed control applied, and road conditions cause transport problems) were statistically significant in distinguishing between projects that did or did not achieve a short-term tree survival rate of ≥80%. The odds of a project achieving a short-term tree survival rate of ≥80% were improved by about 20 times if grazing management was applied, by about 18 times if weed control was applied, and 12.5 times if road conditions did not cause transport problems (Table 1).

Our results reinforce previous extensive field experience in many situations, which indicates that, apart from the need for good planting stock, the single most important activity influencing establishment success is weed control (Evans, 1982). Weeds compete directly with seedlings for light, soil nutrients, and water and can smother and eventually kill young trees. Weed control must be maintained for at least several years until trees are well established (Lamb and Tomlinson, 1994; Weber and Stoney, 1986). Similarly, livestock grazing is a common cause of reforestation failure, especially in the tropics (Mexal et al., 2008; Zhang et al., 2002).

3.2.2. Actual planted area compared to target area

Five variables (main funding source, integrated production system project economic objective, road conditions to the project site, soil depth, and the short-term tree survival rate) were statistically significant in predicting the actual planted area compared to the target area. The beta weights (Table 1) suggest that the main funding source explained most of the variance, followed by integrated production system project objective, road conditions, soil depth, and short-term tree survival rate.

Interestingly, we found that good road conditions improved both the short-term survival rate of trees, as well as the ability of reforestation projects to meeting their planting area targets. Poor road conditions result in poor access and high transportation costs (Rietbergen-McCracken et al., 2007), making it difficult to reforest sites or properly maintain them. Damage to seedlings during transport may also result from poor road conditions, leading to reduced seedlings survival rates. We found a significant association between road type (sealed vs unsealed) and the occurrence of transport problems caused by road conditions ($\chi^2(1, 43) = 5.044$, $p < 0.05$). Hence sealed roads played an important role in improving tree survival and the ability of reforestation projects to meet their planting area targets. This is not to suggest that only areas with sealed road access should be planted. However, our results do indicate the importance of considering road condition when planning reforestation projects, including how to minimise damage to seedlings when being transported to the site.

We found that funding from government (Fund 101 and Fund 158), an integrated production system project objective (e.g. agroforestry, non-timber forest products, livestock, and fish), sealed roads and short-term survival rate of trees all had significant positive effects on the area of a reforestation site planted compared to the target area. Government-funded projects tended to reforest large areas at low cost per hectare, while projects funded by foreign grants or private investment tended to plant small areas at high cost per hectare (Chokkalingam et al., 2006). This explains why government funded projects in our study were better at meeting their planting area targets because they were able to plant large areas at lower cost. We found that there was a significant difference in funding per hectare for pure government-funded projects (Fund 101 and Fund 158) (PHP 11,609 ± 10,187) versus projects funded by foreign grants or private funding (PHP 41,547 ± 55,098; $t(41) = -2.02$, $p < 0.10$).

Integrated production systems help to increase food security and overcome market instability in forest products, and reforestation experience in the Philippines has shown that projects with economic production objectives provide strong incentives for long-term forest management (Chokkalingam et al., 2006), explaining why projects with integrated production system objectives were better at meeting their planting targets. We found a significant positive relationships between integrated production system project objectives and livelihood activity plan implementation (χ^2 (1, 43) = 16.091, $p < .001$), as well as other drivers of project success, including seedlings sourced from project nurseries ($\chi^2(1, 43) = 5.021$, $p < 0.05$), support for reforestation projects through government policies and regulations ($\chi^2(1, 43) = 10.637$, $p < 0.01$), and other project economic objectives such as food production (($\chi^2(1, 43) = 10.637$, $p < 0.001$), and non-timber forest products (($\chi^2(1, 43) = 10.647$, $p < 0.001$).

Actual planted area compared to target area had a significantly negative relationship with project target area in our study (Pearson correlation coefficient = −0.305, $p < 0.05$). Therefore as project target area increased, projects tended to plant less of their target. We found a significant negative relationship between grazing management and project target area (Pearson correlation coefficient = −0.312, $p < 0.05$), indicating that larger projects tended to have poorer site management, which would affect tree survival rates. We also found that as tree survival improved, reforestation projects were better able to meet their planting targets. Therefore, larger projects with fewer resources per unit area, while able to plant larger areas, may struggle to maintain high survival rates due to poorer site management, reducing their ability to meet planting targets.

Soil depth had a significant negative relationship with project target area (Pearson correlation coefficient = −0.305, $p < 0.05$) and we also found a significant difference in soil depth with rock type (with soils on basalt and metamorphic rock types tending to be deeper than those on limestone) and a significant relationship between rock type and elevation (with basalt and metamorphic rock types tending to be at lower elevations and limestone at higher elevations). This indicates that in our study area, shallower soils tended to occur at higher elevations. Generally, good agricultural land occurs in lowland areas on deeper soils, while sites available for reforestation are located at higher elevations with shallower soils less suited to agriculture. Smaller reforestation projects tend to occur in agricultural areas or are better able to target good sites and this may explain why smaller reforestation projects tended to be on deeper soils.

Table 1
Summary of significant relationships among reforestation success drivers and indicators for reforestation projectson Leyte Island, the Philippines.

Factors	Establishment success		Forest growth success		Environmental success				Socio-economic success			
	Indicator 1	Indicator 2	Indicator 3	Indicator 4	Indicator 5	Indicator 6	Indicator 7	Indicator 8	Indicator 9	Indicator 10	Indicator 11	Indicator 12
Technical/biophysical drivers												
Aspect (0 = northeast & northwest; 1 = southeast & southwest)												7.75^{*}
Climate type (0 = type II; 1 = type IV)				$-.286^{**}$	$-.368^{***}$							
Elevation (0 = '≤ 204m'; 1 = '>204m')				$.325^{***}$	$.273^{**}$							
Soil depth (cm)		$.270^{**}$										
Slope (%)				$-.229^{**}$	$-.268^{**}$							
Rock type (0 = basalt, metamorphic; 1 = limestone)						$-.468^{***}$						
Revegetation method (0 = mixed native species or monoculture; 1 = mixed introduced species)				$.351^{***}$	$.357^{***}$							
Revegetation method (0 = monoculture; 1 = mixed native or mixed introduced species)						$.338^{***}$	80.76^{**}	15.23^{**}				
Seedling source: government nursery (0 = no; 1 = yes)						$.231^{**}$						
Stand age (Years)				$-.235^{**}$	$-.249^{**}$							
Weed control applied (0 = no; 1 = yes)	18.27^{**}											
Grazing management applied (0 = no; 1 = yes)	20.36^{**}											
Socio-economic drivers												
Dependence of local people on forests for subsistence (1 = lowest; 5 = highest)											60.14^{**}	
Municipality classification (1st class – 5th class)										$.47^{**}$		
Number of participants when project issued									$.358^{**}$			
Timber harvested from project site (0 = no; 1 = yes)										8.19^{**}		
Socio-economic incentive: direct payments for planting (0 = no; 1 = yes)									$.350^{**}$			
Socio-economic incentive: profit sharing arrangement (0 = no; 1 = yes)			$.316^{**}$									
Institutional, policy and management driv*ers*												
Education, information or awareness building campaign done (0 = no; 1 = yes)							15.59^{**}	23.47^{**}			23.17^{**}	
Protection mechanism implemented (0 = no; 1 = yes)								34.42^{**}				
Fencing (0 = no; 1 = yes)									$.411^{**}$			
Fire breaks/fine lines (0 = no; 1 = yes)							11.54^{**}					
Project characteristics												
Project economic objective: integrated production system (aquaculture, livelihood) (0 = no; 1 = yes)		$.361^{***}$										
Project economic objective: agroforestry (0 = no; 1 = yes)												13.64^{**}
Main funding source (0 = fund 101, Fund158; 1 = fund 102, Private)		$-.429^{***}$										
Distance from project site to the nearest town (km)			$-.408^{***}$									
Project location (0 = eastern part; 1 = western part)									$-.250^{**}$			
Province (0 = southern Leyte; 1 = Leyte)											437.12^{**}	
Road condition to project site (0 = sealed; 1 = unsealed)		$-.304^{***}$										
Road conditions cause transport problems (0 = no; 1 = yes)	0.08^{*}											
Establishment success indicators												
Short-term survival rate of trees (%)		$.236^{**}$										
Actual planted area compared to target area (%)			$.292^{**}$									
Actual planted area compared to target area (0 = ≤ 50%; 1 = >50%)							72.07^{***}	60.96^{***}				
Environmental success indicators												
Tree density for tress with diameter at breast height ≥ 10 cm (tree stems/ha)				$.236^{**}$	$.196^{*}$							
Tree (diameter at breast height) size diversity: Shannon index						$.433^{***}$						

Socio-economic success indicators												
Number of jobs provided by reforestation project											1.08**	
Increase in market access (0 = no; 1 = yes)											71.43**	
Increase in cash income (0 = no; 1 = yes)												60.61***
Model summary of multiple linear regressions												
Number of observations		43	43	43	43	43			43			
F		10.75	9.15	8.35	10.27	9.26			13.43			
df.		5	3	6	6	4			4			
Sig.		***	***	***	***	***			***			
R-squared		.592	.413	.582	.631	.567			.586			
Adj R-squared		.537	.368	.512	.570	.521			.542			
Model summary of binary logistic regressions												
Number of observations	43						43	43		43	43	43
Omnibus tests of model coefficients												
• χ^2	15.37						34.53	29.27		17.37	36.57	29.39
• *df.*	3						4	4		2	5	3
• Sig.	***						***	***		***	***	***
Hosmer and lemeshow test												
• χ^2	0.76						1.038	1.42		2.64	7.08	.926
• Sig.	.944						.994	.985		.853	.528	.968
Model summary												
• −2 log likelihood	19.38						24.87	30.14		41.66	23.02	30.01
• Cox & Snell R square	.301						.552	.494		.332	.573	.495
• Nagelkerke R square	.542						.737	.659		.442	.764	.661
• Predicted percentage correct (%)	90.7						86.0	83.7		74.4	88.4	83.7

(Indicator 1: short-term survival rate (0 = < 80%), 1 = ≥80%); indicator 2: area planted compared to target area (%); indicator 3: remaining area intact to present compared to planted area (%); indicator 4: mean annual increments for total volume ($m^3\,ha^{-1}\,year^{-1}$); indicator 5: mean annual increments for above ground biomass ($Mg\,ha^{-1}\,year^{-1}$); indicator 6: simpson's diversity index of trees; indicator 7: decrease in soil erosion (after–before project) (0 = no, 1 = yes); indicator 8: decrease in landslide frequency (after–before project) (0 = no, 1 = yes); indicator 9: number of jobs provided by project; indicator 10: increase in market access (after–before project) (0 = no, 1 = yes); indicator 11: increase in cash income (after–before project) (0 = no, 1 = yes); indicator 12: increase in food security (after–before project) (0 = no, 1 = yes); +, −: Positive and negative relationship between drivers and indicators for multiple linear regression models respectively; numbers are standardised coefficients (Beta) for standard stepwise multiple linear regression models or odds ratios Exp(B) for forward stepwise binary logistic regression models).

*** Significant at the 0.01 level (2-tailed).

** Significant at the 0.05 level (2-tailed).

* Significant at the 0.10 level (2-tailed).

3.2.3. Area remaining intact compared to actual planted area

Three variables (distance from project site to the nearest town, profit sharing arrangements, and actual planted area compared to target area) were statistically significant in predicting the forest area remaining intact compared to the actual planted area. The beta weights (Table 1) suggest that the distance from the project site to the nearest town explained most of the variance, followed by profit sharing arrangements and the actual planted area compared to the target area.

The distance from a reforestation site to the nearest town was negatively correlated with the area remaining intact compared to the planted area, meaning that sites closer to a town retained more of the planted trees. This result may be due to site access, with sites closer to town being more accessible and therefore better maintained (Schuren and Snelder, 2008). Good access to a reforestation site is important for tree establishment activities and subsequent management operations such as thinning, pruning and fire protection (FAO, 2002). However, it may also be due to tenure security issues, whereby areas near towns are more secure and it is less likely that trees will be illegally harvested in areas with ready access. In such areas owners can monitor activities and site access better compared to remote areas where there is little regular access and illegal activities can go unnoticed.

The positive relationship between project profit sharing arrangements, and the area of forest remaining intact compared to the planted area, suggests that unless socio-economic incentives are provided to local communities, their involvement is not likely to be sustained and consequently the viability of reforestation projects is reduced (Sayer et al., 2001). Chokkalingam et al. (2006), for instance, found that long-term maintenance of plantations in the Philippines was positively related to planned socio-economic incentives. Our results also show that reforestation projects with profit sharing arrangements had a significantly higher number of participants (38.1 ± 27.0) compared to those without (15.0 ± 15.2); ($t(41) = 3.59$, $p < 0.01$).

The positive relationship between actual area planted and target area could reflect the level of resources available to the project or the commitment of the local community to the project. In other words, well-resourced or committed communities are likely to be able to meet planting targets and retain the trees planted.

3.2.4. Mean annual increments for total volume and above ground biomass

Six variables (revegetation method (mixed introduced species vs monoculture species, mixed native species), elevation, climate type, tree density with diameter at breast height $\geq$10 cm, stand age and slope) were statistically significant in predicting mean annual increments for both total volume and above ground biomass. The beta weights (Table 1) suggest that revegetation method explained most of the variance, followed by elevation, climate type, tree density with diameter at breast height $\geq$10 cm, stand age and slope.

Mixed introduced species plantations performed best for mean annual increments for both total volume and above ground biomass, and may be because of complementarity, facilitation or sampling effects that can occur in multi-species plantations (Le, 2013).

We found a significant positive relationship between the density of trees with diameter at breast height $\geq$10 cm and forest growth. Forest growth is related to tree density; generally growth will be slow in stands that are either too dense or too sparse, and less dense stands will tend to produce larger diameter trees than more dense stands (Binkley et al., 1997). In our study, it appears that stands were not dense enough to inhibit forest growth (the maximum stand density with diameter at breast height $\geq$10 cm being 1740 stems ha^{-1}). The density of trees with diameter at breast height $\geq$10 cm in mixed native species plantations (667 ± 353 stems ha^{-1}) was significantly lower than that of mixed introduced species or monoculture plantations (937 ± 271stems ha^{-1}); ($t(41) = -2.30$, $p < 0.05$), which may partly explain why mixed native species plantations generally had the lowest mean annual increments for both total volume and above ground biomass. However, it is more likely that the mixed native species plantations simply had a higher proportion of slower growing species. In a study of 18 rainforestation sites (of which the one in the current study comprised a subsample), Nguyen et al. (2012) reported that stand productivity was positively correlated with both the proportion of fast growing species and the proportion of exotic species.

We also found that those reforestation projects using seedlings produced according to a quality standard had a significantly higher density of trees with diameter at breast height $\geq$10 cm (1132 ± 371 stems ha^{-1}) compared to projects using seedlings with no quality standard (855 ± 273 stems ha^{-1}); ($t(41) = 2.20$, $p < 0.05$). Hence, using higher quality seedlings may have resulted in either better seedling survival with more trees reaching maturity and/or better growth performance. It is likely that the poorest quality seedlings were planted by smallholders, who have little knowledge of tree nursery systems (Baynes et al., 2011).

Stand age had a significant negative relationship with forest growth in our study area, with older stands having lower mean annual increments for total volume and mean annual increments for above ground biomass compared to younger stands. Tree growth curves are generally S-shaped, with slow accumulation in the early years, increasing as the trees become well established, and reaching a peak before slowing (Gorte, 2009).

We found that climate type, elevation and slope had a significant effect on forest growth. Reforestation projects located in climate type II on the eastern side of the study area (no dry season and pronounced maximum rainfall from November to January) had significantly higher mean annual increments for total volume and mean annual increments for above ground biomass compared to projects located in climate type IV on the western side of the study area (short dry season from February to May with even rainfall across the rest of the year). Forest growth had a significantly negative relationship with slope, meaning that projects on flatter land had better growth. Slope affects run-off, soil water infiltration and evapotranspiration, hence flatter parts of the landscape tend to hold water better, facilitating tree growth. From previous research, elevation usually has a significant negative effect on forest growth, meaning that forests tend to have better growth at lower altitudes (Coomes and Allen, 2007). However, we found that elevation had a significant positive effect on growth in our study area, with reforestation projects located >204 m elevation having significantly higher growth compared to those located $\leq$204 m elevation. Most mixed native species plantations were located $\leq$204 m while most monoculture and mixed introduced species plantations were located >204 m in our study area, and the difference in elevation between monoculture or mixed introduced species plantations (247.3 ± 166.2 m) and mixed native species plantations (136.5 ± 105.5 m) was significant ($t(41) = 1.69$, $p < 0.10$). Mixed native species plantations had significantly lower growth compared to mixed introduced species and monoculture plantations; hence the influence of elevation on forest growth in our study area was due to differences in plantation types at high and low elevations.

3.2.5. Tree species diversity

Four variables were statistically significant in predicting tree species diversity measured by the Simpson's diversity index. The beta weights (Table 1) suggest that rock type explained most of the variance, followed by tree diameter at breast height size diversity, revegetation method, and seedlings sourced from government nursery.

The unexpectedly high influence that rock type had on tree species diversity is likely to be planting preferences rather than any particular direct or indirect influence of rock type on diversity. Rock type had a significant relationship with elevation ((χ^2(1, 43) = 6.435, $p < 0.05$)), with basalt occurring a lower and limestone at higher elevations, and mixed native species plantations were preferentially planted at lower elevations on agricultural land, while mixed introduced species and monoculture plantation were planted at higher elevations. Hence, plantations with the highest tree species diversity (mixed native species) were planted in lowland agricultural areas where basaltic soils are dominant and this explains why rock type was related to tree species diversity in our study area.

We also found a significant relationship between tree species diversity and tree diameter at breast height size diversity, however the interaction between species diversity and size diversity in not clear. While previous authors have stated that stand structure can influence tree species diversity (Terradas et al., 2004), presumably by providing a more diverse habitat suited to more species, tree species diversity can also influence size diversity because different tree species have different growth rates. In our study area it is likely that tree species diversity and tree size diversity are mutually reinforcing, with plantations established using higher species diversity also having higher size diversity, and higher size diversity in turn supporting higher species diversity by providing more diversity habitat, which may also attract animals that recruit new species by dispersing seed. We found that reforestation projects with surrounding native forest had significantly higher diameter at breast height size diversity (1.20 ± 0.21) compared to those without surrounding native forests (1.04 ± 0.14) ($t(41) = 2.81$, $p < 0.01$), which may indicate more recruitment in those reforestation sites close to native forest. As would be expected, mixed species plantations had the greatest tree species diversity.

Seedling source had a significant influence on tree species diversity of reforestation sites within our study area, with projects sourcing their seedlings from government nurseries having higher diversity than those sourcing seedlings from private or project nurseries. Previous research in Leyte has found that government nurseries tend to stock a more diverse range of tree species compared to private nurseries (Gregorio et al., 2008). In addition, community based forest management agreement projects tend to source their tree seedlings from government nurseries and also tend to reforest using mixed species plantations while plantations on private tree farms are usually monocultures and source their seedlings from private nurseries or produce their own.

3.2.6. Soil erosion and landslide frequency

Four variables (revegetation method (mixed species vs monoculture), fire breaks, education and awareness campaigns, and actual planted area compared to target area ($\leq$50% vs >50%)) were statistically significant in distinguishing between projects that did or did not reduce soil erosion. The odds of a project reducing soil erosion increased by 81 times if the revegetation method was mixed species (either mixed introduced species or mixed native species), by 72 times if the actual planted area was more than 50% of the target area, by 16 times if education, information or awareness building campaigns were implemented, and by 10 times if fire breaks were established (Table 1).

Four variables (actual planted area compared to target area ($\leq$50% vs >50%), protection mechanism implemented, education and awareness campaigns, and revegetation method (mixed species vs monoculture)) were statistically significant in distinguishing between projects that did or did not reduce landslide frequency. The odds of a project reducing landslide frequency increased by 60 times if actual planted area was more than 50% of the target area, by 34 times if protection mechanisms (such as fire breaks) were implemented, by 23 times if education, information or awareness building campaigns were implemented, and by 15 times if the revegetation method was mixed species (either mixed introduced species or mixed native species) (Table 1).

The effect of tree cover on hill-slope stability is well documented (Greenway, 1987; Sidle et al., 2006a, 1985). Forests play an important role in averting erosion and landslides during less extreme weather events, however deep landslides resulting from continuous heavy rainfall or earthquakes are unlikely to be prevented by forests (Hamilton, 2008). Deep-rooted trees and shrubs strengthen shallow soil layers, improve drainage, and reduce soil water through transpiration, thereby reducing landslide risk (Dolidon et al., 2009; FAO et al., 2012). However, revegetation and management practices can also exacerbate soil erosion and shallow landslides depending on the type of activities involved, and plantations with little ground cover and litter can have high surface runoff and soil erosion (Sidle et al., 2006b). We found that where reforestation projects were able to plant more of their target area, reported erosion and landslide frequency was reduced. Previous research has found that there may be a strong non-linear relationship between reforestation area and erosion and landslide occurrence, with reforestation of small carefully targeted parts of a catchment producing a disproportionately large reduction in landslide occurrence and sediment yield (Reid and Page, 2003). Hence, the site where reforestation is done may be more important to protecting an area against erosion and landslide than the total area planted to forest.

We found that mixed species plantations (either mixed introduced species or mixed native species) had a significant effect on reducing reported soil erosion and landslide frequency in our study area. Mixed species plantations can produce more litter and have higher canopy cover than monocultures (Le, 2013), which can result in greater protection against soil erosion. Soil stability depends not only on above-ground but also the below-ground structure of plant communities and the diversity of root growth forms. Mixed species plantations, having higher root form diversity, can therefore provide better protection against soil erosion in extreme weather events (Beierkuhnlein and Jentsch, 2005).

Reforestation education, information or awareness building campaigns also had a significant effect on reported soil erosion and landslide frequency in our study area. It is not clear why this would be the case; however these campaigns provide technical assistance that can lead to better forest management and selection of appropriate tree species. These campaigns also provide market information, and marketing support for timber and other forest products that can help to increase the cash income of farmers, which in turn can lead to better site management and protection, and reduced erosion and landslide risk. We found that the implementation of forest protection mechanisms (such as fencing, patrolling, fire breaks; watch towers) significantly reduced reported soil erosion and landslide frequency. These protection mechanisms reduce threats to the survival and growth of trees (such as grazing, illegal tree harvesting, fire, diseases and pests) (Zhang et al., 2002) and therefore erosion and landslide risk. Fire is one of the biggest causes of forest degradation in the Philippines and caused 72.86% of forest loss between 1980 and 2001 (Rebugio et al., 2007). Leyte has previously experienced severe forest fires, especially during El Niño periods (Mangaoang and Harrison, 2003), hence fire protect mechanisms are particularly important.

3.2.7. Jobs

Four variables were statistically significant in predicting the number of jobs provided by a reforestation project. The beta weights (Table 1) suggest that fencing explained most of the variance; followed by the number of participants when the project was issued, direct payments for planting and project location.

Fencing resulted in more jobs, presumably due to the higher labour requirement of establishing and maintaining fences. Also, more local participants generally means a larger project scale and a higher diversity of job opportunities, such as tree seedling production, contract tree planting, site maintenance and protection, timber harvesting and wood product processing. Seedling production can be labour-intensive and generate many local jobs. For example, in the Philippines, the total working time spent to fully establish a forest plantation is 204 person-days per hectare over three years. Of this total, 83 days, or 41% is due to seedling nursery operations (Ramirez et al., 1993).

While employment is regarded as one of the most important social benefits of reforestation, plantations may not provide sufficient incentive for rural people to participant in reforestation if alternative land uses present better labour opportunities (Niskanen et al., 1996). Hence direct payments for planting trees are often needed to guarantee local participation in reforestation activities and to retain participation over time Dalfelt (1996). We found that direct payments for planting had a significant positive effect on the number people employed by reforestation projects in our study area, presumably due to increased participation.

Project location (Eastern vs Western Leyte) had a significant relationship with the number of jobs provided by reforestation projects in our study area, however the reasons for this are not obvious. We found no significant difference in the distance to the nearest town, size of projects, the number of participants, direct payments for planting, or fencing between projects located in Eastern and Western Leyte. However, we did find a significant difference in the type of roads (Sealed or Unsealed) and the problems cause by road conditions (Pearson Correlation = 0.259, $p < 0.10$ and 0.268, $p < 0.10$ respectively), with projects located in Eastern Leyte more likely to have access by sealed roads and less transport problems caused by road conditions. This may explain why projects located in Eastern Leyte generated more jobs because access to labour was improved by good road conditions.

3.2.8. Market access

Two variables were statistically significant in distinguishing between projects that did or did not increase market access. The odds of a project improving market access increased by 8 times if timber was harvested from the project site, and by 2 times if the project municipality class improved by one class (for example from class 5 to class 4) (Table 1). Municipalities in the Philippines are divided into classes according to their average annual income during the last three calendar years. Projects located within higher income municipalities were more likely to report an increase in market access as a result of reforestation projects. In addition, municipality classification had a significant negative correlation with the dependency of local people on forests for subsistence (Pearson Correlation = −0.312, $p < 0.05$), meaning that people living in low income municipalities were more dependent on forests. This highlights the ability of reforestation projects to open up markets to the rural poor and was particularly true in our study area when timber was harvested from the project site. Timber harvesting was also strongly associated with those projects that had a timber production economic objective (($\chi^2(1, 43) = 11.30$, $p < 0.001$)).

3.2.9. Cash income

We found that the dependence of local people on forests for subsistence, education and awareness campaigns, province, number of jobs provided by the reforestation project, and increase in market access resulting from the reforestation project, all had significant relationships with reported increases in cash income for local communities (Table 1). These findings generally make sense as those projects providing more jobs, facilitating market access, and involving people who are dependent of reforests for subsistence, would be expected to increase the case income of local people. Education and awareness campaigns also provide technical assistance to projects, such as selecting the right species, market information and marketing support for forest products, and this can help projects to increase their income generation potential.

Projects located in Leyte as opposed to Southern Leyte province were significantly more likely to report increases in cash income from reforestation projects. The influence of province on income is not obvious but can be explained by looking at provincial differences. Projects in Leyte province were generally located in higher income class municipalities and reported significantly less transport problems due to better road conditions. Projects in Leyte province also reported significantly more improvements in market access resulting from reforestation projects and were more likely to harvest timber from project sites. All of these conditions favour income generation.

3.2.10. Food security

The odds of a project improving food security increased by 61 times if a project increased cash income, by 14 times if a project included an agroforestry economic objective, and by 8 times if a project site had a southeast or southwest aspect (Table 1). The influence of agroforestry on food security makes sense since agroforestry incorporates food production with tree growing and is designed to maintain food production where trees are planted on small-scale farms or in areas with limited agricultural land. Agroforestry can also increase economic and biological diversity, which in turn can reduce the income risk of communities (Henderson, 1991) and improve agricultural productivity (Mansourian et al., 2005). Improvements in cash income allow communities to purchase food when subsistence food production falls short of food needs or when crops fail or are damaged. This in turn improves food security.

The influence of aspect on food security in our study area is unclear and could either be due to a climatic affect favouring plant growth (Yang et al., 2006), though this is less likely in tropical countries such as the Philippines, a protection affect from wind or fire (Bennett et al., 2010), or a cultural affect where food is preferentially grown on south facing slopes. We found no significant relationships between aspect and other drivers of reforestation success that would explain why food security was influenced by aspect.

3.3. Relationships among reforestation success drivers and between success drivers and indicators

Correlation tests among the reforestation success drivers revealed 21 drivers had significant relationships with other drivers, with 10 of these having relationships with more than one other driver (Table A.5). Province had significant relationships with four other drivers. Rock type and main funding source were significantly related to three other drivers, while elevation, revegetation method, weed control, grazing management, direct payments for planting and roads conditions were significantly related to two other drivers. There were 9 drivers that were only related to indicators and no other drivers (these are not shown in Table A.5 but are included in Fig. 3).

The overall pattern of significant relationships among reforestation project success drivers and indicators in our study area reveals a highly interconnected system (Fig. 3). Revegetation method (mixed species vs monocultures), funding source, education and awareness campaigns, the dependence of local people of forests, reforestation incentives (such as payments for planting and profit sharing arrangements), project objectives

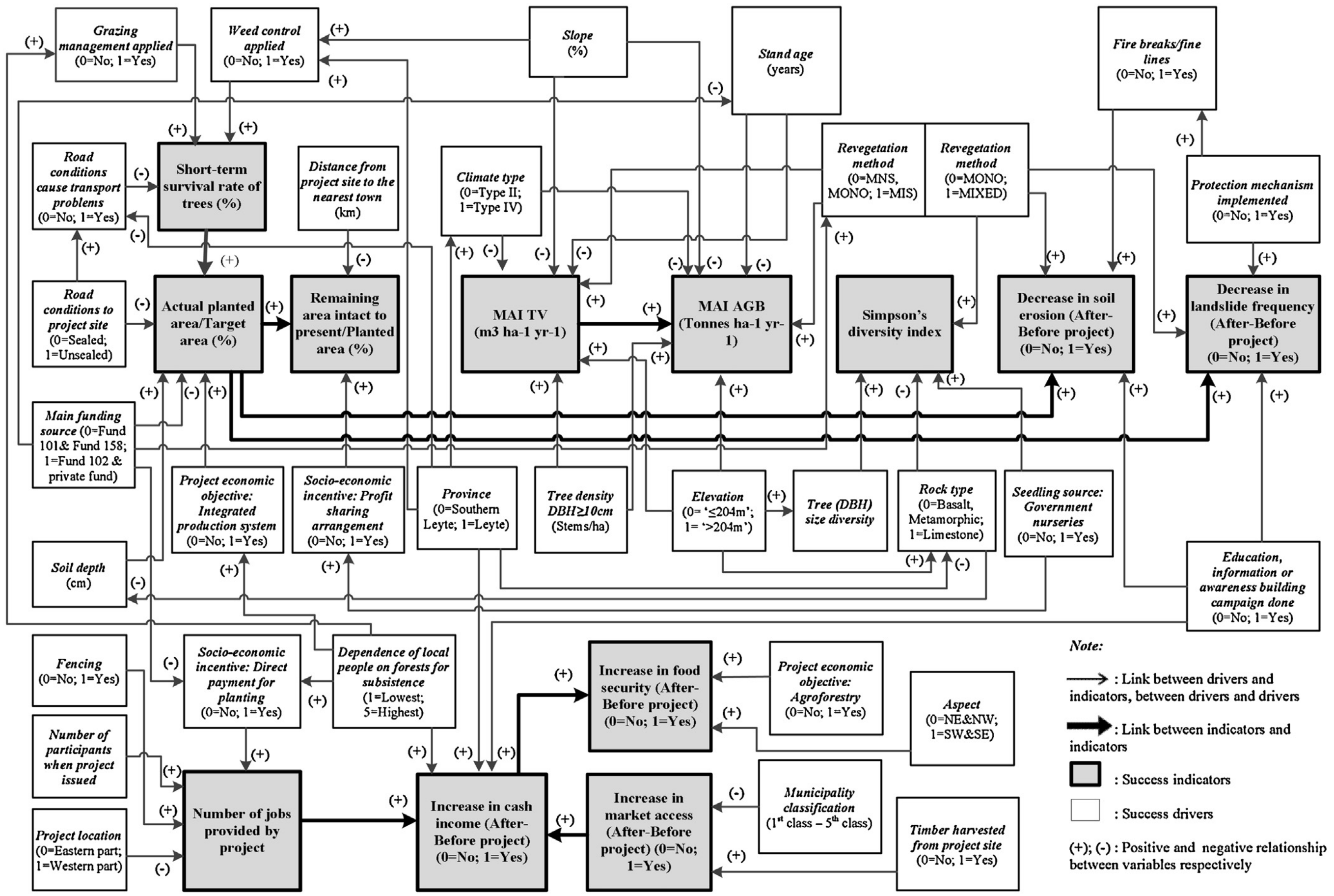

Fig. 3. System of significant relationships among success drivers and indicators for reforestation projects conducted on Leyte Island, the Philippines (MONO, monoculture species plantation; MIS, mixed introduced species plantation; MNS, mixed native species plantation; MIXED, mixed native or introduced species plantation; MAI AGB, mean annual increment of above ground biomass; MAI TV, mean annual increment of total volume; DBH, diameter at breast height; NE, northeast; NW, northwest; SW, southwest, SE, southeast).

(such as integrated production systems, agroforestry and timber production), forest protection mechanisms (such as fire, weed and grazing control) and the condition of road infrastructure are among the most highly connected drivers, influencing many success indicators either directly or indirectly. The success indicators themselves are also connected, with significant relationships between establishment and environmental success indicators, between growth performance indicators and between socio-economic success indicators.

3.4. Implications for reforestation planning and management

Our analysis revealed a complex and highly interconnected system (Fig. 3). The complex system of relationships that exists among reforestation success drivers and indicators means that relying on indicators in isolation to measure success runs the risk of focusing on the symptoms of poor performance rather than the underlying causes. Understanding reforestation success as a system allows policy makers to identify points of leverage where change can have broad systemic affect. It also allows policy makers to identify the potential unintended consequences of well-intentioned policies.

We have attempted to identify empirically significant relationships among drivers and indicators of reforestation success in our study area, and in general found that revegetation method, funding source, education and awareness campaigns, the dependence of local people of forests, reforestation incentives, project objectives, forest protection mechanisms and the condition of road infrastructure are policy areas that are likely to have a broad systemic effect on success. The next step will be to build a policy assessment model to allow for sensitivity, scenario and trade-off analysis so that policy combinations that maximise benefits and minimise potential unintended consequences can be identified. However in developing a policy assessment model it is important to recognise some of the limitations of our results. First, our understanding of the driver/indicator relationships only extends to those variables for which we could collect data and we know that the actual system contains many soft variables that are difficult to measure but are important to system functioning. Second, the reasons for significant relationships between drivers and indicators may not be obvious and our results do not necessarily fully explain why variables are related. Third, our system representation does not contain feedback loops, which are present in all systems, so cannot be used to simulate continuous dynamic behaviour over time. Given these limitations, we recommend that policy makers pay particular attention to the following when designing reforestation programs.

3.4.1. Revegetation method

The success of reforestation efforts strongly depends on species that can fulfil the demands of local people and the ability of the forest to support local livelihoods (Günter et al., 2009; Weyerhaeuser et al., 2005) and well as the ability of the forest to provide environmental benefits. We found that mixed-species plantations containing productive marketable species can improve forest growth performance (mean annual increments for total volume and above ground biomass) and provide environmental benefits (tree diversity, decrease in soil erosion and landslide frequency). The improved growth performance can have direct socio-economic benefits by improving the livelihood prospects of local people.

3.4.2. Socioeconomic incentives

It is important to secure the long-term commitment of local communities to reforestation. One way to secure community commitment is to design incentive mechanisms that to share the costs and benefits of reforestation equitably. Some of the more successful reforestation programmes in the tropics have occurred when national governments have made serious and prolonged effort over a number of years to providing incentives in the form of payment for plantings, profit sharing arrangements, financial loans, micro-financing, subsidies, taxation changes and forest product marketing advice (Nawir et al., 2007).

3.4.3. Forest protection mechanisms

The main agents of forest lost and degradation in the tropics are fire, weeds and grazing (Lamb, 2005). Successful reforestation is impossible if these agents and their underlying causes are not dealt with effectively. Therefore, before any reforestation project starts, it is important to have a process in place to identify potential forest disturbances and have mechanisms in place to mitigate them, which may require coordination with local authorities and good law enforcement (Nawir et al., 2007).

3.4.4. Sustainable livelihoods

In developing countries like the Philippine where there a large numbers of poor rural people, it would a misconception to think of reforestation as successful in the long term if it did not improve livelihoods. Both short and long-term income generating opportunities are essential to the long term success of reforestation and this can be achieved a combination of integrated production systems (agroforestry, non-timber forest products, livestock and fish farming) as well as timber production.

3.4.5. Diversification of funding and partnerships

Funding inadequacy and discontinuity are major threats to reforestation success. In most developing countries, governments do not have the capacity to completely fund reforestation and forest management. Hence funding partnerships are critically important to the success of reforestation projects, including partnerships with corporations, private owners, research institutions, and non-governmental organisations. Many developing countries (such as Laos, Nepal, Vietnam, Kenya, Mozambique and Tanzania) are also moving towards local level forest management and shared forest management authority and responsibility, as well as shared costs and benefits between the state and local people (Luukkanen et al., 2006).

3.4.6. Technical support

Education, information or awareness building campaigns that provide technical assistance and training are key to reforestation success, particularly those project involving community-based forest management (Borlagdan et al., 2001). Besides technical assistance and training, government and nongovernment agencies can play a critical role in providing marketing support for products generated by reforestation. Community-based market information systems, selecting species based on markets, incentives to processing firms to obtain wood from reforested areas, forming marketing associations and forest certification have all been suggested as means to improve marketing (Austria, 1995; Calderon and Nawir, 2006; Hartanto et al., 2002).

3.4.7. Infrastructure development

The improvement of infrastructure, such as roads, as part of reforestation programs is important to success, particular where reforestation sites are isolated and the improved infrastructure can assist communities to reliably access reforestation inputs and product markets. Infrastructure development is very expensive and not all projects are able to fulfil fund it, therefore lower-cost options for infrastructure improvement are vital.

4. Conclusion

A wide range of biophysical, socio-economic, institutional and management factors influence reforestation success and these factors form a complex system of relationships. Therefore, focusing on performance indicators alone will not improve our understanding of why reforestation projects succeed or fail. We must look at reforestation as a system and understand how success drivers and indicators interact so that policies can be formulated that have broad systemic benefit and avoid unintended negative consequences. Many of the success drivers and indicators were connected in predictable ways but in other cases there were unexpected connections. For instance, initial survival rates were not only strongly influenced by weed and grazing control (as expected) but also road condition (unexpected). In addition, a number of indicators were affected by both biophysical and socio-economic drivers, indicating that social and economic components of reforestation must be considered simultaneously.

Based on our analysis we found that revegetation method, funding source, education and awareness campaigns, the dependence of local people on forest and road conditions were among the most highly connected drivers of reforestation success, influencing multiple success indicators directly and indirectly. We also found that the success indicators themselves were connected, with significant relationships between establishment and environmental success indicators, between growth performance indicators and between socio-economic success indicators. Based on these relationships, we conclude that policies targeting revegetation methods (particularly those that encourage mixed species plantations that incorporate productive and marketable species), socio-economic incentives (such as payment for plantings and profit sharing arrangements), forest protection mechanisms (such as fire, weed and grazing control with associated law enforcement), sustainable livelihoods (by using integrated production systems that incorporate agroforestry, non-timber as well as timber forest products), diversification of funding and partnerships (such as partnerships between local communities, government, corporations and non-governmental organisations), technical support (such as marketing support, species selection and forest management training and advice), and infrastructure development (such as improving road conditions) are likely to have a broad systemic and beneficial effect on reforestation success in tropical developing countries.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.plantsci.2004.08.011.

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