

SETBACKS AND SURPRISES

Have mangrove restoration projects worked? An in-depth study in Sri Lanka

Kodikara Arachchilage Sunanda Kodikara^{1,2,3}, Nibedita Mukherjee^{4,5}, Loku Pullukuttige Jayatissa¹, Farid Dahdouh-Guebas^{2,5}, Nico Koedam²

This study investigated the effectiveness of mangrove planting initiatives in Sri Lanka. All the lagoons and estuaries in Sri Lanka were included in the study. We documented all agencies and locations, involved in mangrove planting efforts, along with the major drivers of these planting initiatives, their extents, and the possible causes of the success or failure of planting. An adapted three-step framework and a field survey consisting of vegetation and soil surveys and questionnaires were used to evaluate the objectives. We found that about 1,000–1,200 ha of mangroves, representing 23 project sites with 67 planting efforts, have been under restoration with the participation of several governmental and nongovernmental organizations. However, about 200–220 ha showed successful mangrove restoration. Nine out of 23 project sites (i.e. 36/67 planting efforts) showed no surviving plants. The level of survival of the restoration project sites ranged from 0 to 78% and only three sites, that is, Kalpitiya, Pambala, and Negombo, showed a level of survival higher than 50%. Survival rates were significantly correlated with post-care. Planting mangrove seedlings at the incorrect topography often entails inappropriate soil conditions for mangroves. Survival rates showed significant correlations with a range of soil parameters except soil pH. Disturbance and stress caused by cattle trampling, browsing, algal accumulation, and insect attacks, factors that may themselves relate to choosing sites with inappropriate topography and hydrology, were common to most sites. The findings are a stark illustration of the frequent mismatch between the purported aims of restoration initiatives and the realities on the ground.

Key words: climate zones, field survey, Indian Ocean tsunami, level of survival, mangrove restoration, Sri Lanka

Implications for Practice

- This study can be used as a guide because this gives information on the key factors which govern the success or failure of mangrove restoration attempts.
- Findings of the study hold a key to identify the precious resources that need to be invested in enhancing probability of planting success.
- Establishing a national center with relevant expertise would help to coordinate and monitor mangrove restoration projects and could provide advice and support to help achieve greater success.

Introduction

Mangrove ecosystems are primarily tropical, subtropical, and warm temperate (30°N to 37°S) coastal wetlands occurring in 123 countries (Feller et al. 2010; Spalding et al. 2010; Mukherjee et al. 2015). They are among the most productive ecosystems per unit area, and are exceptionally powerful carbon sinks, which can store in excess of 1,500 mg carbon/ha (Donato et al. 2011; Gress et al. 2016). In addition, mangroves continue to be widely used by coastal communities (e.g. for livelihood like food, fuel, subsistence, shelter, and tourism) throughout most of their geographic distribution (Walters et al. 2008; Lee et al. 2014; Mukherjee et al. 2014).

In spite of their ecological and socioeconomic importance, mangrove conservation has not been able to match the rate of mangrove destruction and loss (Duke et al. 2007; Polidoro et al. 2010; Richards & Friess 2016). In the last few decades, mangrove loss has been an issue of growing concern, with several authors urging stronger measures to stem this loss (Valiela et al. 2001; Duke et al. 2007; Giri et al. 2011).

Although calls for restoration and conservation of mangroves are not new and date back at least to the 1970s (Teas 1977), the effect of mangrove loss on coastal protection was most widely

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¹Department of Botany, University of Ruhuna, Wellamadama, Matara 81000, Sri Lanka

²Laboratory of Plant Biology and Nature Management, Ecology and Biodiversity, Vrije Universiteit Brussel – VUB, Pleinlaan 2, B-1050 Brussels, Belgium

³Address correspondence to Kodikara Arachchilage Sunanda Kodikara, email: sunandaruh@gmail.com

⁴Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge CB23EJ, U.K.

⁵Laboratory of Systems Ecology and Resource Management, Department of Organism Biology, Faculty of Sciences, Université Libre de Bruxelles – ULB, Av. F.D. Roosevelt 50, CPI 264/1, B-1050 Brussels, Belgium

noted recently after several cyclonic and tsunami events in South and Southeast Asia (e.g. Cyclone Haiyan in November 2013, Cyclone Aila in May 2009, and the Indian Ocean tsunami in December 2004). The Indian Ocean tsunami formed a watershed in this context due to its massive effect on human lives and property and the range of initiatives for mangrove restoration which were launched as a consequence (Mukherjee et al. 2015). Projects of mangrove restoration that had already been launched in some nations since the 1950s (e.g. China, India) or 1960s (e.g. Bangladesh) (FAO 2007) gained momentum after the Indian Ocean tsunami and were replicated in several nations across the South Asian region after 2004 (ITTO/ISME 2008). For the sake of clarity, we will use the word “restoration” irrespective of previous existence of mangroves in particular sites, because the planting efforts usually claim that objective.

Given the considerable amount of funding and international attention that mangrove restoration projects have received over the last decade (Primavera & Esteban 2008; Biswas et al. 2009; Mukherjee et al. 2009), it is critical to evaluate the success (or failure) of restoration interventions (Ellison 2000) for three main reasons: (1) to document what proportion of planting projects have led to establishment success of mature mangrove stands; (2) to understand the restoration of ecosystem functions in restored planted sites; and (3) to serve as a guideline for mangrove restoration projects in the future. Evaluating the success of mangrove restoration projects is also critical from a financial and risk-assessment perspective as human lives may depend on the coastal protection claimed to be offered by these planting initiatives.

In this article, we investigate the effectiveness of mangrove restoration initiatives in Sri Lanka, which have almost all taken place in the wake of the 2004 Indian Ocean tsunami. Survival of planted seedlings for at least 5 years was used as the indicator for success in this study. This criterion was used for *Rhizophora mucronata* in studies that were carried out in Sri Lanka by Ranasinghe (2012). Sri Lanka is an important study area to analyze restoration success rates for the following reasons: (1) Sri Lanka was severely affected by the 2004 tsunami. This was followed by substantial investment, that is, about 13 million USD, for planting of mangroves over the past decade (IUCN 2009). (2) Compared to other tsunami-affected nations in South Asia, there has been considerable research on mangroves in Sri Lanka. This provided a baseline for this study (Pinto 1986; Amarasinghe 1996; Dahdouh-Guebas et al. 2002, 2005; Dahdouh-Guebas 2006; Jayatissa et al. 2002; Kodikara & Jayatissa 2010; Dissanayake et al. 2014; Madarasinghe et al. 2015, 2016). (3) The geographical extent of Sri Lanka is conducive for an in-depth nation-wide survey of restoration projects. Several studies on mangrove restoration and success have been reported in Sri Lanka (IUCN 2011; Ratnayake et al. 2012). However, only three to four planting sites were considered and no detailed data on total planting initiatives, the planted extent, the total surviving area, planting agencies involved, and major drivers were included. Therefore, we believe that the causes for the failure and recommendations that have been given are not strong enough when extrapolating to country level. Further, several similar investigations on the failure of mangrove

planting after the 2004 tsunami have been reported in different countries, such as in Aceh, Indonesia, Philippines, and Thailand in Asia, and in non-tsunami-affected countries like Brazil and the United States. In these studies, different aspects of mangrove restoration, e.g. topography of mangrove planting (Primavera & Esteban 2008; Samson & Rollon 2008), causes for mangrove restoration failure (Samson & Rollon 2008; Brown et al. 2014a, 2014b), technical guidance, that is, Ecological Mangrove Restoration/Rehabilitation (EMR) methodology (Lewis 2005) and recommendations (Lewis 2000, 2005; Primavera & Esteban 2008; Lewis & Brown 2014; Asaeda et al. 2016), and socioeconomic aspects of mangrove restoration (Stevenson et al. 1999) have been discussed. Therefore, we intended to carry out our study to provide an extensive, country-wide investigation of the many dimensions of mangrove planting (e.g. agencies, the locations, the extent, etc.), the major drivers of these planting projects, and the success or failure of the planting projects as that gives higher validation for mangrove planting on the country level.

Hence the key objectives of this study were to: (1) document, the locations, the extent, and the number of mangrove planting initiatives along the Sri Lankan coastline along with the agencies involved; (2) calculate the rate of survival of seedlings in these planting projects (as a measure of success of planting effort); and (3) identify the drivers of these planting projects. In addition, attention must be paid to soil conditions since according to previous studies, mangrove plants are frequently subjected to poor soil conditions as the result of planting at unsuitable topographical positions (Field 1996; Elster 2000; Lewis 2000, 2005; Samson & Rollon 2008; Brown et al. 2014a). Therefore, investigating the causes of success or failure of planting initiatives, including soil parameters in planting sites, was also included as one of the objectives.

Methods

Study Site

Sri Lanka is located in the Indian Ocean between 05°55' and 09°51'N latitude, and 079°41' and 081°53'E longitude. It has an area of approximately 65,610 km² with a coastline of about 1,620 km. The country is divided into four major climatic zones, namely wet, dry, intermediate, and arid zones (Pemadasa 1996). The wet zone is mainly confined to the southwestern region, and the dry zone to the northern and the eastern parts of the country. These two zones are separated by the intermediate zone. The arid zone on the other hand is found in the northwestern and the southern parts of the country and climatic conditions are very different in the climatic zones (Table 1). According to CZMP (2003), 5,009 ha of mangrove cover is found in the dry and arid zones, 644 ha in the intermediate zone, and 430 ha in the wet zone. However, mangrove cover between 1983 and 2003 was reduced by about 2,450 ha in the dry and arid zones (CZMP 2003).

Framework for Evaluation

To address our objectives, we used an adapted version of the framework given by Mukherjee et al. (2015) (Fig. 1).

Table 1. Climate data and distribution of true mangrove and associate species with respect to different climate zones. (Sources: Department of Meteorology (DM 2015), Sri Lanka; Jayatissa et al. (2002); CZMP 2003; G.B.M. Ransara, personal communication.)

<i>Climate Zone</i>	<i>Mean Annual Rainfall (mm)</i>	<i>Average Annual Temperature (°C)</i>	<i>Tidal Amplitude (m)</i>	<i>Average Salinity (ppt)</i>	<i>True Mangrove Species</i>	<i>Mangrove Associates</i>
Dry	<1,750	31.5	0.4–0.6	13.8 ± 0.7	11	12
Wet	>2,500	28.5	0.5	5.0 ± 2.5	10	14
Intermediate	1,750–2,500	30.0	0.5	5.6 ± 0.4	16	14
Arid	<1,250	32.5	0.4–0.6	13.2 ± 1.9	11	12

This framework consists of three parts, namely ecological (e.g. species planted), social (e.g. drivers of planting initiatives), and economic (e.g. funding agency of the intervention). Although there is a plethora of frameworks currently available in the literature (e.g. Costanza et al. 1997; Balmford et al. 2002), we chose this framework owing to its ecocentric as opposed to an anthropocentric approach (sensu Binder et al. 2013).

Questionnaire Survey

Using the above three-step framework, a preliminary field survey and interviews, we designed a questionnaire to evaluate mangrove restoration planting in Sri Lanka (Appendix S1, Supporting Information). The survey was conducted between October 2012 and February 2014. The key stakeholders were identified through a combination of methods: expert knowledge elicitation and preliminary field survey that was carried out before October 2012. We used the snowball sampling technique (Atkinson & Flint 2001) to identify further resource persons engaged in mangrove planting. In total, 105 people including 16 community leaders participated in the survey. Site-specific data on the planting agencies, planting objectives, age of planted trees, and major disturbances that occurred before and current experiences, technical guidance and post-planting monitoring schemes were collected through the questionnaire. In addition, data from the questionnaire were cross-checked with the secondary literature on restoration planting through an online search on government and donor agency websites and field surveys.

Field Survey

All brackish water body complexes including lagoons and estuaries along the Sri Lankan coastline (1,620 km) that have been described (Ranasinghe 2012) were surveyed between 2012 and February 2014 in order to evaluate the survival of planted seedlings.

Vegetation Survey. The degree of survival was estimated in two ways. When the number of seedlings in planting sites was around 200 or less and sparsely distributed (nonhomogeneous), they were counted individually. If there were more than 200 plants, at least three vegetation plots of 20 × 20 m² were monitored. Three more representative plots were used for the monitoring when the total area of the planting site exceeded about 0.5 ha. Survival was recorded and afterwards the findings were

extrapolated to the total area of mangrove seedlings, saplings, or shrubs. The number of mangrove species used in restoration, major detectable stress factors, disturbances, and status of post-planting monitoring were recorded. The current total surviving planted area was calculated only using those sites where survival was greater than 50%. For the rest, due to poor survival, surviving plants were scattered sparsely and it was not possible to estimate the area covered.

In addition, the state and morphology of seedlings, saplings, and shrubs was inspected visually for signs of departure from normal leaves (leaf yellowing, browning, wilting, dwarf growth, deformation, and biotic invasion, e.g. insect attacks). Above a 50% threshold of signs of seedling damage (per seedling), seedlings were considered “dead” (Fig. 2). These results were aggregated at the site level based on the dead/alive criterion. The map that shows the mangrove planting project sites was created with Arc GIS 10.1 software.

Soil Survey. Soil pH and redox potential were measured with a Multimeter (18.52.01. Eijkelkamp). The pH was measured at 30 cm depth for the seedlings/saplings and 50 cm depth for the shrubs of the project sites established beyond the intertidal zone by direct insertion of a glass electrode through a wide-enough hole into the soil. Redox potential was also measured at 30 and 50 cm depth by immediate insertion of the electrode through a hole made by using a hollow PVC (polyvinyl chloride) pipe, into the soil. When the planting had been done in the intertidal area, readings of soil slurries that were collected at 30 and 50 cm using scale-up PVC pipe were taken during the exposure of the soils at low tides. We used a plastic pipe to collect soil samples under submerged conditions. Soil bulk density (SBD) was measured using three-inch diameter ring-drive method. A three-inch diameter ring (7.62 cm), beveled edge down, was driven into the soil to a depth of 8 cm by using a hand sledge. Three samples from each site were collected. Soil samples were weighed and each sample was taken into a known-weight ceramic crucible and it was dried until a constant weight was obtained by the oven-drying method (temperature = 80°C) until stable weight. SBD (g/cm³) was calculated using the following Equation 1 (NRCS, Department of Agriculture, U.S.A., 2014). The average value of three soil samples was obtained for each site.

$$\text{SBD} = \frac{\text{oven dry weight of soil}}{\text{volume of soil of 7.62 cm diameter ring}} \quad (1)$$

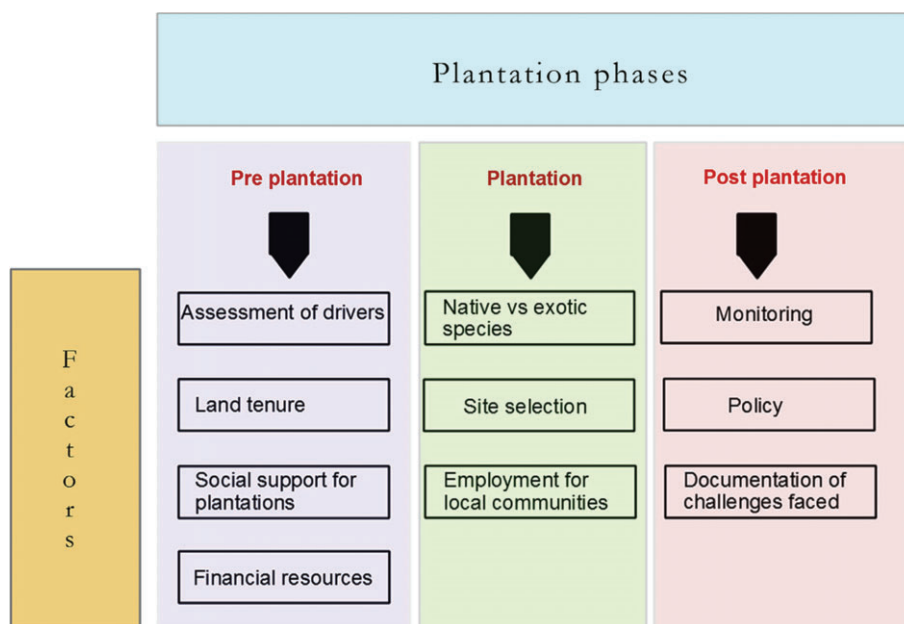


Figure 1. An interdisciplinary framework for evaluating coastal planting initiatives (source: Mukherjee et al. 2015).

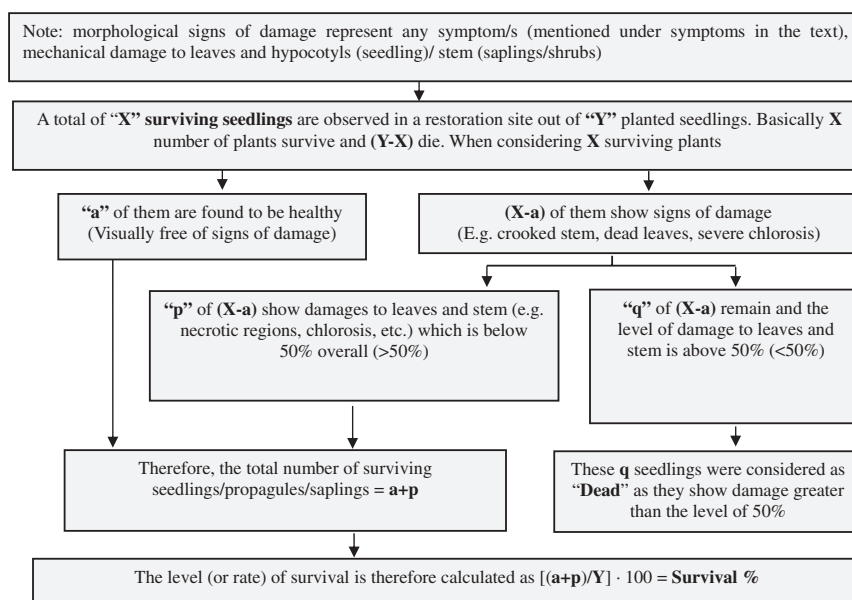


Figure 2. Scheme of the procedure for estimating the rate of survival using the dead/alive criterion in the field.

Salinity for each site was measured with the help of a hand-held refractometer (Atago S/Mill-E, Japan) using 5 mL aqueous solutions under submerged conditions (soil slurry extracted with interstitial water under nonsubmerged conditions) that were collected into a vial and mixed thoroughly before taking the readings. Average salinity of six readings, that is, in both dry and rainy seasons, was calculated (G.B.M. Ransara 2015, Department of Botany, University of Ruhuna, Sri Lanka, personal communication). Geo-coordinates were recorded with a hand-held GPS (Garmin e TREX 10).

Hydrological data (tidal amplitude and freshwater input) were obtained from the National Aquatic Resources Research and Development Agency (NARA 2015), and the Irrigation Department (ID 2015) respectively. The accuracy of demarcation of the climate zones was cross-checked with the Department of Meteorology (DM 2015), Sri Lanka.

Statistical Analysis

Mean and standard deviation of the age of planting initiatives, planted trees, and soil parameters were calculated and all

statistical analyses were performed using R-3.2.2 statistical package. Correlation and regression analyses were performed between survival rate and SBD, pH, redox at 30 cm, redox at 50 cm, technical guidance for planting, and post-care. Normality was tested using the Shapiro test. Data were not normally distributed. Therefore, Spearman correlation tests were conducted. Afterwards, nonlinear transformations were performed and multiple regression was conducted for the variables. Variation of rate of survival with respect to post-care and technical guidance was illustrated using box and whisker plots.

Results

Mangrove Planting Projects Along the Sri Lankan Coastline

Twenty-three restoration/planting project sites were identified in this study (Fig. 3; Tables S2 & S3). Since the Indian Ocean tsunami in 2004, approximately 1,000–1,200 ha of mangroves have been planted. However, the current total surviving planted area is only about 200–220 ha. The projects are situated in all four different climate zones, that is, wet, dry, intermediate, and arid zones. However, the proportion of sites was different in these four zones: 52% of the planted sites were situated in the dry and arid climatic zones, 30% in the wet zone, and the rest, that is, 18%, are in the intermediate zone (Table 2). We observed multiple planting initiatives by different agencies within the same sites. Sixty-seven planting initiatives were recorded within these 23 sites (Table 2). Many planting attempts could be observed in tsunami-affected areas (Table 3; Fig. 4).

The key actors involved in planting initiatives can be broadly categorized as governmental or nongovernmental organizations (national and international). The governmental organizations include the Coastal Conservation Department, Regional Forest Departments, the University of Ruhuna, the National Aquatic Resources Research and Development Agency. IUCN and Mericarp are the international NGOs, while Galle project, Sewalanka, Turtle Conservation Project, Saviya Development Foundation, and Small Fishers Federation of Lanka are local NGOs. In addition, there were five unidentified internationally affiliated NGOs that have attempted mangrove restoration in Sri Lanka in the past decade.

Survival of Seedlings and Age of the Planting Projects

The large majority of seedlings planted were of *Rhizophora* spp., that is, 97%, of the total planted propagules and seedlings (Fig. 5; Table S2), compared to nursery-maintained *Bruguiera* spp., *Excoecaria* sp., and *Sonneratia caseolaris* (i.e. 3%). Thirty-six (36) planting attempts out of 67 (54% of the total) showed no surviving plants. Two-thirds of these complete failures (21) were recorded in the dry and arid zones. In total, for all the project sites, the level of survival (based on the dead/alive criterion) varied from 0 to 78% (Table S2). Even after several planting attempts 40% of the sites had failed (9 out of 23 had no surviving plants). Further, the level of survival for 16 of the project sites was lower than 10% (Table S2). Only three sites, that is, Kalpitiya (arid zone), Pambala (intermediate zone),

and Negombo (wet zone), had a level of survival higher than 50%. Mannar (arid zone) had the fourth highest survival level at 33%. Many failed mangrove restoration project sites could be observed in the tsunami-affected areas (Fig. 4). However, all successful sites mentioned above are located in areas that were less affected by the 2004 tsunami (Table 3; Fig. 4).

The average height of planted mangroves in Thambalangama, Rekawa, Galle, Negombo, Pambala, and Kalpitiya was found to be 4–6 m (Fig. 3) in 8–10 years. However, stunted growth and crooked saplings were observed in the project sites situated in Panama, Panakala, and Halawa (Figs. 3 & 6).

Most of the restoration projects were initiated after the Indian Ocean tsunami of 2004. However, some of the attempts, like those of the University of Ruhuna in Galle and of the Small Fishers Federation of Lanka in Pambala and Kalpitiya, were initiated in the 1990s and are about 17–20 years old. The average time after planting was 9.5 (SD ± 0.8) years as of 2016.

Soil pH for the study sites ranged from 7.1 to 5.8 (Table S4). The sites in the wet zone showed significantly lower pH values ($p = 0.0003$; sig. level 0.001) as compared to the rest. SBD ranged from 1.22 to 1.89 g/cm³. The bulk densities were significantly lower ($p = 0.03$; sig. level 0.05) in the arid zone. Redox potential at 30 and 50 cm ranged from +6 to –146 mV and –43 to –171 mV, respectively. Redox potential at 30 cm was relatively higher in the intermediate and wet zones than in the dry and arid zones. Below a depth of 30 cm, redox potential varied between –100 and –200 mV. However, there was no significant difference of redox potential at 30 and 50 cm between the different climate zones.

Drivers of These Planting Projects

According to the data obtained from the questionnaire survey, the main planting objective of 20 restoration sites that were established after the 2004 tsunami was coastal protection and the rest, which were initiated before the tsunami, were for mangrove regeneration (e.g. some planted sites in Pambala and Galle). We observed that the mixed planted sites which were established before and after the tsunami 2004 were found in only five sites including Galle, Pambala, Kaluwamodara, Maggona, and Kalpitiya, thus representing both the above objectives (Table S2).

Causes of Success/Failure of Planting Initiatives

The choice of topographic positioning for mangrove planting showed remarkable variation. Some planting efforts were situated at the high intertidal area and even beyond, in abandoned swamps, and meadows, e.g. Komari, Palandi, Helawa, and Panakala, while some were in the low intertidal zone, e.g. Rekawa, Medilla, Meegama, and Ittapana. Inappropriate topographic positioning such as this subjects mangrove seedlings to several stress factors and disturbances. Indications of stress factors and disturbances (drought, smothering, high irradiance, flooding, algal accumulation, infestation by barnacles, browsing, and cattle trampling) (Fig. 6) were observed in all restoration sites. Cattle trampling and browsing were

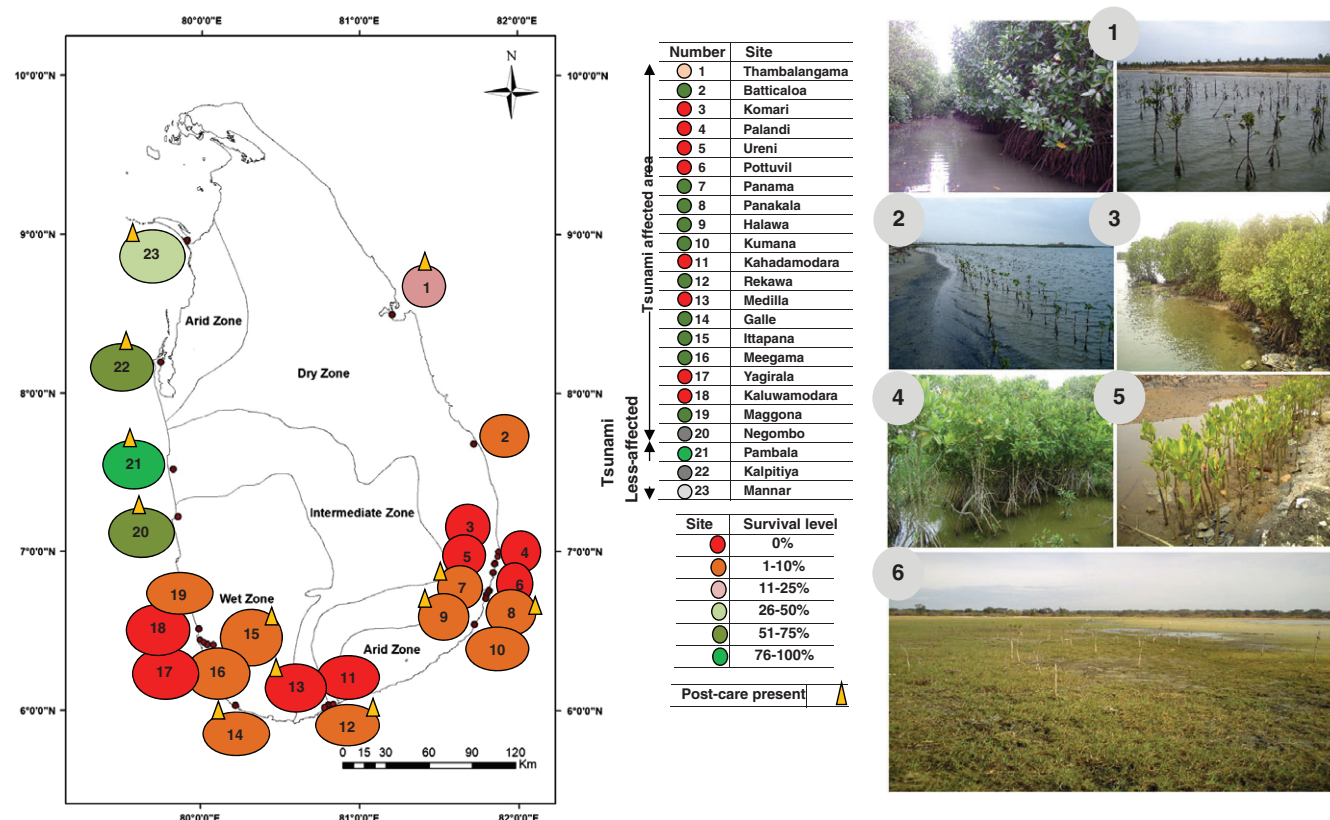


Figure 3. Map showing the restoration project sites along the Sri Lankan coastline with respect to major climate zones. Black circles show the actual locations of restoration project sites. Different colors represent the level of success and a yellow triangle shows the status of post-care in each site. Images refer to (1) Thambalangama, (2) Mannar, (3) Kalpitiya, (4) Rekawa, (5) Batticaloa, and (6) Halawa. (Photos taken by K. A. S. Kodikara.)

ubiquitous (Table S2). In addition, algal accumulation through flotsam collection (i.e. 77%) and insect attacks (i.e. 95%) were also frequent for most of the sites (Table 2). The occurrence of some types of stress factors and disturbances were related to the climate zone. For instance, mangrove seedlings/propagules planted in the low intertidal area were exposed to long-term submergence due to heavy rains in the wet zone while mangrove seedlings/propagules at the higher intertidal area suffered due to drought and high irradiance (average 79,524.48 [SD \pm 1,630.2] Lux between 11:45 and 14:30 hours) in the dry and arid zones. Post-care has not been observed for all the sites (Table S2). Even though technical guidance (whether EMR guidelines are followed) and consultation are one of the key elements in mangrove restoration success, respondents reported the use of such principles from six sites only (Kalpitiya, Pambala, Negombo, Mannar, Galle, and Rekawa). Ten sites demonstrated post-planting some monitoring process; we were unable to find any evidence from the respondents and on-site observations for the other ones. Removing flotsam, debris, and attached barnacles, up-righting fallen seedlings/propagules, avoiding cattle trampling, and secured fencing and frequent site visits, and replacing dead seedlings/propagules were observed and identified as post-planting monitoring processes. Survival rate was significantly correlated with post-planting care (Fig. 7) and soil parameters except soil pH.

Table 2. The number of sites and the number of planting attempts (plantations) in each site with respect to different climate zones. Failed planting efforts in this table are defined as “zero survival.”

Zone	No. of Sites	Distribution of the Sites (%)	No. of Planting Attempts (within 8 years)	No. of Failed Planting Initiatives
Wet	07	30.43	18	11
Dry	06	26.08	18	13
Arid	06	26.08	20	08
Intermediate	04	17.39	11	04
Total	23		67	36

Discussion

This study found that 54% of planting attempts resulted in complete failure and roughly 40% of the sites chosen for planting had no success (survival rate of saplings after 5 years). Of the 14 sites that had some recruitment, 50% (i.e. 7 sites) had survival rates of less than 10%. These figures are of grave concern given that 13 million USD were invested in such planting efforts and the trend of investing in mangrove planting is still growing (Mukherjee et al. 2009). Only three project sites (Pambala, Kalpitiya, and Negombo) had high survival rates (78, 68, and 60% respectively) and such survival rates are comparable to

Table 3. The distribution of the replanted mangrove sites and their extent along the coastline sectors affected and nonaffected by the tsunami of 2004. Figure 4 gives further details on the affected and nonaffected coastline.

Coastline Sector	Approximate Length of the Coastline Sector (km)	No. of Restoration Sites	Approximate Coverage Replanted (ha)	Approximate Coverage of Surviving Planted Area (ha)	Proportion of Replanted Extent (ha) per km of the Coastline
Severely affected by the 2004 tsunami	12,11.2	20	700–800	40–50	0.62
Less affected by the 2004 tsunami	512.1	03	300–400	150–200	0.68
Total	17,22.4	23	1,000–1,200	200–220	0.64

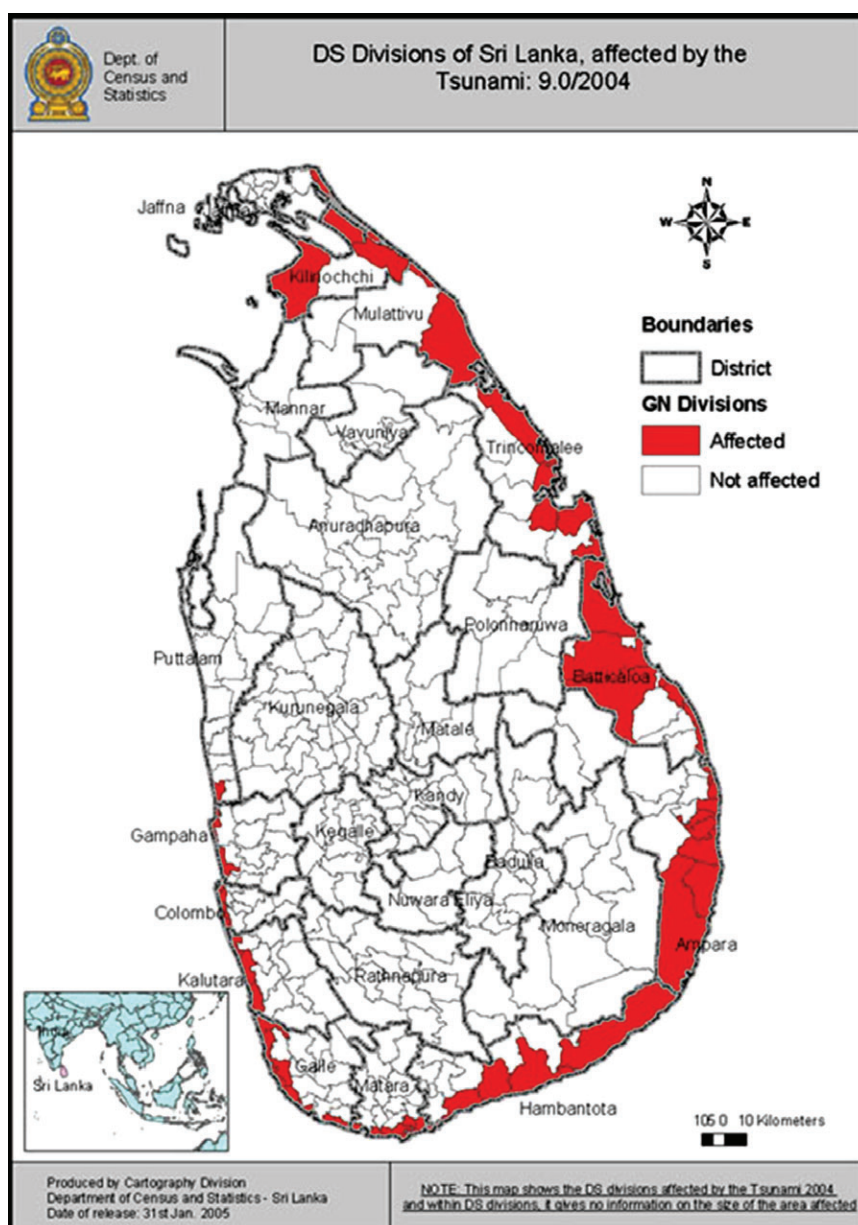


Figure 4. A map of Sri Lanka showing tsunami-affected Divisional Secretariat (DS) divisions in Sri Lanka (adopted from the official website of the Department of Census and Statistics, 2015, http://www.statistics.gov.lk/tsunami/maps/Map_affected%20DS%20division.htm).

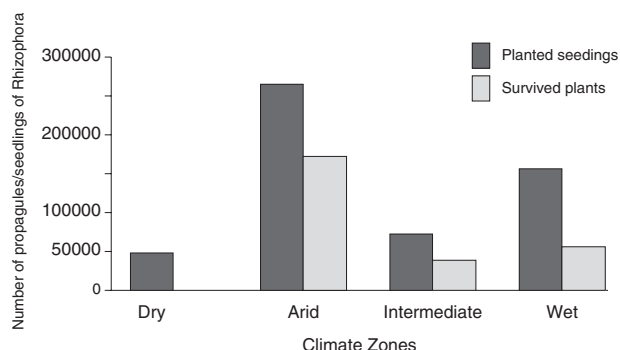


Figure 5. Number of planted and surviving propagules and seedlings of *Rhizophora* spp. with respect to the climate zones in Sri Lanka. Black bars: planted propagules and seedlings and gray bars: surviving plants.

those of the other studies carried out on mangrove species like *Rhizophora mucronata* (Toledo et al. 2001; Ratnayake et al. 2012). In this study, a minimum of 5-year survival rate was used in evaluating the success of the mangrove restoration sites. We realize that surveys of vegetation structure including plant diversity, density, biomass, faunal recruitment, and ecological processes such as nutrient cycling would add to the understanding of effective ecological restoration (Ruiz-Jaen & Aide 2005; Bosire et al. 2008). However, we intended to have a country-wide appraisal of survival rates as a key indicator of success. Applying all criteria to evaluate ecological restoration in all sites along the 1,620 km coastal belt with more than 60 restoration initiatives demands intensive scrutiny, for which more research is needed.

The failure which we observed can be attributed to several causes. Firstly, the degree of damage caused by the tsunami of 2004 was a major factor in selecting restoration project sites. More sites were selected in the dry and arid zones than a careful scrutiny would have warranted (Feagin et al. 2010). Not surprisingly, the restoration failure rates were proportionately higher in these two zones, especially along the east coast of the island. Most of the projects which sprang up after the 2004 tsunami were largely donor-driven projects. The implementing parties had a mandate to rapidly plant some vegetation, intended to lead to the establishment of a green belt in the tsunami-affected areas (IUCN 2009). This was further confirmed by some of the signboards that denote “ghost planting initiatives” as no surviving mangrove saplings could be observed during our field survey in the planting sites with such signboards. Due to this unscientific approach and intervention, deviating from the properly set technical guidance for mangrove restoration (EMR), many failed mangrove restoration sites could be observed in the tsunami-affected areas. Technical guidance in this paper means recognizing basic principles like understanding autecology of mangrove species, and the normal hydrology of the sites, assessing appropriate modifications to hydrology, selecting restoration sites based on technical, political, social, and economic considerations, planting mangroves only as needed. These are the guiding principles of the EMR methodology (Lewis 2005, 2009; Lewis & Brown 2014). From the ecological

point of view, ignorance of the major ecological drivers of mangrove health such as requirements for salinity, hydrology, and appropriate species composition were the main causes for mangrove restoration failure (Elster 2000; Primavera & Esteban 2008; Ahmad 2012). The data collected in the current study do not show high salinity values or fluctuations. However, our previous research and some other research records (IUCN 2011) indicated high salinities (about 30 ppt) in the dry and arid zones during the dry season. Therefore, such high salinities are not uncommon in Sri Lanka. In fact, inappropriate site selection that violates the basic technical aspects of EMR and lack of preliminary research on mangrove restoration can be highlighted as the root causes of failure. The placement of plants at locations with inappropriate topography which subjects them to too short or too long periods of depth, duration, and frequency of inundation, either from local rainfall or local tides, or a combination of both, has been the key factor. In addition, crucial factors for planting success such as awareness of the history of the sites including species composition, hydrological requirements, optimum depth of substrate, and freshwater input (Elster 2000; Bosire et al. 2008; IUCN 2009; Lewis 2009; Kathiresan 2011) were ignored in most of our study sites. This was a direct consequence of selection of inappropriate topographic positions for planting. The mangrove seedlings and saplings therefore were subjected to severe stress conditions such as prolonged submergence and soil water deficit (Field 1998; Hoppe-Speer et al. 2011). Prolonged submergence and soil water deficit play a crucial role in reducing the survival potential of mangrove seedlings and saplings especially in the dry and the arid climate zones in Sri Lanka. The situation was similar along the Sri Lankan coastline as we observed that in Thambalangama, Halawa, Panama, and Panakala project sites where the technical guidelines were completely ignored, mangroves were planted beyond the limits of the intertidal zone (i.e. at higher intertidal zone) which caused restoration failure in such sites. Only three planting initiatives (established by the University of Ruhuna in Galle and SFFL in Pambala and Kalpitiya) had followed technical guidelines of mangrove restoration such as selection of suitable species, investigation on hydrology of the site, and assessment of the stress factors. These were also established in the neighborhood of natural mangrove forests and were about 20 years old (in sharp contrast to the ad hoc planting sites established after the tsunami of 2004). However, some technically guided project sites (e.g. Rekawa lagoon) also showed little evidence of survival due to lack of maintenance and monitoring. Cattle trampling and browsing were the common disturbance factors for all the project sites. The observed symptoms in the field could be due to the stress factors like prolonged submergence, high irradiance, etc., or nutrient deficiency/imbalance in soil (Bergmann 1992; Vollenweider & Günthardt-Goerg 2005). However, it is evident that mangrove seedlings experience poor soil conditions due to improper positioning at the planting sites. Such conditions directly affect nutrient availability, soil organic matter, and porosity (Boto & Wellington 1984; Kidd & Proctor 2001; IPNI 2010; Tokarz & Urban 2015) which ultimately determines the survival of mangrove plants.

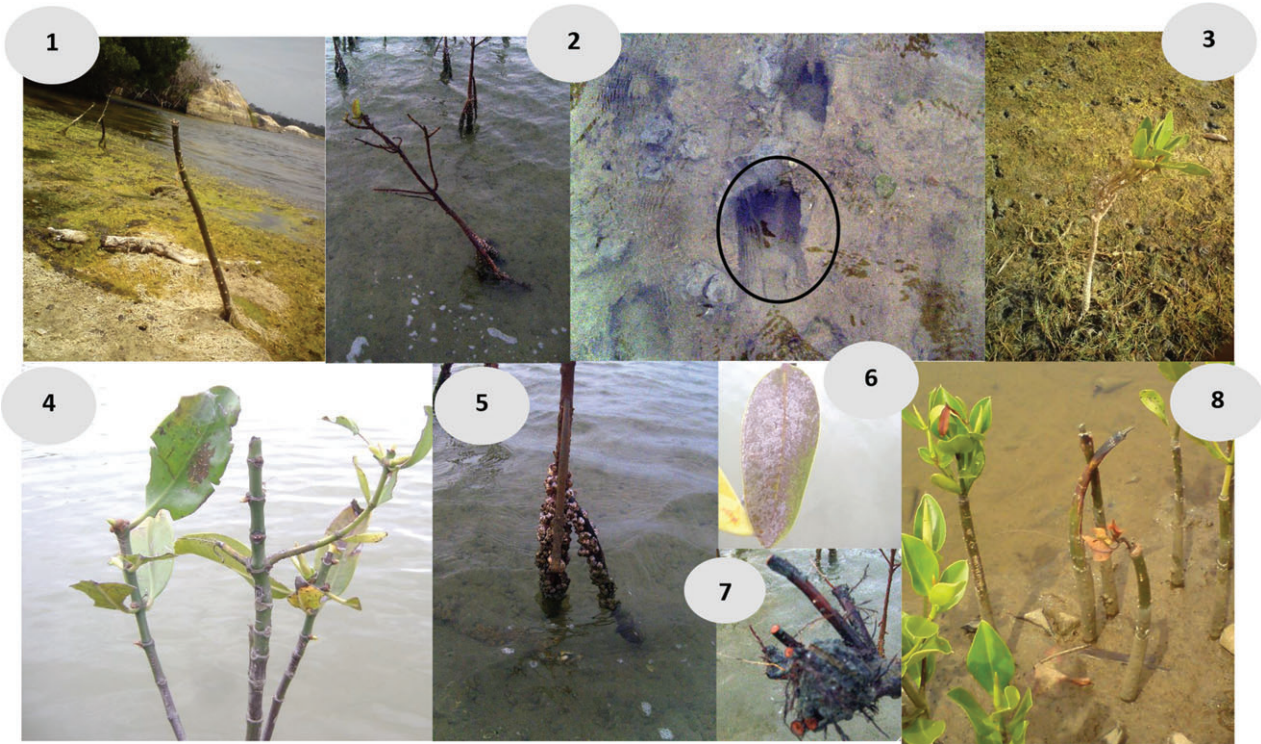


Figure 6. Disturbances and the common symptoms that were observed in the project sites. (1) Browsing (propagule tips grazed by cattle) and algal accumulation; (2) trampling; (3) growth stunted and crooked stems; (4) insect attacks; (5) infestation by barnacles; (6) leaf yellowing and rust; (7) root rotting; and (8) propagule tip die-back and stem browning. (Photos taken by K. A. S. Kodikara.)

Selection of unsuitable species like *Bruguiera* spp., *Sonneratia caseolaris* (as indicated by species composition in respective reference forests nearby, e.g. in Meegama, Maggona, and Kaluwamodara) was another cause of restoration failure. In contrast, planting organized by the Small Fishers Federation of Lanka that has a Mangrove Re-plantation Advisory Board had the highest survival rates. *Rhizophora mucronata* has been used for restoration and the reasons for the selection given by the practitioners were: ease of access, ease of handling both in nursery condition (as nursery seedlings used for some sites, e.g. Pambala, Kalpitiya, and Mannar) and planting, larger propagules hence higher survival rate, and better establishment at the lagoon water edge. The planting agencies did not survey which species occur naturally in the area nor did they use nearby natural forests as reference sites as recommended in restoration guides (Bosire et al. 2008; Lewis 2009). Such forced planting attempts of *Rhizophora* spp., often lead to the creation of monospecific stands of mangroves in the open waters of lagoons, or along bare shorelines in Sri Lanka which are not ecologically considered as natural mangrove stands (IUCN 2011). Therefore, replacement of functional habitats of fish and wildlife by such less functional mangrove stands should be avoided. Thus, in these cases, topographic surveys combined with hydrologic characterization of reference sites over a period of months during the wet and dry seasons is essential (Lewis 2000, 2005; Samson & Rollon 2008). However, such preparatory investigations have not been recorded during our survey.

Therefore, it is obvious that none of the planting sites followed all the technical guidelines indicate in EMR methodology. However, some of the planting sites like Kalpitiya, Pambala, and Rekawa used the guidelines up to a certain extent.

The governance structure of restoration projects was also found to be of major concern. Lack of coordination between institutions implementing restoration projects, e.g. Forest Department and Coastal Conservation Department, was observed in our study sites and is also reportedly one of the major causes for mangrove restoration failure in Sri Lanka (Primavera & Esteban 2008; IUCN 2009; Mangora 2011). For example, interviewed officials in the FD and CCD had no awareness of the planting efforts established by them even though the government records and our field observations stated otherwise.

Conversion of mangroves and potential planting sites to shrimp farming has been traced as the major socioeconomic issue in Sri Lanka (Dahdouh-Guebas et al. 2002). As far as we observed, no political support exists for mangrove planting. Nevertheless, shrimp farming extends under political patronage.

Mangrove restoration projects in Sri Lanka have generally not been successful in restoring mangroves despite the good intentions which fueled them in the first place. The findings of this study demonstrate a frequent mismatch between the purported aims of restoration initiatives and the realities on the ground. The need to conserve and restore mangroves is critical and our results should not be used as a motivation to stop

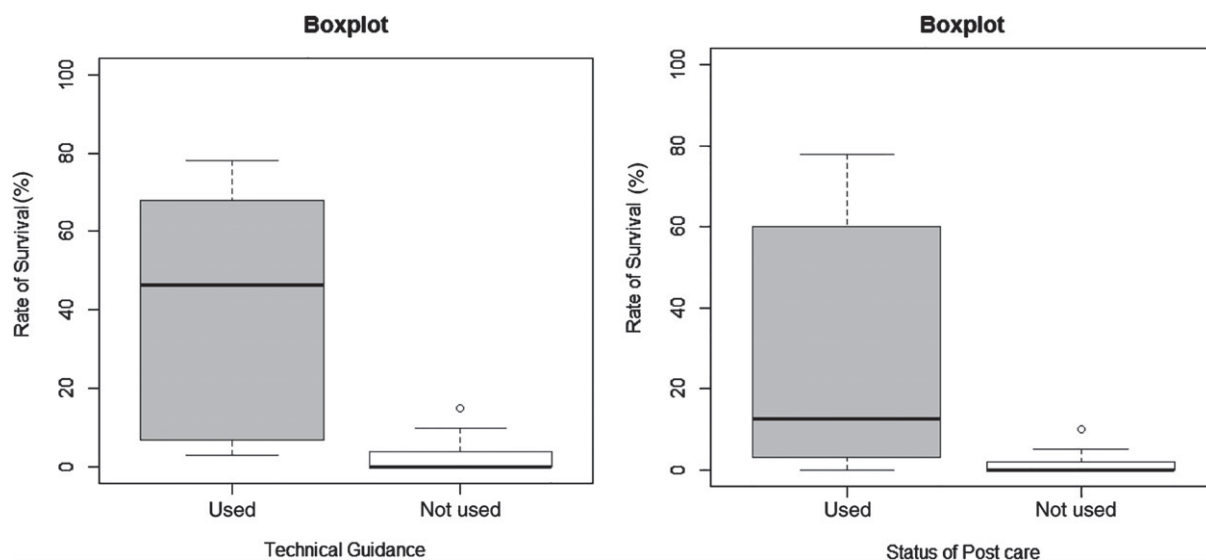


Figure 7. Rate of survival (%) with respect to technical guidance and post-care (multiple regression, technical guidance significant at 0.01 level, $p = 0.0148$ and Spearman rank correlation test, post-care positively correlated at the 0.05 level; $p = 0.0009$). A thick black line indicates the second quartile (median) and small circle data points indicate the outliers.

investing in mangrove conservation. Well prepared and well managed mangrove planting with post-care can lead to successful restoration, as has been amply shown, e.g. in Kenya, East Africa (Bosire et al. 2008), to the benefit of multiple stakeholders. Rather, our findings help identify where precious resources need to be invested such that future projects have a higher probability of success. It might also be worthwhile to conduct similar nation-wide evaluations of planting initiatives in the Southeast Asian region, where the bulk of global mangroves occur, and where most mangrove restoration has taken place, to compare the findings of this study. One such area is Matang Mangrove Forest Reserve, which has been reafforested in 30-year cycles and managed since 1902 (Goessens et al. 2014).

Following the precautionary principle, mangroves should be protected where they still occur. In addition, mangroves can be replanted in areas where they have been degraded as far as the environmental conditions (particularly the hydrography) are still conducive for hosting mangroves (Lewis 2005; Lewis & Brown 2014). However, planting mangroves in areas that have undergone major changes or in areas where mangroves were never reported should be preceded by a scientific assessment of whether or not mangroves can grow there. For Sri Lanka, Feagin et al. (2010) demonstrated that greater than 90% of the Sri Lankan coastline is vulnerable to ocean surges (e.g. tsunami) while mangroves can only grow along less than one-third of it. Unfortunately this has not been respected as this study documented. Particular attention has to be given to identify alternative bioshields or other means of coastal protection for the two-thirds of the coastline where mangroves cannot grow. Therefore, we believe that strong scientific control should be exercised over future mangrove planting in Sri Lanka. First, sound mangrove planting guidelines should be formulated according to the Sri Lankan conditions adapting the EMR methodology. Immediate direct planting, which was

the major practice in previous mangrove planting attempts in Sri Lanka, should be avoided, with a focus instead on promoting appropriate site conditions such as through hydrologic restoration and breaching dikes in aquaculture ponds, etc. This practice facilitates natural regeneration that may lead to the establishment of functional, mixed natural mangrove stands instead of monospecific stands. In cases of poor natural regeneration, mangrove planting should be implemented according to technical guidelines. Apart from this, establishment of national government authority which grants approval and provides technical guidance and leadership for mangrove planting is an urgent need in setting planting practitioners on the right track. This process should further be coupled with proper post-planting care. These propositions may assist to enhance the success of future mangrove planting in Sri Lanka.

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Supporting Information

The following information may be found in the online version of this article:

Appendix S1. Questionnaire.

Table S1. Site-specific data collected during the survey.

Table S2. Restoration project site-specific data on hydrology and planting status.

Table S3. Soil characteristic of the mangrove restoration project sites.