MANGROVE RESTORATION: ESTABLISHMENT OF A MANGROVE NURSERY ON ACID SULPHATE SOILS

TP Nguyen[1, *], VA Tong[2], LP Quoi[3] & KE Parnell[1]

[1]*Centre for Tropical Environmental and Sustainability Sciences, College of Marine and Environmental Sciences, James Cook University, 4811 Australia*
[2]*Vam Ray Resident, Hon Dat District, Kien Giang Province, 920000 Vietnam*
[3]*The Centre for Environmental Science and Ecology, Institute for Environment and Natural Resources, Vietnam National University of Ho Chi Minh City, 760000 Vietnam*

**phong.nguyen@my.jcu.edu.au*

Received September 2015

NGUYEN TP, TONG VA, QUOI LP & PARNELL KE. 2016. Mangrove restoration: establishment of a mangrove nursery on acid sulphate soils. Mangrove restoration requires the cultivation of healthy seedlings and propagules for transplantation. Nurseries established near the restoration sites provide local employment and involvement. Using a participatory action research methodology, this study showed the successful establishment and operation of a mangrove nursery on the landward side of a sea dyke, on acid sulphate soils normally considered unsuitable for mangrove growth. This nursery in Vam Ray area, Kien Giang province, Vietnam produced 37,500 seedlings of five mangrove species, *Avicennia marina, Rhizophora apiculata, Bruguiera cylindrica, Sonneratia alba* and *Nypa fruticans*. The seedlings had 100% survival and were available for transplantation within three months, at a reasonable cost. The nursery procedures and techniques were based on local practices and knowledge. The study showed that a successful nursery on acid sulphate soils was achievable. Key differences compared with other mangrove nursery projects were land-based location, use of sea-bed mud to improve acid sulphate soils, use of local resources and locally traded products to minimise cost, reduced waste, local livelihood improvement and planting of multiple individuals per pot for selected species.

Keywords: Mekong Delta, community participation, livelihoods, local knowledge, muddy coastal erosion, mangrove seedling production

INTRODUCTION

Engineered solutions to address erosion of muddy coasts have had adverse impact on the ecology, biodiversity and functioning of coastal ecosystems (Miles et al. 2001). As a consequence, mangrove restoration was adopted as a cost-effective ecologically engineered option to address the erosion problem (Winterwerp et al. 2005). Mangrove restoration is a dedicated attempt to restore severely degraded mangrove areas by planting mangrove species to substitute for insufficient natural regeneration (Lewis-III 2005). However, mangrove restoration could be difficult without sufficient supplies of seeds or seedlings. A mangrove nursery, to raise and tend seedlings for transplanting, is needed due to insufficient naturally sourced seedlings ((Melana et al. 2000, Ravishankar & Ramasubramanian 2004).

There are many types of mangrove nurseries. Permanent nurseries are constructed for mangrove planting over an extended period of time. Temporary nurseries are established for a short period of time, especially in limited planting areas. Subsidiary nurseries are constructed at a distance from permanent nurseries. Floating mangrove nurseries are constructed above the highest tidal range to provide long-term seedling supply (Melana et al. 2000). Flooded mangrove nurseries are constructed in low intertidal areas to provide short-term supply of seedlings which require less effort, time and capital investment (Thoi & Thinh 2011, Dung et al. 2008).

Ravishankar and Ramasubramanian (2004) reported that mangrove restoration using seedlings raised in nurseries had higher survival rate, above 90%, than direct planting of seeds.

This is because nursery-raised seedlings develop well-established root systems prior to planting in degraded areas.

Mangrove nursery practices were designed to assist mangrove seedlings to gradually adapt to the environmental conditions of the restoration sites with minimised mortality rates. Mangrove nursery techniques were based on application of standard propagation and rearing methods for terrestrial plants (Clarke & Johns 2002). Common practices were (1) mangrove seedling propagation which included species selection, mature seed collection, transportation and management, and (2) nursery construction, maintenance and operation which included consideration of site selection, soil material identification, nursery bags, preparation of nursery beds, sowing, irrigation using saline/fresh water, application of fertilisers, grading and pest control (Melana et al. 2000, Bovell 2011).

Successful mangrove seedling propagation require adequate understanding of fruiting seasons and careful collection and transportation of seeds and seedlings, as well as good information on the receiving degraded area with respect to salinity profile to avoid stress on transplanted seedlings (Ravishankar & Ramasubramanian 2004, Bovell 2011). A significant challenge for any nursery is to create similar environmental conditions as the restoration sites so as to minimise mortality after transplant (Clarke & Johns 2002).

Acid suphate soils, < pH 4, are characterised by pyrite formation and oxidation, increased mobility of potentially toxic elements and limited bioavailability of nutrients. A total of 350,589 ha of acid sulphate soils, approximately 55% of Kien Giang land area, were found along the low lying coastal areas of Kien Giang province. Acid sulphate soils had adverse effects on agriculture, aquaculture, mangrove growth and mangrove restoration (Kien Giang Provincial People's Committee 2012, Attanandana & Vacharotayan 1986, Minh et al. 1994, Ljung et al. 2009, Amaral et al. 2011, Isyrini et al. 2012).

This paper describes the establishment of a mangrove nursery on acid sulphate soils on the landward side of a sea dyke in Vam Ray area, Kien Giang province, Vietnam to supply seedlings to a local restoration project. The study documented nursery techniques, designed and implemented in Vam Ray nursery, and provided recommendations for other similar projects. Although some aspects have been previously reported (CDBRP 2011, 2012), they failed to detail the importance of local involvement and incorporation of conventional methods and local knowledge.

MATERIALS AND METHODS

Site description and history

Vam Ray is located 40 km north-west to Rach Gia city, the capital of Kien Giang province,

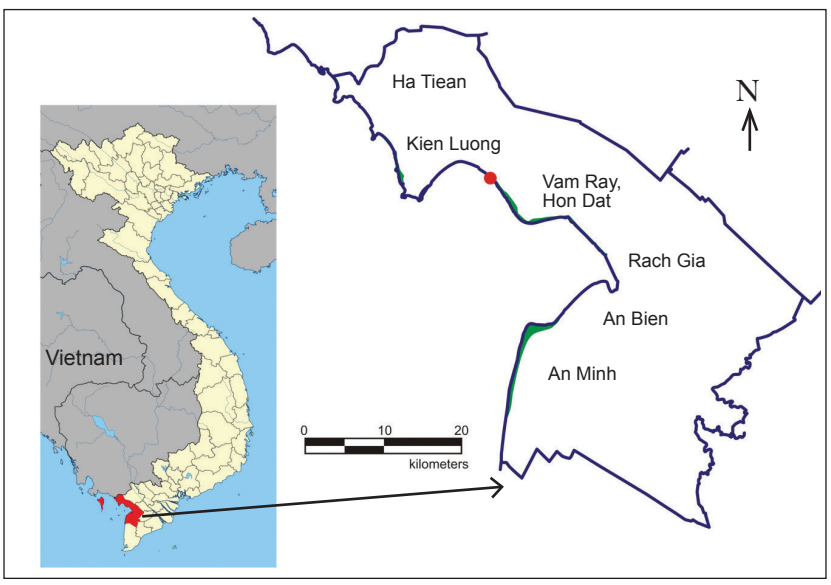

Figure 1 Kien Giang map showing the location of the Vam Ray area, Hon Dat

Vietnam. The Vam Ray population consisted of approximately 14 households who settled in the 1980s. The locals were involved in agriculture, mainly three months of rice production, fish/crab aquaculture farming and recently fruit and sugarcane farming. The farmed area had acid sulphate soils which were problematic during rainy season between May and November each year.

The Vam Ray sea dyke was seriously breached between 2006 and 2008. It was damaged by natural as well as anthropogenic factors and mangroves were geographically and ecologically fragmented. As a consequence, Vam Ray was isolated and agricultural products were badly affected. The species present were *Avicennia marina, Rhizophora apiculata, Bruguiera cylindrica, Bruguiera gymnorhiza* and *Nypa fruticans* (CDBRP 2008).

Between 2005 and 2008, mangrove restoration was undertaken in Vam Ray in an area of 3.66 ha using a single species, *A. marina*. Traditionally, mangrove nurseries were established on low intertidal areas or immediately above the high tide line. In Vam Ray, these areas could not be used being either too exposed or restricted by the presence of the sea dyke. Thus, seeds and seedlings were raised and tended in distant nurseries, both above the high tide line and on low intertidal areas, for a minimum of 6 months. In 2007 mature seedlings were purchased at a cost of 8,000 VND. Seedlings at a minimum height of 0.6 m were transplanted, supported by three crossed *Melaleuca* sticks and protected from strong waves by a long fence made of *Eucalyptus* poles. However, the restoration failed because many seedlings were uprooted due to insufficiently developed root systems and were weighed down and killed by floating plastic bags. No seedlings survived after 2 years.

Between 2008 and 2009, a series of consultation activities and meetings were organized to engage relevant provincial agencies, the funding body, CDBRP and the local communities to address the problems associated with mangrove nurseries. This resulted in a collaboration of the government agencies, CDBRP and local communities. The Department of Agriculture & Rural Development of Kien Giang Province (DARD) was given the responsibility to build a new concrete sea dyke, 428 m in length, in Vam Ray (DARD 2008). CDBRP provided funding for the purchases of nursery construction materials, sourced locally, i.e. *Melaleuca* poles, plastic bags and small gauge black colored fishing nets for shading, purchases of seedlings, transportation costs, laborers' wages and land rental.

The only available area in the vicinity suitable for a nursery operation was on acid sulphate soils on a private land situated on the landward side of the sea dyke. The key goal of the nursery was to supply a large number of seedlings, well-suited to the environmental conditions of Vam Ray muddy coast. The nursery was established in May 2009 on the landward side of the new sea dyke using practices that integrated conventional methods and local ideas. Three months later, approximately 37,500 seedlings of the five mangrove species were ready to be transplanted.

Participatory action research method

This study was undertaken between July and December 2013 where participatory action research method (Mcintyre 2008) was applied to systematically record the successes and failures of the techniques used in the nursery, as well as local involvement in the project. The research methodology promoted the active involvement of researchers and participants towards co-learning and co-construction of knowledge.

Data were collected from different sources including meetings with governmental agencies of Kien Giang province, i.e. DARD, Department of Science and Technology and Kien-Hai-Ha Coastal Mangrove Management Board, online publications of CDBRP, participatory meetings with Vam Ray community, in depth interviews with contracted nursery workers and a good collection of photos regularly taken in the area. Data collected was systematically recorded into a multi-dimensional summary for subsequent analysis. The dimensional summary was analysed, collated and categorised into themes, i.e (1) nursery planning, (2) nursery construction and (3) operation, using participatory action research data analysis methods, namely reflective diaries, development of a matrix of issues in

relation to nursery construction, thematic analysis and photo voice. The themes were reviewed and confirmed by the minutes of the meetings and signed by the community representatives.

RESULTS

Nursery planning

A series of consultations and meetings with relevant stakeholders, i.e. DARD, Management Board of Forestry Projects of DARD and Vam Ray community, resulted in a shared understanding of technical guidelines on nursery construction and mangrove seedling propagation and tending, within the local context. All parties agreed to incorporate local knowledge, capacity and resources so as to be able to replicate the successful model elsewhere.

Ideas for mangrove nursery construction and effective establishment were further developed into detailed strategies. Challenges due to inland locations were tackled by simulating natural environmental conditions so that transplanted seedlings were not subjected to stress. The strategies included construction of a nursery near the restoration site to ensure easy logistics, local involvement and the use of local mangrove seeds/propagules, as well as local materials for construction. Seedlings were treated and grown as close as possible to the targeted habitat to ensure high survival rates.

Nursery construction

In May 2009, a nursery (15 m × 35 m) was constructed landward side of the damaged sea dyke on the property of Tong Van Anh. The nursery was unlike most others, being inland on acid sulphate soils with acidic water during wet season. Residents believed the soil would not support tree growth. Thus, a 50 cm layer of liquid sea mud was laid on the surface to prevent surfacing acidic water, prior to establishment of seedlings.

Materials used to construct the nursery were locally made products. *Melaleuca* and *Eucalyptus* poles were sustainably harvested from Kien Giang's production forests, while locally made small gauge fishing nets and bamboo mats were readily available. The fishing nets were placed around the nursery to keep away insects and domestic animals. Two thirds of the nursery area was covered with fishing nets to shade mangrove seedlings from the sun.

Nursery operation

Seed collection

Mangrove seed and propagule collection commenced in June 2009. Seeds/propagules were collected from two areas in Kien Giang province, i.e. Rach Dung (Kien Luong) and Xeo Ro (An Bien), which had similar mangrove species as Vam Ray. As recommended by the Ministry of Agriculture and Rural Development of Vietnam (2002), seeds and propagules were collected from mother trees of a minimum age of 13 years.

However, in June, not all seeds and propagules of the five mangrove species in Kien Giang coast were mature, resulting in insufficient stock. To overcome the difficulty, local labourers were employed to collect and store mangrove seeds and propagules in shady areas before being transported to the nursery site. The mangrove seeds were covered with wet banana or palm leaves or stored in wet plastic bags during transportation. They were transported from collection sites early in the morning using the traditional long-tail boats and trucks and arrived at the nursery site by noon the same day.

Potting process

Potting took place in June 2009. As standard pots were difficult to source, locally available plastic shopping bags of different sizes were used for potting the mangrove seeds and seedlings. Bags were holed and filled by hand with semi-liquid sea mud collected at low tide, using buckets (Figure 2). After filling, the bags were transported to the nursery ground. Propagation was carried out when the liquid sea mud has dried up so that seeds and propagules could be firmly placed. Mangrove seeds of *A. marina, S. alba* and *N. fruticans,* and propagules of *R. apiculata* and *B. cylindrica* were propagated.

Unlike many restoration projects, more than one individual was propagated together in an attempt to increase survival rates during transplantation. *Rhizophora apiculata* had three propagules per pot, *B. cylindrica* had 5 propagules

per pot while *A. marina, S. alba* and *N. fruticans* were potted as single individuals (Figure 3). Planting of multiple propagules in a pot for *R. apiculata* and *B. cylindrica* enabled the seedlings to support each other in a cluster, improving survival when exposed to strong waves. In addition, during transplantation, clusters of these species were planted at high density to assist recolonisation of the eroded area in the shortest time possible. Local knowledge indicated that *N. fruticans* would grow well in exposed full sun while *A. marina, R. apiculata, B. cylindrical* and *S. alba* prefer less sunlight. Thus the four species were positioned in nursery sections covered with fishing nets.

Irrigation

Mangrove seeds and propagules were irrigated twice a day, early morning and late afternoon, with saline water pumped over the sea dyke. The owner of the land, where the nursery was

Figure 2 Liquid sea mud collected to fill plastic shopping bags

Figure 3 (a) *Nypa fruticans* propagated with single seed per pot, (b) *Bruguiera cylindrica* with five propagules per pot, (c) *Rhizophora apiculata* with three propagules per pot, planted on a 50 cm thick sea mud, overlying acid sulphate soils

located, was given the responsibility to irrigate the mangrove seeds and propagules. Irrigation was not needed on wet days. Pesticides and fertilisers were not used. Weeds growing around the pots were removed for the first two months. After the third month, it was not necessary to eradicate the weeds since the seedlings grew faster than the weeds, making it impossible for the weeds to compete for nutrition and sunlight.

Seedlings and survival rates

A total of 37,500 seeds in 26,500 pots were propagated in June 2009. A total of 36,000 seeds and propagules of the five species were purchased from contracted collectors and 1,500 seeds of *A. marina* were collected by Vam Ray residents (Table 1). Seeds and propagules propagated in the nursery had 100% survival rate with no disease damage. Seedlings were ready for transplantation in early September 2009 (Figure 4). Transplantation took place in four phases, i.e. early September for *N. fruticans* and *R. apiculata*, late September for *B. cylindrica, N. fruticans* and *R. apiculata,* early October for *B. cylindrica, N. fruticans* and *R. apiculata* and late October for *B. cylindrica, A. marina, N. fruticans* and *S. alba*.

In October 2009, DARD requested for 4,000 seedlings of *A. marina* and 2,500 of *S. alba* to be supplied to another planting program in Hon Dat area, which was reported to have survived well.

Nursery costs

The utilisation of local resources and plastic shopping bags minimised the costs of nursery construction. The production cost for a seedling ready for transplantation including labour, land rent, nursery construction, seed collection and seedling maintenance, was approximately 2,770 VND, equivalent to USD16 cents as of July 2009.

DISCUSSION

Local, practical perspectives to mangrove nursery establishment and operation

Having observed failures in the past, the Vam Ray people were certain that previous practices could not be emulated if the nursery was to be successful. Taking into account of established practices applicable to local situations, the Vam Ray people worked with project staff through co-learning processes and made decisions to solve their own problems. The Vam Ray mangrove nursery has provided an ecologically-based alternative solution compared with other mangrove nurseries. Standard mangrove nursery techniques, location selections, construction and maintenance methods (Clarke & Johns 2002, Thoi & Thinh 2011) were regarded by Vam Ray residents as impossible to be implemented for many reasons. The location of the nursery being inland of the sea dyke and on acid sulphate soils required improved methods. The treatment of marine mud prior to nursery establishment, the use of pumped irrigation sea water and the potting of multiple individuals were methods used in Vam Ray, but not commonly used elsewhere. Despite the lack of pesticides and fertilizers and the adverse acid sulphate conditions, the success of the nursery was evident by the high survival rate of successful transplants, a source of considerable pride for the community.

Table 1 Number of seeds and propagules of five mangrove species potted and their heights, June 2009

Species	Seed/propagules	No. of seeds / propagules in each pot	No. of pots	Average height of seedlings after 3 months (cm)
Nypa fruticans	Seed	1	6000	35
Ryzophora apiculata	Fruit	3	2500	43
Bruguiera cylindrica	Fruit	5	1500	32
Sonneratia alba	Seed	1	7500	60
Avicennia marina	Seed	1	9000	55

Figure 4 Three-month seedlings of (a) *Rhizophora apiculata*, (b) *Bruguiera cylindrica*, (c) *Nypa fruticans* and *(d) Avicennia marina*

Local resources

The use of local resources, particularly *Melaleuca* and *Eucalyptus* poles and plastic shopping bags, was a priority in establishing the Vam Ray mangrove nursery. As Vam Ray was located in a relatively remote rural area, the availability of local resources and materials contributed significantly to the effectiveness and efficiency of the mangrove nursery construction and maintenance. It significantly reduced costs, providing a successful model for replication elsewhere. In addition, utilisation of local resources created demand, especially for *Melaleuca* and *Eucalyptus* poles, improving local livelihoods in the region.

Acid sulphate soils

More than 40% of the Mekong Delta region of Vietnam has been reported to have acid sulphate soils (Minh et al. 1994). Acid sulphate soils were normally ameliorated by a change in drainage design from deep narrow drains to wide shallow ones, the addition of lime, construction of channels and streams to remove toxic ions and water table management to minimise disturbance to the pyritic layers (White et al. 1997, Le et al. 2008, Simpson & Pedini 1985). Alternatively, the Vam Ray community used a 50-cm layer of semi-liquid sea mud to protect seedlings from acidic water surfacing on rainy days. The placement of sea mud was a cost-effective and environmentally friendly solution to the problem of establishing a mangrove nursery on acid sulphate soils.

Monitoring and record keeping

Monitoring and good record keeping were matters of concern to Vam Ray nursery. Seedlings had to be regularly monitored and moved around to prevent roots from growing into the base soil. Otherwise, upon removal, the roots may be damaged and acidic soils accessed. However *N. fruticans* grew quickly and developed roots through the plastic bags into the base soil. The roots of *N. fruticans* were carelessly cut before transplantation, resulting in high death rate.

In many community-based projects, particularly in developing countries, systematically collated records were not well kept during nursery operation. The lack of formal records

caused difficulty in transferring knowledge to other locations. Fortunately, Vam Ray had a range of records including photographs and a good collection and understanding of the nursery planning, construction and operation that occurred between May and December 2009. The informal recording of events in this study greatly assisted the systematic reporting and evaluation, even 3 years after its completion.

Transferring of knowledge

The Vam Ray mangrove nursery provided valuable technical reference for many provincial plans and strategies, including the 2013–2020 KFW (Kreditanstalt Für Wiederaufbau-German Development Bank) Loan Projects in Kien Giang and Ca Mau Provinces, the 2011–2020 Plan for Restoration and Development of the Coastal Mangroves Along the Coastline of Kien Giang Province, the 2010–2020 Detailed Plan for Upgrading and Strengthening the Sea Dyke System of Kien Giang Province and Decision No. 25 Regarding Detailed Guidelines on Mangrove Planting and Mangrove Thinning. It has great potential for application elsewhere in South-east Asia where mangrove restoration is being considered with nurseries close to the sites.

RECOMMENDATIONS AND CONCLUSIONS

In meetings with residents of Vam Ray in 2013, recommendations to ensure efficiency and effectiveness of mangrove nurseries in similar locations were discussed and recorded. These recommendations were not been experimentally tested, but were based on the collective understanding and knowledge of those involved in the nursery project.

(1) A nursery established landward of the tidal limit is feasible. Covering the ground with semi-liquid sea mud at a minimum depth of 50 cm was sufficient to avoid problems associated with acid sulphate soils.
(2) The use of local products, i.e. *Melaleuca* and *Eucalyptus* poles, shopping bags and fishing nets, contributed towards nursery success by minimising costs, avoiding unnecessary waste and improving local livelihoods.
(3) Nursery construction and collection of mangrove seeds and propagules should be undertaken at the beginning of the wet season (early June), where mature seeds and propagules of ecologically similar mangrove species are available for propagation. Seeds and propagules should be collected from mother trees of a minimum age of 13 years to ensure fruit/seed maturity. It is important to purchase/ collect seed and propagules additional to the number required in order to provide for poor quality seeds and propagules and loss during transportation.
(4) For collections located at a distance, seeds and propagules could be stored in a shady area for one day before transporting to nursery site. While being transported by boat or vehicle, they should be covered with wet banana or palm leaves or stored in wet bags. Transportation should be undertaken early in the morning or late afternoon to avoid excessive exposure to sunlight.
(5) In this study, bags filled with semi-liquid sea mud were dried before propagation to ensure that the seeds and propagules were firmly placed. *Rhizophora apiculata* and *B. cylindrica* were propagated with more than one individual per pot to form a cluster which improved survival against strong waves. To facilitate rapid recolonization, clusters were transplanted in high density. *Rhizophora apiculata* seedlings were potted with three individuals and *B. cylindrica* with five individuals in a pot. *Avicennia marina, S. alba* and *N. fruticans* had single seed propagation in a pot.
(6) *Nypa fruticans* were best tended and raised in the sun to promote full growth, while *A. marina, R. apiculata, B. cylindrical* and *S. alba* did best in shaded areas.
(7) Irrigation with saline water twice a day, early morning and late afternoon, seemed sufficient and successful. Seedling bags, especially those containing *N. fruticans* should be moved around regularly to avoid roots growing into the base soil.

The Vam Ray mangrove nursery was established in June 2009 in Kien Giang province. The nursery produced 37,500 healthy seedlings with 100% survival at low cost, for transplanting within 3 months. The nursery was successful despite being established on acid sulphate conditions which adversely affect natural growth

and restoration. Due to unavoidable necessity, the nursery was established on acid sulphate soils. Although not an ideal situation, it was demonstrated that success was possible in the hostile acid sulphate soil environment. The nursery used some unconventional techniques and procedures based on local knowledge of mangrove ecology. Establishing a base of sea mud and regular irrigation with pumped sea water proved successful to overcome problems associated with the location.

The active involvement of community was fundamental to the nursery project. It empowered local people to promote their knowledge alongside conventional practices to develop ecologically-based and cost-effective production techniques for mangrove seedlings, ensuring high survival rates. The fundamental goal of all processes was to reduce stress on seedlings at all stages. The use of local resources and materials was the key to success of the project.

Although the results have not been tested experimentally, the nursery has been widely regarded as successful. However, the procedures used are yet to be documented adequately. The Vam Ray nursery served as a model for replication in other mangrove restoration projects in Kien Giang and Mekong delta of acid sulphate soils.

ACKNOWLEDGEMENTS

The authors would like to thank Nguyen Van Thua & Nguyen Thi Minh Huong for photographs, Nguyen Phi Thong, Nguyen Thanh Trung, Nguyen Van Loi, Nguyen Quang Huy & Nguyen Quang Hoang for their work, feedback and support, and Tran Thi Thu Hang for facilitating the research work at Kien Giang province, Vietnam.

REFERENCES

Amaral V, Cabral HN & Bishop MJ. 2011. Effect of runoff from acid-sulfate soils on pneumatophores of the grey mangrove, *Avicennia marina*. *Marine and Freshwater Research* 62: 974–979.

Attanandana T & Vacharotayan S. 1986. Acid sulphate soils: their characteristics, genesis, amelioration and utilization. *Southeast Asian Studies* 24**:** 154–180.

Bovell O. 2011. *Guyana mangrove nursery manual*. http://www.gcca.eu/sites/default/files/catherine.paul/guyana_mangrove_nursery_manual_2011.pdf.

CDBRP (Conservation and Development of Kien Giang Biosphere Reserve Project). 2008. *Mangroves and Climate Change: Observations of Two Mangrove Areas of Kien Giang Province, Including the Districts of Hon Dat and An Minh*. CDBRP, Rach Gia.

CDBRP. 2011. *Climate Change, Conservation and Development: Lessons Learnt and Practical Solution*. CDBRP, Rach Gia.

CDBRP (Conservation and Development of Kien Giang Biosphere Reserve Project). 2012. *Coastal Rehabilitation and Mangrove Restoration Using Melaleuca Fences: Practical Experience From Kien Giang Province*. CDBRP, Rach Gia.

Clarke A & Johns L. 2002. *Mangrove Nurseries: Construction, Propagation and Planting. Fisheries Guidelines—Fish Habitat Guideline FHG 004*. Department of Primary Industries, Queensland.

DARD (Department of Agriculture and Rural Development of Kien Giang Province). 2008. *Letter of Request to the Conservation and Development of the Kien Giang Biosphere Reserve Project—Reconstruction of Cement Reinforced Sea Dyke by DARD in Vam Ray Area*. DARD, Rach Gia.

Dung PH, Van DT, Ha HTN & Mai CT. 2008. *The Mangroves of Ha Long Bay and Nearby Areas*. The Vietnam Education Publishing House, Hanoi.

Isyrini R, Gust D, Williamson I, Scharaschkin T & Noor A. 2012. Natural improvements of geochemical conditions of acid sulphate soils caused by free tidal inundation and its effects on the mangrove seedlings. Paper presented at the Asian Conference on Sustainability, Energy and the Environment, 3-6 May 2012, Osaka.

Kien Giang Provincial People's Committee. 2012. *Master Plan for Land Use Planning for Kien Giang Province until 2020*. Kien Giang Provincial People's Committee, Rach Gia.

Le TMH, Pham AN, Collins RN & Waite TD. 2008. Impact of soil consolidation and solution composition on the hydraulic properties of coastal acid sulphate soils. *Australian Journal of Soil Science* 46: 112–121.

Lewis-III RR. 2005. Ecological engineering for successful management and restoration of mangrove forests. *Ecological Engineering* 24: 403–418.

Ljung K, Maley F, Cook A & Weinstein P. 2009. Acid sulphate soils and human health—a millennium ecosystem assessment. *Environmental International* 35: 1234–1242.

Mcintyre A. 2008. *Participatory Action Research. Qualitative Action Research Methods Series 52*. Sage Publication Inc., Thousand Oaks.

Melana DM, Melana EE, Atchue JIII, Yao CE, Edwards R & Gonzales HI. 2000. *Mangrove Management Handbook*. The Coastal Resource Management Project, Department of Environment and Natural Resources, Manila.

Miles JR, Russell PE & Huntley DA. 2001. Field measurements of sediment dynamics in front of a seawall. *Journal of Coastal Research* 17: 195–206.

Minh LQ, Tuong TP & Vo TX. 1994. Leaching of acid sulphate soils and its environmental hazard in the Mekong River Delta. Pp 99–109 in Denning GL & Vo TX (eds.) *Proceedings of the Vietnam and IRRI—A Partnership in Rice Research Conference.* 4–7 May 1994, Hanoi.

Ministry of Agriculture and Rural Development of Vietnam. 2002. *Decision 4533/QD—BNN/KHCN Re Technical Guidelines on Transplanting, Tending and Protection of Rhizophora species.* Ministry of Agriculture and Rural Development, Hanoi.

Ravishankar T & Ramasubramanian R. 2004. *Manual on Mangrove Nursery Techniques.* M.S. Swaminathan Research Foundation, Chennai.

Simpson HJ & Pedini M. 1985. *Brackish Water Aquaculture in the Tropics: The Problem of Acid Sulphate Soil Environment.* FAO Fisheries, Rome.

Thoi HV & Thinh PT. 2011. *Mangrove Nursery Manual.* GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), Hanoi.

White I, Melville MD, Wilson BP & Sammut J. 1997. Reducing acid discharge from coastal wetlands in eastern Australia. *Wetland Ecology Management* 5: 55–72.

Winterwerp JC, Borst WG & De-Vries MB. 2005. Pilot study on the erosion and rehabilitation of mangrove mud coast. *Journal of Coastal Research* 21: 223–230.