Investigating approaches to optimise the value of a blue carbon initiative on Yirrganydji Country

Summary Paper

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Keywords: Blue carbon, Carbon credit, First Nations, Mangrove

1 TARGET AUDIENCE

Individuals or organisations developing or evaluating blue carbon credit schemes, especially in First Nations contexts and/or through tropical mangrove rehabilitation.

2 BACKGROUND

Since the Kyoto Protocol, cash-redeemable carbon credit schemes have emerged as a powerful market mechanism to mitigate anthropogenic climate change. Such schemes where carbon is sequestered through marine ecosystems, such as mangrove forests, are called 'blue carbon'. The Dawul Wuru Aboriginal Corporation, representatives of the Traditional Owners of Yirrganydji Country in Far North Queensland in tropical Australia, have partnered with Engineers Without Borders Australia to investigate approaches to blue carbon initiatives.

3 PURPOSE

To investigate different approaches to optimise the value of a blue carbon initiative on Yirrganydji Country.

4 METHOD

Engineers Without Borders Australia's Technology Development Approach was adapted for this study, particularly in applying the strategy and pre-design stages. This involved synthesising literature around the Yirrganydji context, the science and politics of blue carbon credit schemes, and case studies related to mangrove blue carbon schemes. Evaluation criteria were then developed to make recommendations of the potential for blue carbon mangrove schemes in the Yirrganydji context.

5 RESULTS

Evaluation criteria were developed along three main categories: site location, mangrove species, and plantation method. Within each category, different criteria were identified:

- Site location
  - Accessibility
  - Protection
  - Soil and water characteristics
- Mangrove species
  - Resilience
  - Carbon sequestration
  - Growth rate
- Plantation method
  - Cost
  - Difficulty
  - Community involvement

These criteria were then applied to the Yirrganydji context, from which it is recommended that direct propagule dibbling of *Avicennia marina* (grey mangrove) be undertaken at Dungarra, otherwise known as Redden Island, a site on the northern side of the Barron River mouth.

6 IMPLICATIONS FOR TARGET AUDIENCES

In this specific context, the above recommendation has been made. More generally, it is recommended that the three categories of evaluation – site location, mangrove species, and plantation method – be applied to evaluate the potential for mangrove blue carbon projects in other contexts. Other considerations include the alignment of such carbon abatement projects with local Traditional Owner's cultural values; the availability of local materials in implementing such projects; the resourcing required for the preparation, implementation, and ongoing operation and maintenance of the plantation site (especially in the critical 18-24 month period after initial planting when the seedlings are most vulnerable); risk assessment and management in the specific project context; and how resilient the plantation site is to seasonal variation and climatic events.

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Abstract: *Engineers Without Borders Australia have identified the opportunity to implement a blue carbon scheme on Yirrganydji Country (between Cairns and Port Douglas), supporting the Yirrganydji community to conduct carbon abatement activities in exchange for carbon credits with monetary value. Mangroves are prevalent throughout Yirrganydji Country, and this type of forest can sequester significantly higher rates of carbon than other forest ecosystems. However, mangrove-focussed carbon abatement projects are relatively new, and this specific project involves additional considerations regarding the needs and values of the Yirrganydji community. In order to identify design solutions that deliver optimised economic, environmental, and socio-cultural value, the context of Yirrganydji Country is analysed. The literature regarding two key factors is then reviewed: the legal mechanisms through which First Nations peoples are returned land in Australia, and how carbon markets function. Two relevant case studies are then analysed: the first investigates best practices in developing First Nations carbon abatement projects in Australia; the second comes from the Indian Sundarbans, featuring a cost-benefit analysis of several mangrove species that are also prevalent throughout Yirrganydji Country. Several potential project designs are then identified, with a criteria-based evaluation framework used to assess each option. From this evaluation, it is recommended that direct propagule dibbling of Avicennia marina be undertaken at Dungarra. Additional considerations are also provided, as well as recommendations for future research. The results are applicable to the multi-disciplinary field of humanitarian engineering and can be applied to other First Nations contexts, both within Australia and internationally.*

Keywords: Blue carbon, Carbon credit, First Nations, Mangrove

1 INTRODUCTION

1.1 Yirrganydji Country overview

Location

Situated in Far North Queensland, Yirrganydji Country comprises both land Country from Cairns to Port Douglas and sea Country extending "from the coastline to the horizon" (Dawul Wuru Aboriginal Corporation 2014). Yirrganydji Country is characterised by its rainforestcovered mountains, dense mangroves, and tropical Pacific waters that form parts of the UNESCO-listed Wet Tropics and Great Barrier Reef.

Figure 1: Yirrganydji Country (adapted from Engineers Without Borders Australia (2022b)).

Social context

There are approximately 3,000 Yirrganydji Traditional Owners presently living on Country, most of whom reside in Cairns as well as in the towns of Kuranda and Yarrabah (Engineers Without Borders Australia 2022d). To this day, they continue to uphold their traditions, passing down knowledge to younger generations, and both maintaining a connection to and caring for Country.

Yirrganydji people practise traditional food and resource gathering (including protected species) in accordance with a Traditional Use of Marine Resources Agreement (TUMRA), through which government bodies regulate traditional resource use to ensure sustainability, cultural appropriateness, and humane collection methods (Dawul Wuru Aboriginal Corporation 2019). The TUMRA also supports the Yirrganydji community to develop and employ collaborative programs, such as the Land and Sea Ranger teams that conduct fieldwork and land management, run education workshops, and deter and combat illegal activities (Dawul Wuru Aboriginal Corporation 2019).

Cultural context

The Yirrganydji people have a culture that is deeply interconnected with their land and sea Country, with a rich and nuanced understanding of the natural environment that has been refined and passed on over thousands of years (Great Barrier Reef Marine Park Authority 2022). For Yirrganydji people, 'Country' is not limited to the physical realms of the land and sea; it also encapsulates human relationships, arts, philosophy, and spirituality (Engineers Without Borders Australia 2022d).

1.2 Dawul Wuru Aboriginal Corporation and Engineers Without Borders Australia

Dawul Wuru Aboriginal Corporation (DWAC) is an "Aboriginal Traditional Owner owned, managed, and governed community organisation" (Dawul Wuru Aboriginal Corporation 2022a) situated on Yirrganydji Country. Since its establishment in 2010, DWAC's focus has been to defend, maintain, and improve local First Nations' capabilities to retain their cultural identities and traditional practices. Multiple successful projects have been implemented on Country – such as the Yirrganydji Land and Sea Ranger program – which uphold traditional values and create education and employment opportunities (Dawul Wuru Aboriginal Corporation 2019).

Engineers Without Borders Australia (EWB) is a non-profit organisation that aims to assist and empower underprivileged communities, undertaking a range of humanitarian engineering projects both domestically and globally (Engineers Without Borders Australia 2018). EWB typically partners with a local organisation that provides contextual knowledge and on-the-ground support. EWB is currently collaborating with DWAC to help improve the livelihoods of the Yirrganydji and neighbouring Aboriginal communities, and to help them retain a powerful and lasting connection to Country (Engineers Without Borders Australia 2022d).

2 LITERATURE REVIEW

2.1 Yirrganydji Country land tenure

Yirrganydji Country is used by its Traditional Owners for several purposes, such as cultural practices, hunting/gathering resources, and office facilities for strategic planning and administration (Dawul Wuru Aboriginal Corporation 2022b). Mangrove habitat is abundant in Yirrganydji Country (Vinall 2019), which has led DWAC and EWB to explore carbon abatement project opportunities.

2.2 Carbon sinks

The term 'carbon sink' is used to describe anything – be it artificial or naturally-occurring – that absorbs carbon at a higher rate than it releases it into the atmosphere (Selin 2019). The main natural carbon sinks are plants, oceans, and soils. Photosynthetic organisms such as plants and algae play a major role in mitigating carbon emissions, and together with soils and other land-based ecosystems annually sequester over 2.6 billion tonnes of carbon dioxide (CO_2) (Selin 2019).

2.3 The Kyoto Protocol and the Paris Agreement

In 1997, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (or simply the 'Kyoto Protocol') was adopted. This involved several market-based mechanisms using carbon credits to incentivise reductions in greenhouse-gas (GHG) emissions. Despite evidence that the Kyoto Protocol was partially successful (Maamoun 2019), the Paris Agreement Under the United Nations Framework Convention on Climate Change (the 'Paris

Agreement') was signed in 2015 during the 21st Conference of the Parties (COP21). This new treaty was developed to replace the Kyoto Protocol after its expiry in 2020 and outlined the goal of limiting the mean global temperature increase to less than 2°C (ideally 1.5°C) above pre-industrial levels (The Editors of Encyclopaedia Britannica 2022). Unlike its predecessor, the Paris Agreement was both legally binding and included all countries; this addressed the major flaw that saw China (the world's largest contributor of GHGs) and India exempt from the Protocol due to being classed as developing countries, and the United States of America also excluded having not ratified the protocol (Maamoun 2019). The Paris Agreement requires countries to develop their own nationally determined contributions (NDCs), which are essentially detailed plans that describe how they each intend to reduce their GHG emissions in accordance with the treaty.

2.4 Australia's nationally determined contributions

One of Australia's key NDC components is the Australian Carbon Credit Unit (ACCU) Scheme, formerly known as the Emissions Reduction Fund (Department of Climate Change, Energy, the Environment and Water 2024). This scheme enables farmers, landholders, businesses, state governments, and local councils to participate in Australia's own carbon market. Australian Carbon Credit Units – which each represent one tonne of CO_2 equivalent in GHG emissions – are generated over time through projects that either reduce GHG emissions or sequester CO_2.

For a project to be eligible for the scheme, it must be new and not already delivered under some other regulatory compliance or with other government funding (Clean Energy Regulator 2021). Registration with the regulator entails some 'abatement estimate' to be made, using expert advice and complex modelling tools like the Full Carbon Accounting Model. The model can distinguish environments with differing carbon sequestration capacities (e.g., underground versus surface biomass), and applies unique 'vegetation methodology determinations' depending on the nominated carbon abatement activities. Examples of these methodology topics include "avoidance of native regrowth clearing, human-induced native forest regeneration, and native forest growth from managed forest" (Department of Climate Change, Energy, the Environment and Water 2020).

2.5 Mangroves and blue carbon

'Blue carbon' refers to carbon sequestered within coastal and marine ecosystems, such as kelp forests, seagrass beds, and mangrove forests. The term 'mangrove' refers to a group of approximately 65 plant species that have adapted to exist in intertidal zones (Department of Environment and Science 2019). These plants range in shape and size, appearing as shrubs, trees, or palms. Despite this, they all share the ability to thrive in high-salinity environments such as seawater, classifying them as halophytes. As a collective noun, 'mangrove' describes the unique type of ecosystem that mangrove plants form alongside other certain halophytic plants, as well as a range of animals, microbes, bacteria, and fungi (Australian Institute of Marine Science 2022).

As shown in Figure 2, mangroves have a significantly higher carbon storage capacity than purely terrestrial forests, storing up to five times more carbon than tropical upland forests (Chatting et al. 2022). Mangroves typically have a complex, sprawling root system, exposed to the surface to allow access to the oxygen required for aerobic respiration while also extending into the oxygen-poor soil beneath, predominantly for structural support (Alongi 2012). These roots trap carbon-containing debris and sediment, causing it to accumulate underground. The roots that die underground are also trapped, adding to the organic matter which undergoes a very slow decomposition that increases the level of captured CO_2 and allows for the formation of a carbon-dense soil called peat (Izquierdo 2017).

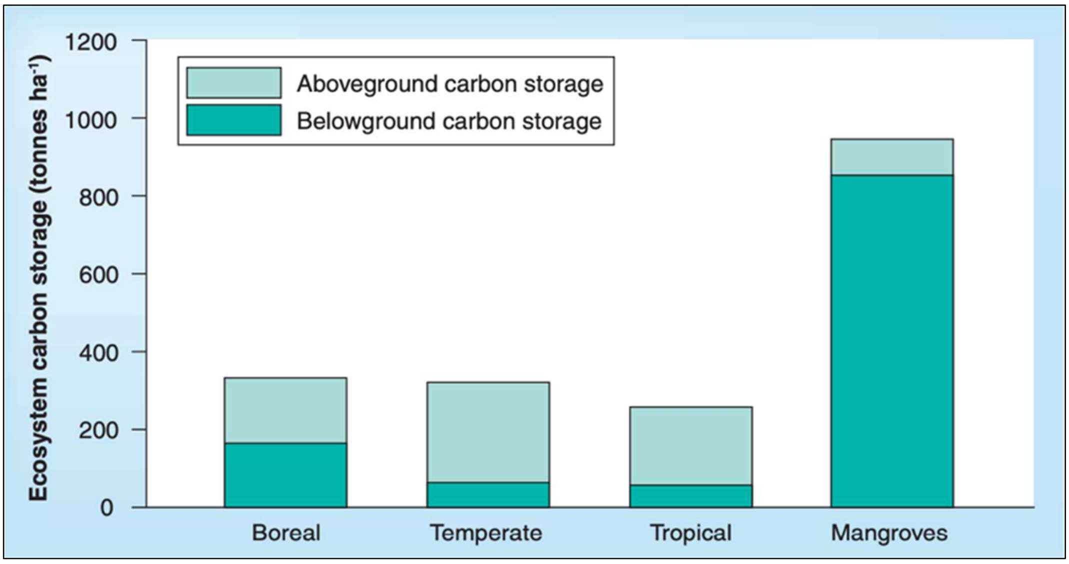

Figure 2: Comparison of the carbon storage capabilities of different types of forest (Chatting et al. 2022).

2.6 Case study one: First Nations carbon offset schemes in Australia

Robinson et al. (2016) interviewed representatives from more than 100 First Nations organisations from across Australia to understand their motivations for pursuing and engaging in carbon payment for ecosystem services (PES) schemes. These schemes financially incentivise activities that deliver improved ecosystem services, such as air and water purification, food, and shelter. Participants were posed the question: "What benefits are desired by the local Aboriginal community participating, or interested in engaging, in a carbon PES scheme?" The most common responses were:

- Participation is viewed as a pathway to improved Indigenous economic development and self-esteem (92%).
- Local ways of life and landscapes are able to be maintained (88%).
- Indigenous communities play a central role in the planning and decision making of PES projects (83%).
- Indigenous communities have professional development and networking opportunities, leading to improved employment and conservation (both cultural and environmental) outcomes (71%).

- Plantation projects should incorporate native flora that improve the 'health' of the environment by creating cultural, ceremonial, or culinary value (65%).

Overall, Robinson et al. (2016) concluded that successful First Nations PES carbon schemes must identify and maintain the equilibrium between First Nations' needs and carbon sequestration. This involves conducting preliminary negotiation with First Nations stakeholders as well as active collaboration throughout the entire project – including full transparency of information between parties – to account for the delivery of First Nations co-benefits. Additionally, carbon abatement capacity and project finances must be assessed and managed judiciously.

2.7 Case study two: Mangrove restoration in the Indian Sundarbans

The Sundarbans are the largest mangrove forest on Earth, covering roughly 10,000 km^2. They have been World Heritage-listed since 1987 (UNESCO World Heritage Convention 2022) and were recently granted Ramsar Wetland status (Ramsar Sites Information Service 2019). As shown in Table 1, the climate of the Sundarbans is quite similar to that of Yirrganydji Country, with both regions experiencing frequent thunderstorms which occasionally develop into cyclones.

Table 1: Comparing the climate of the Sundarbans and Yirrganydji Country (Bureau of Meteorology 2022a; Bureau of Meteorology 2022b; World Heritage Datasheet 2022)

Climate Measure	**Sundarbans**	**Yirrganydji Country**
Average max (°C)	34	29.4
Average min (°C)	20	21
Annual rainfall (mm)	2000	1975
Average humidity (%)	75	65

Over a five-year period, Chowdhury et al. (2019) analysed the costs and success rates of community-orchestrated mangrove plantation projects on the Sundarbans' Satjelia Island. This involved the restoration of over 100 hectares of barren mudflats across 10 separate sites. Five endemic mangrove species (that also occur in Yirrganydji Country) were selected for planting:

- *Avicennia marina* (grey or white mangrove; Atlas of Living Australia 2022b)
- *Bruguiera sexangula* (northern large-leaved mangrove or upriver orange mangrove; Atlas of Living Australia 2022d)
- *Ceriops tagal* (spurred mangrove; Atlas of Living Australia 2022e)
- *Rhizophora mucronata* (long-fruited stilted mangrove; Atlas of Living Australia 2022c)
- *Xylocarpus moluccensis* (cedar mangrove; Atlas of Living Australia 2022a)

Each of these species exhibit viviparous reproduction, meaning that their seeds germinate while still attached to the parent plant. This results in the development of growths called 'propagules', which quickly establish roots after detaching from the parent and encountering a suitable substrate (Simpson 2019). If the buoyant propagules fall into the sea after detaching, they can float for long periods of time, allowing for transoceanic dispersal and population establishment elsewhere (Van der Stocken et al. 2018).

Three different plantation techniques were trialled by Chowdhury et al. (2019). Their key features are summarised in Table 2.

Table 2: Comparing key features of different mangrove plantation methods

Plantation Method	**Key Steps**	**Comments**
Direct Sapling Planting	1. Saplings transplanted from nurseries after growing for ~75 days. 2. Plantation zone cleared. 3. 1 ft^3 pits excavated at 6 ft intervals, then left to fill with soft mud from tidal movement. 4. Saplings planted in centre of pits.	Relatively labour-intensive.
Drain and Trench	• Used in conjunction with 'Direct Sapling Planting', with species with 'stilt root' systems (e.g., *Rhizophora mucronata*). • Drains excavated along the mudflat's natural gradient, 6 ft (length) * 1 ft (width) * 1.5 ft (depth).	Captured rainwater helps regulate salinity.
Direct Propagule Dibbling	1. Seeds (i.e., propagules) collected (in this study by local fishermen). 2. Making small indents in the mud. 3. Inserting propagules into the prepared indents, with care taken to avoid damaging roots or stems that may have developed.	Only *Avicennia marina* was evaluated using this technique in this study, but it can also be used for other species and typically leads to a higher number of mangroves per hectare.

Soil samples from each plantation site were analysed between 2012 and 2016, with organic carbon density (OCD) used as a key carbon sequestration measure for each mangrove species. The data showed that *A. marina* seed (using direct propagule-dibbling) resulted in the highest OCD increase over the five-year period, while *C. tagal* (using the direct-sapling planting method) showed the lowest OCD increase. The findings are summarised in Table 3.

Table 3: Changes in OCD at five mangrove plantations between 2012 and 2016 (Chowdhury et al. 2019)

Mangrove Species	**Organic Carbon Density (OCD)**				
	2012	**2013**	**2014**	**2015**	**2016**
A. marina	60	65	85	98	111
A. marina seed	66	78	105	116	132
B. sexangula	55	65	78	81	85
C. tagal	57	69	71	73	83
R. mucronata	54	64	70	80	91
X. moluccensis	69	72	81	84	87

Table 4 shows the average height and survival rate for each species at the end of the five-year Chowdhury et al. (2019) study. '*A. marina* seed' refers to the species planted using the direct propagule dibbling method, whereas the other listed species are all nursery-grown saplings (rather than propagules) that were transplanted at different restoration sites. Note that the number of saplings/propagules planted varies significantly between species; those with a relatively smaller sample size (i.e., number of saplings/propagules planted) will have survival rates with lower confidence levels.

Table 4: Average height and survival rates observed from different mangrove species at the end of a five-year study period (adapted from Chowdhury et al. 2019)

Mangrove Species	**No. of Saplings or Propagules Planted**	**Avg Height (ft)**	**No. of Plants Survived**	**Survival Rate (%)**
A. marina	69366	8'2"	56505	81.46
A. marina seed	710000	8'2"	192628	27.13
B. sexangula	1964	4'4"	770	39.21
C. tagal	264	5'6"	264	100
R. mucronata	32382	6'	18009	55.61
X. moluccensis	4309	5'9"	1860	43.17

Although Chowdhury et al. (2019) concluded that direct propagule dibbling of *A. marina* was the most cost-effective among each of the plantation configurations utilised across the 10 sites on Satjelia Island, several important contextual considerations and post-plantation management practices were identified. Variables such as soil composition, tidal influence, salinity, labour cost, and availability of mangrove propagules must be assessed independently at a local level prior to the design of a plantation project. Then risk factors including livestock grazing, logging of young trees, algal growth, barnacle infestation, and crab attacks should be incorporated into post-plantation management plans (Chowdhury et al. 2020).

2.8 Other case studies

Other relevant case studies that readers might be interested in exploring further cover topics such as: successful mangrove restoration along an artificial tidal creek in Western Australia (Erftemeijer et al. 2017), the role of Indigenous communities in Asia-Oceania in managing natural resources (Sangha et al. 2019), the conversion of an urban Brisbane dump-site into a thriving mangrove ecosystem (Coleby-Williams 2020), assessment of mangrove dieback factors in Kakadu National Park (Asbridge et al. 2019), the effect of mangrove biomass on aquacultural production in Indonesia (Sumarga et al. 2022), mangrove restoration by fishing communities in Indonesia (Firdaus et al. 2021), and economic opportunities (including carbon abatement projects) for remote First Nations communities in the Northern Territory (Sangha et al. 2020).

3 METHOD AND METHODOLOGY

3.1 EWB Australia's Technology Development Approach

Human-centred design is a problem-solving approach that places human perceptions and emotions at the core of each phase of the design process (Landry 2020). This approach ensures that projects successfully address the needs and values of relevant stakeholders. EWB has adapted human-centred design into a fit-for-purpose framework called the Technology Development Approach (TDA; Engineers Without Borders Australia 2022c), which is suited to the unique range of humanitarian work that they carry out. The TDA is comprised of five key elements: Knowledge Sets, Guiding Principles, Design Process, Collaboration Styles, and Tools and Techniques.

Knowledge Sets

This element is based around the requirement of three specific knowledge sets for the effective design of human-centred projects, i.e., *technical*, *contextual*, and *process* knowledge, as depicted in Figure 3. Relevant examples of each type of knowledge set are summarised in Table 5.

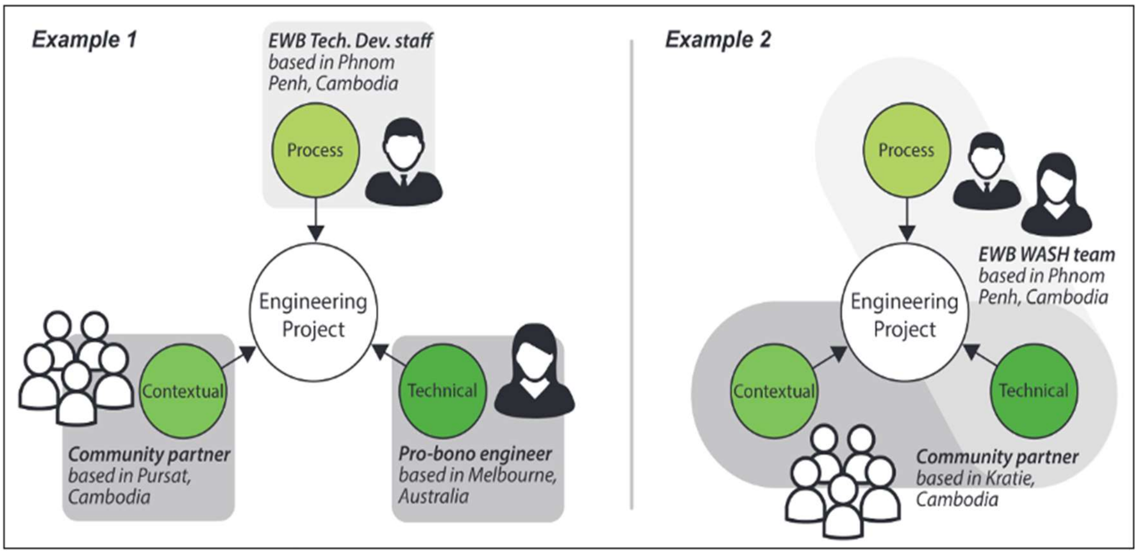

Figure 3: Examples of the key knowledge sets required for the delivery of effective human-centred engineering projects (Engineers Without Borders Australia 2022c).

Table 5: Example knowledge sets

Knowledge Set	**Examples from this Project**
Contextual	DWAC context, Yirrganydji land tenure
Technical	Mangrove sequestration rates, carbon abatement policy
Process	project management techniques, EWB design approach

Guiding Principles

The TDA follows 10 'Guiding Principles' derived from EWB's own values as well as human-centred engineering-focussed literature. The Guiding Principles are summarised in Figure 4.

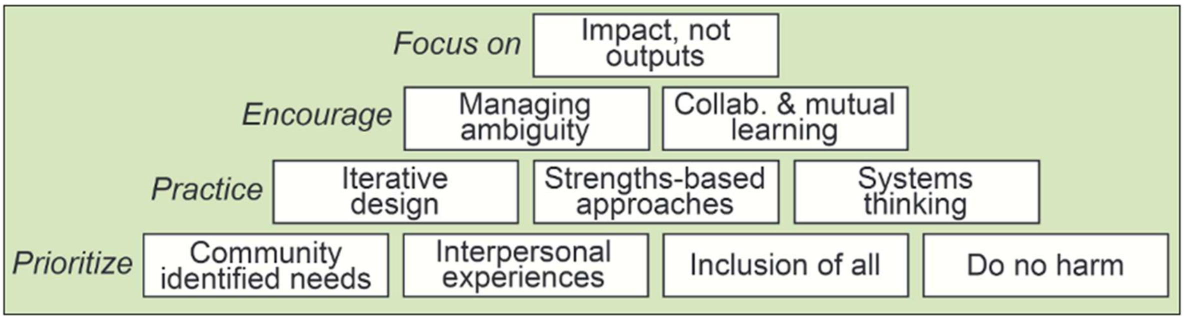

Figure 4: Summary of the guiding principles of human-centred engineering (Engineers Without Borders Australia 2022c).

Design Process

Humanitarian engineering projects are often highly variable in scope, ranging from tangible technical designs to abstract methodologies. To accommodate this, EWB developed the TDA Design Process by tailoring a framework known as the 'human-centred engineering design process' which incorporates the 'Double Diamond' model (see Figure 5 below).

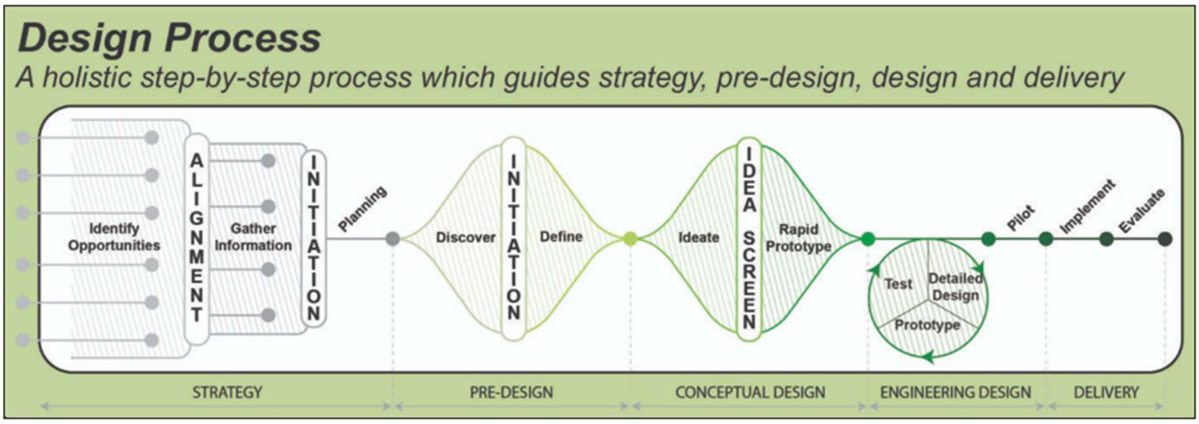

Figure 5: The Technology Development Approach Design Process (Engineers Without Borders Australia 2022c).

This study falls within the *strategy* and *pre-design* stages, i.e., between *alignment* and the second *initiation* phase (Figure 5). Existing information had already been internally "reviewed against EWB values, strategy and risks" (Engineers Without Borders Australia 2022c) by EWB to *identify opportunities* related to blue carbon on Yirrganydji Country, which allowed for this project topic to be listed under the EWB Research Challenge. This study focusses on *gathering* and synthesising information to evaluate project potential and make recommendations to assist in possible subsequent stages of the design process (likely to be undertaken by other Research Challenge participants working on related topics).

Collaboration Styles

Rather than engineers making every project decision on their own (with little to no community engagement, i.e., passive interaction; Mazzurco et al. 2018) projects should incorporate meaningful stakeholder participation. The participatory collaborative approaches typical of EWB projects include (in order of increasing stakeholder input): *human-centred design*, *co-design, co-production,* and *community-led design*.

Tools and Techniques

EWB utilises a diverse range of tools and techniques that cater to each design stage, divided into five categories based on the desired objective. These categories are shown below in Table 6*,* alongside examples related to either the pre-design or conceptual design stages (while the latter set of examples are not directly applicable to the scope of this study, they may be useful to anyone conducting further work).

Table 6: Example TDA tools and techniques applicable to this study (adapted from Engineers Without Borders Australia 2022c)

Category \ Stage	Pre-design	Conceptual Design
Contextual Learning	• Interviewing • Community asset mapping • Empathy mapping	• Co-design idea selection • Value proposition mapping • Storyboarding
Creativity	• Co-design of project requirements	• Brainstorming • Idea screening • SWOT (strengths, weaknesses, opportunities, and threats) analysis
Human Factors	• Ergonomic principles • Task analysis • User wants and needs	• Behavioural economics • User-experience design • Inclusive development
Systems Thinking	• Value chain mapping • Systems dynamics • Collaborative conceptual modelling	• Leverage point identification • Value vs. complexity mapping • Stakeholder ecosystem mapping
Technology Development	• Quality function deployment • Market research • Commercial and cultural intellectual property	• FMEA (failure modes and effects analysis) • Design for X

3.2 Design evaluation categories and criteria

Site location

The first criterion in identifying a suitable site location is *accessibility*. While not essential, it is beneficial for a plantation site to be readily accessible. This should consider the adequacy of roads and their proximity to the site, as well as its connectedness to townships and emergency facilities such as medical centres.

The site location should provide mangrove saplings with sufficient *protection* against wind, waves, and tidal currents. While some mangrove species have adaptations that protect them from these factors, it is nonetheless preferable for plantations to be situated in areas with natural barriers, e.g., mature trees, coral reefs, or sand banks.

The site should also have *soil and water characteristics* that support the growth of mangrove seedlings or saplings. Whilst an in-depth analysis has not been undertaken (due to a lack of relevant data and the inability to physically access each site), the expected soil type and tidal influence at each location can be inferred from sources such as satellite imagery. Though there is some variability, most species prefer tidal entrances with well-proportioned brackish water, as well as nutrient-rich soils that receive organic matter from sources such as adjoining mangrove forests (Department of Environment and Science 2019).

Mangrove species

Another criterion is that the chosen mangrove species should exhibit strong *resilience* against factors including salinity, tidal inundation, temperature fluctuation, and sandy soil; otherwise, the growth and/or survival rates of the mangroves would be greatly reduced (Asian Development Bank 2018).

Perhaps the most important factor to consider when selecting a mangrove species is the rate of *carbon sequestration* that it can provide, as this directly correlates with the resulting environmental and economic impacts.

Another important criterion is the *growth rate*. While growth rate and carbon sequestration are related, they are not directly proportional, as carbon sequestration is also driven by factors such as root structure (affecting the collection and accumulation of sediment and organic debris). Faster growth will likely increase survival rates due to improved resistance against factors such as wind, waves, and tidal currents. Habitat generation and biodiversity increase is also likely to occur faster due to the expansion of root systems, branches, and foliage (Department of Environment and Science 2019).

Plantation method

The first criterion regarding plantation methods is *cost*, as it is important that the chosen method is financially appropriate and accounts for the finite monetary power available to DWAC and EWB.

The second plantation method-related criterion is the *difficulty* of implementation. Reducing the logistical complexity associated with a project will assist in ensuring a punctual delivery that satisfies budget requirements.

The plantation method should also involve a high level of *community involvement*, as socio-cultural impact is one of the key deliverables of the project and should be considered equally important as economic and environmental impact.

4 ANALYSIS

4.1 Potential site locations

The sites chosen for evaluation have been classified as "areas of interest" by EWB (Engineers Without Borders Australia 2022a), as they have identified a higher likelihood of obtaining access to and use of these sites via mechanisms such as Native Title determination or buyback of privately-owned freehold. It is nevertheless possible that DWAC and the Yirrganydji community will acquire land in areas that have not been included in this study. In this scenario, any relevant information from the three discussed locations should be mapped to an alternative location, with additional research undertaken prior to deciding whether it could be a suitable plantation site. The potential site options are described below.

Yule Point

Mangrove habitat is already prevalent throughout this site, although the plants are somewhat sparse in some locations, leaving adequate space for a plantation project to be undertaken. The site appears to be easily accessible, as it is close to a major highway and only 16 km from Port Douglas. The existing adult trees could provide saplings with some protection, although most of the site is very exposed to wind, waves, and tidal movement. Soil across most of the site appears to be comprised of sand with low to moderate amounts of organic matter due to its relatively 'clean' appearance, and there do not appear to be many above-ground sources of freshwater outflow, indicating that salinity levels are close to that of seawater.

Dungarra

Also known as Redden Island, Dungarra is located on the northern side of the Barron River mouth. This site is located 10 km from Cairns' centre and can be rendered inaccessible during the wet season if the only entrance road becomes submerged (Engineers Without Borders 2022b). Activities should be planned accordingly. Good levels of protection are provided from the vegetation and sand banks alongside the river, although the ocean side of the site appears to be very exposed to wind and waves. The soil close to existing vegetation (i.e., alongside the riverbanks) appears to be muddy and nutrient-rich, and the freshwater from the Barron River likely results in a desirable salinity level.

Taylor Point

This site is located at Trinity Beach, a Cairns suburb approximately 20 km from the city centre. The beach and creek are readily accessible via footpath, and services (e.g., medical facilities) are available within the town. The headland and sand flats appear to offer some protection from the wind and waves, dependent on direction. The existing mangroves indicate the soil has adequate nutrients and salinity levels, although consideration should be given to the varying adaptability of different mangrove species.

4.2 Potential mangrove species

The mangrove species chosen for evaluation were confined to those listed in the Sundarbans case study (cf. Section 2.7) to allow valid comparisons of factors such as carbon sequestration and growth rates. Only the results from the 'transplantation of nursery-raised seedlings' method were analysed to compare these factors, as *A. marina* was the only species that was also planted via 'direct propagule dibbling'. As previously stated, each mangrove species from the case study is commonly found throughout Australia.

Avicennia marina

A. marina is the most common mangrove found in Australia (Department of Environment and Science 2019). This is attributed to its high salt tolerance, tolerance of a wide range of temperatures and soil conditions, and resistance to wind, waves, and tidal movement (Samuel 2014). *A. marina* also exhibited the highest carbon sequestration and growth rates among each of the five species from the case study.

Rhizophora mucronata

This species is well-adapted to survive in areas susceptible to regular inundation and is also able to resist wind, waves, and currents due to its strong "stilted" root structure (Atlas of Living Australia 2022c). This species recorded the second highest carbon sequestration rate and average plant height over the five-year case study period.

Xylocarpus moluccensis

Typically found alongside rivers and creeks, *X. moluccensis* prefers muddy, nutrient-rich soils and moderate levels of salinity (Atlas of Living Australia 2022a). This species recorded the third highest carbon sequestration and growth rates of those studied and notably can reach heights of up to 30 m (Atlas of Living Australia 2022a).

4.3 Potential plantation methods

The first plantation method that has been selected for evaluation is 'transplantation of nursery-raised seedlings'. As outlined in Section 2.7, this method involves raising mangrove seedlings within a controlled nursery environment until they have reached sapling stage, at which point they are transplanted into pits that have been prepared at the plantation site. This method is relatively costly compared to alternative methods, although survival rates are typically higher (Chowdhury et al. 2019). The need for a nursery increases the logistical complexity of this method, although operating and maintaining it could create opportunities for community involvement alongside potential community involvement during site preparation, transplantation, and post-transplantation management.

The second plantation method that has been chosen is 'direct propagule dibbling'. As mentioned in Section 2.7, this technique involves the collection of mangrove propagules which are usually gathered from the shoreline, beneath adult trees, or from the water's surface. This method is significantly cheaper and simpler than sapling transplantation due to the lack of nursery-related costs and operation requirements, as well as the logistical simplicity of transporting small propagules versus 75-day-old saplings. The community can be involved in this approach through the collection and planting of propagules as well as the monitoring of established plantation sites.

5 DISCUSSION

5.1 Limitations and assumptions

Due to limited data being available, some simplifying assumptions have been made. Investigating these assumptions is recommended for future research to bring more nuance to the findings and conclusions:

- Yirrganydji-related design considerations have largely been sourced through contact with EWB, rather than directly from DWAC or Yirrganydji community members out of respect for both resourcing capabilities and privacy.
- The characteristics and viability of potential plantation sites have been largely based on the analysis of satellite imagery, social media posts, and council websites due to inability to physically inspect these sites.
- It has been assumed that the Yirrganydji community and/or DWAC will successfully acquire land in the near future.
- It has been assumed that both the ACCU Scheme (i.e., no significant changes are made to the existing scheme) and the economy (including the carbon market and national and global economies in general) are relatively stable.
- The proposed design approach involves planting one species of mangrove. It is possible that planting a range of species at the chosen location may yield more favourable results than a monoculture, but investigating this is beyond the scope of this study.
- The organic carbon density (OCD) calculations discussed earlier are limited to a dataset collected over a five-year period. It is likely that the OCD and associated sequestration rate of each mangrove species are not constant over time and may change as the mangroves mature, but such detailed data was unable to be found.
- Mangroves are fragile, eco-sensitive species that exhibit regional adaptations. The Sundarbans will invariably have different abiotic factors and species compositions to the mangrove habitats in Yirrganydji Country, so blue carbon sequestration dynamics could differ significantly between the two locations.

5.2 Recommended design selections

Recommended site location

Dungarra achieved the highest total score among the three potential site locations (see Table 7 below), as it is highly accessible (disregarding flooding events, as any plantation site on Yirrganydji Country would likely be rendered inaccessible under such circumstances), has desirable protective features, and appears to have very good soil and salinity conditions. As healthy mangroves ecosystems are present at each of the evaluated sites, it is possible that all three would be able to support a plantation site. As previously stated, there is no guarantee that any of the discussed sites will actually be returned to the Yirrganydji Community. In the case that alternative locations are acquired by the Yirrganydji Community/DWAC in the near future, the site considerations that were used in this study should be applied accordingly.

Table 7: Evaluated site locations

Site Location	Criterion	Score 1 - Low	2 - Good	3 - Excellent
Yule Point	Accessibility			X
	Protection		X	
	Soil and Water Characteristics	X		
Dungarra (Redden Island)	Accessibility			X
	Protection		X	
	Soil and Water Characteristics			X
Taylor Point	Accessibility			X
	Protection		X	
	Soil and Water Characteristics		X	

Recommended mangrove species

A. marina achieved excellent scores for each of the three criteria (as shown in Table 8) due to its resistances to high salt levels, extreme temperatures, tidal inundation, currents, winds, and waves as well as its high carbon sequestration and growth rates in comparison to the other mangrove species examined in the Sundarbans case study. Depending on the physical characteristics of available site locations, different mangrove species may be more appropriate, as certain species are highly adapted to specific ecosystems. For example, some mangrove plants thrive in swampy, forested areas, while mangroves such as *R. mucronata* develop robust stilt roots that enable them to assist strong wind and waves.

Table 8: Evaluated mangrove species

Mangrove Species	Criterion	Score 1 - Low	2 - Good	3 - Excellent
Avicennia marina	Resilience			X
	Carbon Sequestration			X
	Growth Rate			X
Rhizophora mucronata	Resilience			X
	Carbon Sequestration		X	
	Growth Rate		X	
Xylocarpus moluccensis	Resilience		X	
	Carbon Sequestration		X	
	Growth Rate		X	

Recommended plantation method

Direct propagule dibbling achieved the highest evaluation score between the two mangrove plantation methods (see Table 9). This is largely due to the comparatively high cost and difficulty associated with a nursery, as such a facility would generate significant resourcing and logistical requirements. While this could allow for additional community involvement opportunities, this criterion is also effectively addressed in the propagule dibbling method during propagule collection, planting, and plantation site management.

Table 9: Evaluated plantation methods

Plantation Method	Criterion	Score 1 - Low	2 - Good	3 - Excellent
Nursery Transplantation	Cost	X		
	Difficulty	X		
	Community Involvement			X
Direct Propagule Dibbling	Cost			X
	Difficulty		X	
	Community Involvement			X

5.3 Additional considerations

In addition to the recommended design options, several other key considerations must be incorporated to ensure the project delivers optimised impact:

- Yirrganydji representatives and DWAC should be consulted to identify any additional needs that have not been covered within this study.
- Wherever possible, designs should also make use of materials that are readily available on Country, sustainable, and aligned with Yirrganydji cultural practices.
- Resources required during preparation, implementation, and operation/maintenance of the plantation site (e.g., propagule collection could be undertaken either through paid contractual agreements, or voluntarily).
- While there are many benefits to community involvement, it is essential that the chosen approach does not result in a risk of community burden.
- Plantation sites must be actively maintained during the 18–24-month period after the initial planting activity has been conducted (Chowdhury et al. 2020), as seedlings are vulnerable to factors such as algae, barnacles, herbivorous insects, and organic debris (Asian Development Bank 2018).
- The wet season from November to March is typically associated with an increased risk of flooding and cyclones, as well as high humidity (Bureau of Meteorology 2024).
- Areas that are currently suitable for plantation sites could become unviable in the future due to sea-level rise. Conversely, areas that are currently at higher elevations may eventually become suitable mangrove habitat as the intertidal zone shifts.
- Risk management planning must be undertaken prior to working on plantation sites, as there are many hazards prevalent around typical mangrove habitat in the region including saltwater crocodiles, venomous fauna, and tidal movement.

6 CONCLUSION

The objective of this study has been to identify potential design options for a blue carbon scheme on Yirrganydji Country. While alternative design configurations could also be used to achieve this objective, this study has shown that:

- The most suitable mangrove plantation site (from those specified as "areas of interest" by EWB) is Dungarra.
- The most suitable mangrove species to be planted is *Avicennia marina* (also known as the grey mangrove).
- The most suitable plantation method is direct propagule dibbling.

If successfully implemented and registered under the ACCU Scheme, a mangrove plantation project on Yirrganydji Country will create economic value through the generation of carbon credits.

Environmental value will be delivered through carbon sequestration, biodiversity increases from habitat generation, as well as the protection that mangroves offer against wind and coastal erosion.

Socio-economic value will also be achieved, as the implementation and operation of a plantation project will create opportunities for the Yirrganydji community to care for and heal Country. Participation in such an activity would allow Yirrganydji community members to develop transferable skills and technical knowledge, as well as exposure to professional connections that could lead to job opportunities.

6.1 Recommendations for future research

As this study is intended to act as a guide to inform the subsequent design stages of a mangrove plantation project in Yirrganydji Country, a list of recommended actions and pathways for research has been provided. These are as follows:

- Identify alignment between Yirrganydji community needs and values and carbon project-specific outcomes (cf. Section 2.6).
- Investigate modular designs for storage facilities or nurseries, as land is often allocated to First Nations groups or representative bodies as a temporary leasehold, making transportability desirable.
- Analyse soil and water conditions at potential plantation sites to determine parameters such as soil type, soil nutrients, salinity, and tidal influence.
- Conduct pilot testing or prototyping of mangrove plantations at areas of interest to identify survival rates and feasibility (with permission from relevant authorities).
- Research local and government regulations concerning mangrove propagule collection, storage, and plantation (note: collection of propagules by the Yirrganydji community could be permissible as per the TUMRA agreement, cf. Section 1.1.2).
- Investigate opportunities for concurrent projects unrelated to carbon abatement (e.g., sustainable tourism at plantation sites) and the potential for non-mangrove carbon abatement activities to be incorporated (e.g., salt marsh restoration in areas adjacent to mangroves that feature more favourable conditions to restore the former ecosystem type).
- Investigate opportunities for grants, public funding, and other subsidisation avenues.

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