Assessment of Ecosystem Impacts by Engineering Measures Using the Concept of Building with Nature

C Y Chen¹ and C R Ku²

¹ Department of Civil and Water Resources Engineering, National Chiayi University, Chiayi City 60004, Taiwan R.O.C.
² Liu-Yi Development Co., Ltd, Tainan City, Taiwan R.O.C.

Abstract. A field investigation monitored a river restoration indicator, Kandelia, following the idea of Building with Nature (BwN). The main objective of the present study is to understand the relationship between Kandelia growth areas and river patterns; such an understanding can support river watershed management after engineering measures have altered rivers. The fitness-existence of Kandelia was evaluated through measurements and numerical simulations of river discharge, flow velocity, and depth of the river flow. The ecological survey results showed that although the quantity of Kandelia exhibited periods of growth and decline, the overall quantity did not change substantially. Even though the growing area shrunk, the number of Kandelia plants did not decline and the biomass density increased. The flow rate was less than 0.4 m/s, equivalent to static. The numerical simulations indicated that the downstream sandbar area favored the growth of Kandelia, even under floodwater after typhoons had brought rain. When typhoons bring rain, the upstream has a high flow rate, which is not conducive to plant growth. A 5S model and a SWOT analysis were used for a comprehensive analysis. The indicator Kandelia is a local ecosystem index of environmental impacts after engineering measures have been conducted. The results may be used as a reference for river watershed engineering planning and to enhance the concept of BwN.

1. Introduction
Climate change has recently caused numerous natural disasters worldwide. We are forced to consider different measures for disaster prevention and mitigation and are obligated to alleviate stress on the natural ecosphere. Engineering measures for disaster prevention and mitigation require financial expenditures and have effects on the ecosystem. It would be desirable to reduce the ecological footprint of engineering measures by the restorative capacities of nature. The program of Building with Nature (BwN) is sourced from the Netherlands [1]. The core element of the philosophy is to provide a solution that integrates both engineering design and protection of the natural environment. The philosophy entails learning the principles of ecosystem restoration and engineering design; the purpose is to develop more effective and sustainable hydraulic infrastructure. Engineering planning has rarely been concerned about the impacts on the natural environment; in 1970, in the Netherlands, scholars sought to promote both economic development and environmental protection simultaneously. Government provisions were made for planning engineering measures to minimize harm to the environment. The initial core concept was “Building in Nature,” which asserted that when planning measures, engineers should consider their effects on nature. The concept was further enhanced into “Building of Nature.” In the 1990s Environmental Impact Assessment laws of the Netherlands, the notion of “reshape nature” was introduced to mitigate the impacts of engineering measures.
construction. A slogan, “Room for the River,” was proposed at this stage; this slogan was used in the plan of Black Stork [2]. The concept of the Room for the River Program was to allocate land area to the river to accommodate and manage higher water levels. The engineering planning for the program included lowering of floodplains, deepening of summer bed areas, storing water, relocating dikes, creating high water channels, lowering groynes, removing polders, removing obstacles, and strengthening dikes [3]. The habitat area of native aquatic plants in floodplain wetlands is a local ecosystem indicator of “Building of Nature.”

In recent years, BwN proposals have planned engineering projects for the benefit of the natural environment [4]. The idea of BwN is to promote natural development of the environment to reduce the ecological footprint of engineering measures; ultimately, it is hoped that this will benefit humankind. BwN combines diverse purposes, including safety, sustainability, nature, and socioeconomic development for the benefit of coastal communities and river delta communities [4-9]. The following five steps are adopted for the implementation of BwN design [4]:

- Understand the system (including ecosystem services, values, and interests).
- Identify realistic alternatives that use or provide ecosystem services.
- Evaluate the qualities of each alternative and preselect an integral solution.
- Fine tune the selected solution (in light of practical restrictions and the governance context).
- Prepare the solution for implementation in the next project phase.

Rivers in Taiwan are short in length and have steep slopes that cause soil deposition at river mouths; such rivers favour the growing of mangrove forests in the dry season. Nevertheless, these aquatic plants could be eroded and destroyed by flash floods in the rainy season. Climate change frequently causes typhoons, rainstorms, and abrupt changes in hydrological environments that influence ecological systems. It is necessary to combine engineering measures and environmental conservation for effective and economical natural disaster prevention engineering. The basis of BwN is the concept that humankind can live sustainably in the natural environment. This new design philosophy proposes to utilize the forces of nature, thereby strengthening the nature, economy, and society to prevent and mitigate natural disasters.

2. Study area and methodology
The study area is located at the mouth of Touchien River in Hsinchu County in northern Taiwan (Figure 1). The area at the confluence of a large river and its smaller branch has a sandbar called Jiugang Island. The branch has low discharge; masses of sand are deposited, which cause flood disasters when the area receives torrential rains. Engineering measures for flood disaster mitigation started in 2008 with a precast flood control dam and bypass flow engineering; river dredging works began in 2013. The field investigation area was located at the west side of Jiugang Island near the bypass flow and bank protection facility and the island’s flood detention pond. The study site was tidal land that formed after the formation of Jiugang Island; Kandelia grows in the study area because the bypass flow engineering facilities are upstream.

There are six types of relevant plants in the mangrove forest in Taiwan. The present study concerns the ecological system of Taiwan’s mangrove forest. The species Kandelia is selected as the indicator for the ecological restoration of the river after engineering measures. Kandelia is saltproof and submergence tolerant. It is commonly distributed at river mouths as a pioneer plant for newly formed beaches. Its growing status reflects the environmental tendencies of erosion or deposition.

Three specific field investigations were conducted in December 2014, April 2015 (before the flood season), and October 2015 (after the flood season). Items for the investigation included the number of Kandelia plants, their growth statuses, and distribution areas. Measuring tapes, counters, and GPS units were used for recording Kandelia plants’ heights, densities, and coordinates (Figure 2). Data were subjected to statistical analysis.

3. Results and discussion

3.1. Investigation in December 2014
The first field investigation started in December 2014; the number and heights of Kandelia specimens were recorded, and the growing area was calculated using a geographical information system (GIS). The investigation was conducted in the winter season and thus avoided the effects of rainstorms; the weather was suitable for investigation of the Kandelia ecosystem. Results show that a growing area of 20,164 m$^2$ (Figure 3) had 99 plants with an average height of 17.57 cm (Table 1). Most of these Kandelia plants were just within two months of vivipation and were considered to be young plants. The Kandelia showed periodic succession that was affected by tides and floods. Some of the Kandelia plants were 30 cm in height and were speculated to be over 6 months of age. Biomass and biomass density are used to present the growing status of Kandelia in the environment. The biomass density is defined as the number of plants (Q) divided by their growing area (m$^2$), and the biomass is the height (cm) divided by area. High biomass density indicates that the Kandelia colony is healthy.

![Image](Figure 1. Study area at the mouth of Touchien River with (a) artificial dredging and (b) engineering measures in 2013.)

3.2. Investigation in April 2015
The second field investigation started in April 2015. The growing area of Kandelia was separated into two parts (Figure 3), and the growing area decreased to 11,220 m$^2$. Between the first and second investigations, there were no typhoons and no torrential rains. It is speculated that the area was affected by tides, and the plants that were observed were adapted only for growth during nonflood seasons. The plant number and heights were increased during this survey, although the growing area was lower. The biomass density increased from 49 to 93 plants per 10$^4$ m$^2$ (Table 1).

3.3. Investigation in October 2015
In October 2015, the third field investigation showed that the growing area of Kandelia was further decreased to 533 m$^2$ (Figure 3). In 2015, Typhoon Soudelor hit Taiwan on August 6 and Typhoon
Dujuan hit on September 29; they brought torrential rainfalls that caused high flow velocity and water levels that did not favour Kandelia growth. The three investigations showed that the number of Kandelia remained stable at approximately 100 plants after one year of periodic changes (Table 1). The Kandelia undergoing vivipation, the aggregate plants, the biomass, and the density increased from 0.93% in April to 18.59% in October in 2015. Kandelia continued growing in the area, even when the area was separated into two zones (Figure 3). In the future, even if the Kandelia colony becomes a forest, plant aggregation can cause soil deposition, and the growing area may increase in area.

| Date     | Plant number | Average height (cm) | Area (m²) | Biomass density (Q/m²) | Biomass (cm/m²) |
|----------|--------------|---------------------|-----------|------------------------|----------------|
| Dec. 2014 | 99           | 17.57               | 20164     | 0.49 %                 | 0.087          |
| April 2015 | 104         | 25.27               | 11220     | 0.93 %                 | 0.225          |
| Oct. 2015 | 99           | 28.42               | 533       | 18.59 %                | 5.337          |

Table 1. Statistical results for three field investigations.

4. Soil particle size distribution and growth of Kandelia
The riverbed soil particle size distribution within the Kandelia growing area can be examined using GIS spatial analysis. Some soil in the area is silt–fine sand soil in which the sizes of 90% of the particles (d₉₀) are smaller than 2 mm. Another soil is cobble–gravel, which has d₉₀ larger than 2 mm. In Taiwan, Kandelia grows on fluvial plains and tidal areas near river mouths or deltas; these areas have clayey muddy soil. The GIS cover layer analysis showed that Kandelia was growing only in areas with silt–fine sand soil area (Figure 4).

5. Flow velocity modeling and distribution of Kandelia
Typhoon Soudelor hit Taiwan in 2015 with a high sea level of EL 2.35 m. A numerical simulation of constant flow discharge (4.75 cm) at an average tidal sea level of EL 0.115 m by using CCHE2D modelling [10] for August 7–9 was analysed for hydrologic characteristics [11]. CCHE2D is a general surface water flow model that simulates the dynamic processes of water flow and sediment transport and water quality in rivers and along coasts. The peak discharge at high sea level was 1,180 cm at the river mouth according to the model. The model showed that the peak flow velocity during Typhoon Soudelor was 1.6–2.4 m/s at the south channel, 1.2–1.6 m/s at the north channel, and 0.4 m/s downstream of the island (Figure 5). It showed that for low discharge (4.75 cm) and a sea level of EL 0.115 m, the study area was equivalent to static water and favoured the growing of Kandelia. However, high flow velocity caused by rainstorm-induced peak discharge (1,180 cm) could erode the soil of young Kandelia plants at the river channel.
Figure 4. Kandelia distribution areas and corresponding soil types (the Second River Management Office of Water Resource Agency, http://www.wra02.gov.tw/).

Young Kandelia plants can survive beneath 0.5 m of water at static flow velocity. High flow velocity and long-term submergence (no more than 12 h) can threaten the young plants. Normal tidal conditions (12 h cycle of high and low tides) do not threaten the growth of Kandelia. However, if a typhoon brings a rainstorm, Kandelia plants can be submerged for periods longer than 12 h and could die even under low flow velocity.

Figure 5. Modeled flow velocity during Typhoon Soudelor brought rainfall-induced (a) peak discharge, and (b) during average tidal of water depth [11].

6. 5S model analysis
A 5S model analysis featuring system conditions, stream hydrology, structures, substances, and species was used for the verification analysis of various parameters and the growing status of Kandelia (Table 2).

7. SWOT analysis
The study recorded the growing status of Kandelia in the specified river environment. For the assessment of the environmental impacts of engineering measures, a 5S model analysis formalized strengths and weaknesses (Table 3). A large Kandelia colony would have various strengths (S): it could incise the main channel of the river, purify water, and increase biological reproduction and biodiversity. Potential weaknesses (W) of a large Kandelia colony can include soil deposition at a river channel, attracting alien species that would be natural enemies, and imbalancing the ecosystem. A few engineering measures (opportunity, O) can control the threat (T) to optimize the ecosystem. For instance, reducing the number of Kandelia to avoid excessive proliferation can reduce the
chance of flooding during rainy seasons.

Table 2. Comparisons between 5S model and Kandelia distribution areas.

| Remarks                  | Factors                  | Parameters             | Kandelia | Field status | Fitness |
|--------------------------|--------------------------|------------------------|----------|--------------|---------|
| Ecosystem status         | Climate                  | average temperature   | >20      | 22.7         | ++      |
|                          |                          | per month (°C)        |          |              |         |
| Habitat type             | wetland                  | ++                     | ++       | ++           |         |
|                          | intertidal               | +++                    | +++      | +++          |         |
| Hydrology                | Hydrography              | water depth (m)       | <2.5     | 0.00-4.00    | +       |
|                          |                          | daily soaking period  | <12      | +++          | +++     |
|                          |                          | Hydrography           |          |              |         |
|                          |                          | flow velocity (m/s)   | <0.5     | 0.00-4.983   | -       |
| River type and structure | Riverbed material        | mud                    | +++      | +++          | ++      |
|                          |                          | sand                   | +++      | ++           |         |
|                          |                          | cobble                 | —        | —            | —       |
|                          |                          | gravel                 | —        | —            | —       |
| Water quality            | Basic water quality      | pH value               | no data  | 7.2-8.6      |         |
|                          |                          | salinity               | 5-15     | 3.0-22.2     | ++      |
|                          | Hydrated ions            | conductivity (μs/cm)   | no data  | 299-563      |         |
|                          | RPI                      | Dissolved Oxygen       | no data  | 6.6-13.7     |         |
|                          |                          | Biochemical oxygen     | no data  | 1.2-3.7      |         |
|                          |                          | demand (mg/L)          |          |              |         |
| Nutrients                | Total phosphorus (mg/L)  | no data                | no data  | 0.065-0.21   |         |
|                          | Nitrate (mg/L)           | no data                | no data  | 0.79-2.26    |         |
| Species                  | Plant                    | degree of competition  | Black    | none         | +++     |
|                          |                          |                        | Mangrove |             |         |
|                          |                          |                        | (extrusion|             |         |
|                          |                          |                        | the growing|             |         |
|                          |                          |                        | of young  |             |         |
|                          |                          |                        | Kandelia) |             |         |
|                          | Animal                   | predators              | Anoplophora| none         | +++     |
|                          |                          |                        | maculata  |             |         |

Note: The environmental fitness for the indicator Kandelia: + fair, + + favorable, + + + very favorable, - acceptable,
- - unfavorable, - - - organism cannot survive.
The 5S model analysis shows that the temperature and environment are favorable to the growth of Kandelia without natural enemies in the study area. Both high sea levels and high flow velocities during rainstorms can adversely affect Kandelia growth. Rivers in Taiwan show high flow velocity upstream with mass sediments, which changes water flow and can adversely affect Kandelia growth downstream. The River Pollution Index of water quality was in the range of 2.25 to 3.75 and was classified as light to moderate pollution according to the criteria of the Environmental Protection Administration in Taiwan (http://web.epa.gov.tw/en/index.aspx). The field growth status of Kandelia shows that the effects of water quality do not pose a threat to survival; however, the analysis requires additional monitoring data.

### Table 3. SWOT analysis of Kandelia distribution areas and ecosystem restoration strategy.

| Strategy | Strengths (S)                                                                 | Weaknesses (W)                                                                 |
|----------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
|          | 1. Incise the main river channel                                               | 1. Could develop into forest and contribute to rising water table             |
|          | 2. Purify water quality                                                        | 2. Overdevelopment could affect other species                                 |
|          | 3. Biological diversity                                                        | Engineering measures can limit Kandelia’s multiplication.                     |
| Opportunity (O) | Using engineering measures                                                   |                                                                              |
|          | 1. Environmental and engineering superiority can manage the growth of Kandelia.|                                                                              |
|          | 2. Superiority of Kandelia can create extra benefits for the ecosystem.        |                                                                              |
| Threat (T) | Alien species are natural enemies                                              | Engineering measures can limit Kandelia’s growing area.                      |
|          | 1. Channel incision can limit Kandelia’s growing areas to deep water areas    |                                                                              |
|          | 2. Biodiversity can change the numbers of natural enemies or can reduce the number of Kandelia by some alien species. |                                                                              |

8. Conclusions
This paper reports field investigations of the quantities of Kandelia near the Touchien River in northern Taiwan in the years 2014 to 2015. Results were analyzed to assess the environmental impacts of engineering measures. Kandelia was used as a local environmental indicator of the ecosystem after engineering measures. The study verified riverbed particle size distribution, flow velocity, and flow depth within the Kandelia growing area; the analysis explained the changes in hydrologic characteristics after engineering measures. Field investigations from October 2014 to October 2015 before and after two typhoon events showed that the biomass density of Kandelia was increasing. The water quality, flow velocity, and 5S model analysis showed that the study area was suitable for the growth of Kandelia after engineering measures. Some new Kandelia growing areas were vulnerable to floods and excessively fast river flows; these vulnerabilities limited the extent of the area suited to Kandelia. The study shows an example of a local indicator to be used when BwN for minimizing ecological harm caused by engineering measures. The species Kandelia can be used as an indicator for ecosystem impacts assessment after engineering measures have been conducted. Considerable time is required for observation, tracing, and collection of data to assess the ecological impacts of engineering measures for implementing the design of BwN.
9. References

[1] EcoShape 2012 The Building with Nature Design Guideline http://ecoshape.nl/en_GB/wiki-guideline.html (last visited January 11, 2017)

[2] De Bruin D, Hamhuis D, van Nieuwenhuijze L, Overmars W, Sijmons D and Vera F 1987 De toekomst van het rivierengebied (The future of the rivers region) Stichting Gelderse Milieufederatie, Arnhem, the Netherlands.

[3] UNEISO-IHE 2016 Room for the River (https://www.unesco-ihe.org/sites/default/files/13270-rvdr-brochure-governance-engels_def-pdf-a.pdf)

[4] De Vriend HJ, Van Koningsveld M, Aarninkhof SGJ, de Vries MB and Baptist MJ 2015 Sustainable hydraulic engineering through Building with Nature, Journal of Hydro-environment Research 9 pp 159–171

[5] De Vriend HJ and Wesselink A 2009 Building with Nature: ecodynamic design in practice 2nd German Environmental Sociology Summit Reshaping Nature: Old Limits and New Possibilities Leipzig 6-7 November 2009 Keynote paper http://www.ufz.de/index.php?de=17540

[6] De Vriend HJ and Van Koningsveld M 2012 Building with Nature: Thinking, acting and interacting differently, EcoShape, Building with Nature, Dordrecht, Los Paises Bajos

[7] De Vriend HJ, Van Koningsveld M and Aarninkhof S 2014 Building with nature: The new Dutch approach to coastal and river works. ICE Proceedings Civil Engineering 167 pp 18–24

[8] De Vriend HJ, Van Koningsveld M, Aarninkhof SGJ, and Baptist MJ 2015 Sustainable hydraulic engineering through building with nature. Journal of Hydro-environment Research 9 pp 159-171

[9] Wilms T, Van der Goot F and Debrot AO 2017 Building with Nature - an integrated approach for coastal zone solutions using natural, socio-economic and institutional processes. Coasts & Ports 2017 Conference – Cairns, 21-23 June 2017

[10] Jia Y and Wang SSY 1999 Numerical model for channel flow and morphological change studies. Journal of Hydraulic Engineering 125 pp 924–933

[11] Yeh KC et al. 2015 Study on overall planning of eco-hydraulics and benefit assessment of diversion dike in Touchien River’s estuary The Second River Management Office of Water Resource Agency (http://www.wra02.gov.tw/)

Acknowledgments
Authors wishing to acknowledge financial support from Ministry of Science and Technology in Taiwan under contract No. MOST 106-2625-M-415-003.