Mangroves in Taiwan: current status and restoration projects

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This paper presents an overview of **Taiwan's mangroves**, including diversity and distribution, uses, major threats, conservation and other problems. The restoration of mangroves in Taiwan is also discussed, and five partially successful mangrove restoration projects are described, with particular reference to the Anping Harbor restoration project in Tainan City that successfully restored *Rhizophora stylosa* and *Lumnitzera racemosa*.

Photo 1.
Arrested mangrove growth due to adverse environmental conditions in Chinglo, Penghu; example of a seven year-old *Avicennia marina* with a sapling height of only 35-70 cm. August 2001. Photo K.-C. Fan.

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RÉSUMÉ

LA MANGROVE DE TAIWAN : ÉTAT ACTUEL ET PROGRAMMES DE RESTAURATION

Taiwan a une ligne de côte longue de 1 140 km, mais c'est seulement dans la partie ouest de l'île que la mangrove trouve un habitat favorable à son développement. Elle y occupe une surface de 287 ha, ce qui peut être considéré comme négligeable au regard de l'aire totale de cet écosystème dans le monde. *Avicennia marina, Lumnitzera racemosa*, *Kandelia candel* et *Rhizophora stylosa* sont les quatre espèces principales de palétuviers de cette mangrove, considérées chacune pour le pays comme étant en voie d'extinction. L'objectif de cet article est de présenter les caractéristiques générales de la mangrove taiwanaise, notamment sa distribution et sa diversité, l'utilisation du milieu, les problèmes de gestion et de protection. Les questions de restauration sont aussi discutées et cinq projets, ayant réussi au moins en partie, sont présentés. Le programme d'Anping Harbor (Tainan City) suit une méthode originale (utilisation de tubes PVC pour protéger des plants de *R. stylosa* et de *L. racemosa*) qui a permis de réhabiliter avec succès des secteurs inondés.

Mots-clés : mangrove, protection, restauration, *Kandelia candel*, Taiwan.

ABSTRACT

MANGROVES IN TAIWAN: CURRENT STATUS AND RESTORATION PROJECTS

Taiwan has a shoreline 1 140 km long, and the western coastal zone is a suitable habitat for mangroves. The total mangrove area in Taiwan covers only 287 ha, a tiny proportion of the total area of mangroves in the world. Four main mangrove species are found in Taiwan, namely *Avicennia marina, Lumnitzera racemosa*, *Kandelia candel* and *Rhizophora stylosa*, all of which have been declared as endangered. This paper aims primarily to present an overview of Taiwan's mangroves, including diversity and distribution, uses, major threats, conservation and other problems. The restoration of mangroves in Taiwan is also discussed, and five partially successful mangrove restoration projects are described. In particular, the Anping Harbor restoration project in Tainan City used a planting method that employed polyvinyl chloride (PVC) pipes and successfully restored *R. stylosa* and *L. racemosa* seedlings in flooded areas. Finally, the problems of mangrove restoration in Taiwan are discussed.

Keywords: mangrove, Taiwan, preservation, restoration, *Kandelia candel*.

RESUMEN

MANGLARES DE TAIWÁN: ESTADO ACTUAL Y PROYECTOS DE RESTAURACIÓN

Taiwán tiene una línea costera de 1 140 km de longitud y la costa occidental es un hábitat favorable para los manglares. La superficie total ocupada por el manglar de Taiwán es sólo de 287 ha, representando una proporción insignificante de la superficie total de los manglares del planeta. En Taiwán se encuentran cuatro especies principales de mangle: *Avicennia marina*, *Lumnitzera racemosa*, *Kandelia candel* y *Rhizophora stylosa*. Especies que han sido declaradas plantas amenazadas. Este artículo intenta, en primer lugar, presentar una visión global estos manglares, incluidas su diversidad y distribución, su utilización, características principales, conservación y problemas. También se examina la restauración de los manglares en Taiwán y se describen cinco proyectos de restauración del manglar que fueron, en parte, exitosos. En particular, el proyecto de Anping Harbor, en Tainan City, con un método de plantación que utiliza tubos de policloruro de vinilo. Permitió restaurar *R. stylosa* y *L. racemosa*, a partir de siembra en zonas inundadas.

Palabras clave: manglar, preservación, restauración, *Kandelia candel*, Taiwán.

Introduction

Taiwan is located at the western edge of the Pacific Ocean, between 21° 45' 25" and 25° 37' 53" N, and 119° 18' 13" and 122° 6' 25" E (figure 1). The Tropic of Cancer runs through Chiayi County, roughly dividing the island into the tropical southern and subtropical northern half (Hsueh, 1995). The current population of this island exceeds 21 million. With an area of only 36 000 km², the population density in Taiwan stands at over 580 persons per square kilometer today (Chiau, 1998). Taiwan's climate varies in each region because of the diverse terrain and the monsoon season. The coastal lowlands are subtropical to tropical, with a hot, windy climate and abundant rainfall. The average annual temperature in Taiwan is about 22-25 °C, and annual precipitation averages 2 500 mm, with nearly 80 % falling during the May-October typhoon season. The climate is suitable for mangrove growth.

Mangrove forests are among the most productive ecosystems in the world. They enrich coastal waters, supply commercial forest products, protect coastlines, and support coastal fisheries. Mangroves are an ideal niche ecosystem for birds, crabs, and other animals, and offer a natural "classroom" for learning and leisure. The total area of mangroves around the world is between 181 077 and 198 818 km² (Spalding *et al.*, 1997), with Taiwan's mangroves only accounting for 287 ha in 1995. Mangroves have therefore been declared as endangered species requiring special care (Hsueh, 1995).

Because mangroves in Taiwan represent a negligible proportion of the total mangrove area in the world, very few authors have focused on mangrove research in this country and only a small number of general articles have been published, mostly in Chinese. International mangrove literature therefore has little information on Taiwan's mangroves. This report provides an overview of Taiwan's mangroves (diversity, distribution, uses, major threats, conservation and current problems) and describes current mangrove restoration projects in Taiwan. Information on this specific aspect of Taiwan's mangroves will hopefully provide a different perspective on mangrove ecosystems around the world.

Diversity and distribution of species

Historical data suggest that the earliest record of collecting the mangrove species *Kandelia candel* (L.) Druce in the Tanshui area (figures 1 and 2) could date from 1864, and that it is likely to be a native Taiwan species (Liu, Lai, 1982). The other mangrove species were transplanted from Thailand and Malaysia during the 1940s (Yang, 1974).

Figure 1.
Geographical location of Taiwan (based on Spalding *et al.*, 1997).

Photo 2.
The Tanshui River Mangrove Nature Reserve protects an unusually pure stand of *Kandelia candel*. December 2001, at low tide.
Photo K.-C. Fan.

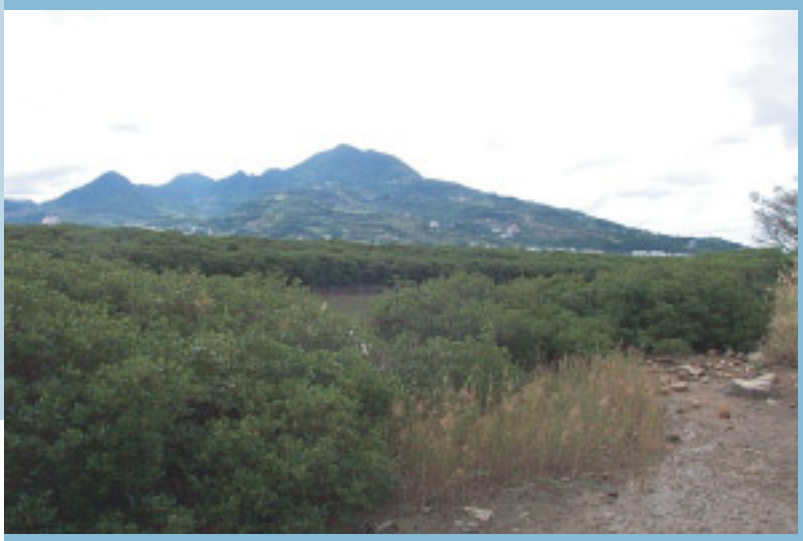

Figure 2.
Mangrove distribution in Taiwan (based on HSUEH, 1995).

Extinction and introduction of species

According to TOMLINSON's (1994) classification, Taiwan once hosted six major mangrove species (table I). However, harbor construction had already caused the extinction of *Ceriops tagal* C.B. Rob. and *Bruguiera gymnorhiza* (L.) Lam. by the 1960s (LIU, 1982). Four species, namely *Avicennia marina* (Forssk.) Vierh., *Lumnitzera racemosa* Willd., *K. candel* and *Rhizophora stylosa* Griff. are currently widespread along the western coast of Taiwan. However, mangrove habitats have rapidly diminished due to intensive industrial and urban developments, to the extent that *R. stylosa* and *L. racemosa* have recently become rare species.

Three minor components and seven mangrove associates exist on the island (table II). These trees and shrubs occupy peripheral tidal areas along the western coastline. They include *Excoecaria agallocha* L., *Pemphis acidula* J.R. Forst, *Heritiera littoralis* Dryand, *Cerbera manghas* L., *Terminalia catappa* L., *Barringtonia racemosa* (L.) Spreng., *B. asiatica* (L.) Kurz., *Pongamia pinnata* (L.) Pierre, *Hibiscus tiliaceus* L. and *Thespesia populnea* (L.) Sol. However, *B. asiatica* is found only in the Kenting and Henchuan areas in southern Taiwan, whereas *B. racemosa* grows only in the Ilan area in north-east Taiwan. *Pemphis acidula* is not found in intertidal areas but grows on the dry coral rocks on Kenting and Lanyu Island. These three species have also become rare because their habitats are fairly restricted. The other mangrove associates such as *C. manghas, P. pinnata* and *H. tiliaceus* have recently been widely planted in the coastal windbreak and urban environments. *Clerodendrum inerme* Gaertn., *Scaevola sericea* L. and *Myoporum bontioides* also occur in the transitional habitats in southern Taiwan, and should be considered as mangrove associates.

Distribution and surface areas

Taiwan has a shoreline of 1 140 km (CHIAU, 1998). The western coastal zone is characterized by tidal flats, offshore sandbars, lagoons and sand dunes, which form suitable habitats for mangroves. The eastern shoreline contains no mangroves because the coastal areas are rocky and steeply sloping and therefore unsuited to mangrove growth. The literature does not give exact indications as to the total area of mangroves in Taiwan. According to the earliest estimate (LIU, 1982), economic development by that time had reduced the mangrove area to only 120 ha. In a new survey, of mangrove distribution (figure 2) and areas (table II), HSUEH (1995) estimated the total mangrove area at 287 ha, an insignificant total compared with the world total.

Table II also shows that cold shocks below 15 °C are a constant feature during December and January in the areas north of Chiayi, including Taipei, Taoyuan, Shingchu, and Miaolia County. The cold-tolerant species *K. candel* is dominant in these areas, and Chuwei Nature Reserve is

Photo 3.
Four mangrove seedlings successfully established in a degraded *Casuarina* stand at the Shuangchun restoration project in Tainan County. August 2001. Photo K.-C. Fan.

the biggest mangrove area (50 ha) in Taiwan. On the other hand, the average temperature in the Chiayi, Tainan, and Kaoshiung areas exceeds 22 °C in the summer months. These areas are affected by long periods of drought from October to the following February. These conditions explain why *A. marina* is the dominant mangrove species in southern Taiwan. The Peimen Coastal Reserve in Tainan County is the biggest *A. marina* stand, but only covers 28 ha.

Uses of mangroves in Taiwan

Traditional uses

Mangroves were used in the past for many purposes in different countries, including for timber and fuelwood, food, pasture, salt and bioactive compounds for tanning and medicinal purposes (Kovacs, 1999; Ellison, 2000). Mangrove areas in Taiwan are very small, and the trees do not grow large enough to be employed as building materials for example. Fuelwood is the most important traditional use on this island. Fish farmers in the south-west coastal areas of Yunlin, Chiayi and Tainan County planted rows of mangroves to protect their ponds against wind, waves and soil erosion in the development stage (Lee *et al.*, 1977).

Current uses

Conservation of mangrove ecosystems around the world is currently receiving a lot of attention. Mangrove habitats in Taiwan also play a significant role in conservation and recreation, and in research programs on nature reserves and locally protected areas. Since 1995, mangroves have thus been used as resources for ecotourism or environmental education.

Major threats

In the last few decades, all of Taiwan's mangroves have been affected by threats as severe as those in other countries. As from the mid 1980s, many mangrove areas were lost to Taiwan's rapid economic growth; mangrove swamps were reclaimed for harbor construction, power plants, road building and industry. Some major threats to mangroves still exist and have in fact become more serious, as described in the following paragraphs.

Table I.
Major, minor mangrove and mangrove associates in Taiwan.

Family	Species	Life form	Remarks
Major components			
Avicenniaceae	*Avicennia marina*	T	
Combretaceae	*Lumnitzera racemosa*	S/T	
Rhizophoraceae	*Bruguiera gymnorhiza*	T	Recorded, but not found recently
	Ceriops tagal	T	Recorded, but not found recently
	Kandelia candel	T	
	Rhizophora stylosa	T	
Minor components			
Euphorbiaceae	*Excoecaria agallocha*	T	
Lythraceae	*Pemphis acidula*	S	Grows on coral rock in Kenting and Lanyu Island
Sterculiaceae	*Heritiera littoralis*	T	
Mangrove associates			
Apocynaceae	*Cerbera manghas*	T	Used as a windbreak species
Combretaceae	*Terminalia catappa*	T	Used as a windbreak and urban greening species
Lecythidaceae	*Barringtonia asiatica*	T	
	Barringtonia racemosa	T	
Leguminosae	*Pongamia pinnata*	S	Used as a windbreak and urban greening species
Malvaceae	*Hibiscus tiliaceus*	S/T	Used as a windbreak species
	Thespesia populnea	S/T	
Other species			
Verbenaceae	*Clerodendrum inerme*	S	
Goodeniaceae	*Scaevola sericea*	S	Used as a windbreak species
Myoporaceae	*Myoporum bontioides*	S	

Categories according to Tomlinson (1994); T: tree, S: shrub.

Coastal area reclamation may destroy the most sensitive mangrove habitats

Coastal zone management has become one of the most important issues in Taiwan in the last few years. The scarcity and high value of available land have attracted both public and private developers to the island's coastal zones. Because coastal lands are generally perceived as suitable for development, the coastal zone has become a complex area of competing uses. Rapid urbanization, pollution, tideland reclamation, coastal aquaculture and the development of tourism are exerting increasing pressure on Taiwan's coastal zone. The Environmental Protection Administration (EPA) reports that more than 80 industrial projects have been proposed or undertaken recently. Most of these projects, developed on the western tideland, require areas exceeding 1 000 ha, and some of them even demand 10 000 ha (Chiau, 1998). This situation reveals the increasing negative impact on the environmental and ecological state of mangrove habitats.

Table II.
Present status of major mangrove areas in Taiwan.

Location	Species	Habitat	Area (ha)	Protective measures (Management Agency)
Taipei County				
Watzuwei	*K. candel*	River bank	8.79 (30.00)*	Watzuwei Nature Preserve (Taipei County Government)
Taipei City				
Chuwei	*K. candel*	River bank	50.00 (74.61)*	Chuwei Nature Preserve (Taiwan Forestry Bureau)
Kuantu	*K. candel*	River bank	19.00 (55.00)*	Kuantu Nature Preserve (Taipei Municipal Government)
Taoyuan County	*K. candel*	River bank	0.04	
Hsingchu County	*A. marina* *K. candel*	River bank; coastal plains	5.69	Hsinfeng mangrove reserve (Hsingchu County Government)
Miaoli County	*K. candel*	River bank; coastal plains	4.03	Chunan mangrove reserve (Miaoli County Government)
Taichung County	*K. candel*	River bank	2.00	
Changhua County	*K. candel*	River bank; coastal plains	3.76	
Chiayi County	*A. marina* *K. candel* *R. stylosa*	River bank; coastal plains; lagoon	45.26	Chang-Yun-Cha, Haomeiliao Coastal Reserve (Chiayi County Government)
Tainan County	*A. marina* *K. candel* *L. racemosa*	Lagoon; river bank; sand bar	75.27	Peimen Coastal Reserve (Tainan County Government)
Tainan City	*A. marina* *L. racemosa* *R. stylosa*	Drainage bank; protected area	14.92	Sutsa protected area (Tainan City Government)
Kaohsiung County	*A. marina* *K. candel* *R. stylosa*	River side; Salt pan; Drainage bank	55.53	
Pingtung County	*A. marina*	Drainage and fishpond bank	2.66	
Total			286.95	

* Area of nature reserves.

Photo 4.
Extremely strong growth of five year-old *Rhizophora stylosa* saplings with abundant prop roots, in favorable fringe sites. June 2001. Photo K.-C. Fan.

Land subsidence : one of the most serious problems along the west coast

Overpumping of groundwater for coastal aquaculture has caused land subsidence. A recent report conducted by the Provincial Water Conservancy Bureau revealed that an area of 1 010 km² – more than 10 % of Taiwan's flat land – along Taiwan's south-western coastal zone was affected by land subsidence (Chiau, 1998). This situation has obviously exacerbated risks of excessive flooding in mangrove habitats. For example, the coastal area in Chiayi County has sunk 90 cm since 1987, causing flooding that killed off about 10 ha of *Avicennia* stands in 1993 (Chen, 1997).

Pest damage in mangrove ecosystems is gradually increasing in Taiwan

All mangrove ecosystems in Taiwan have been designated as protected areas. This status restricts all human activity and management. However, the legislation does not provide for proper management practices to preserve mangrove growth and habitat. Excessive expansion of mangroves causes drainage problems and is also encouraging pests. For example, the larvae of *Zeuzera coffeae* and *Anoplophora maculata* are the primary wood borers of *K. candel* stands and have recently caused the death of mature trees.

Conservation problems

The Tanshui River Mangrove Nature Reserve, the first mangrove reserve in Taiwan, was established near Taipei in 1986 to protect *K. candel*. This species is found at the northern limit of global mangrove distribution, at 31° 23' N on the Kyushu Island of Japan, and is able to withstand winter chills with temperatures as low as -4 - 5 °C . This species is generally found as an understory or subdominant species within mixed mangrove stands in Thailand, Hong Kong, southern China, and the southern islands of Japan (Maxwell *et al.*, 1997). Therefore, the Tanshui reserve is not only the biggest mangrove area in Taiwan, but is also one of the world's very few pure stands of this species (photo 2). The Kuantu Reserve (protecting waterfowl in particular) and Watzuwei Nature Reserve were established at a later stage, bringing the total national protected area to 78 ha and covering 27% of existing mangroves (table II). However, mangrove conservation and protection are still fraught with problems.

Suitability of mangrove conservation and protection laws

National level

The Watzuwei, Chuwei and Kuantu Nature Reserves were established under the Cultural Heritage Preservation Law (CHPL). Their management agencies are Taipei County Government, Taiwan Forestry Bureau, and Taipei Municipal Government, respectively (table II), but no one agency co-ordinates the conservation of the three mangrove reserves. The CHPL strictly enforces conservation legislation, and entirely restricts any interference in nature preserves. For example, *K. candel* has recently grown well and thus enlarged the sand bar at the mouth of Kellung River. A simulation of hydrological conditions up to 2006 has demonstrated that mangrove growth increases flow velocity, raises the water level by approximately 18 cm during floods and damages dikes (Hsu *et al.*, 1999). However, government officials think the CHPL is presently the best way to protect *K. candel*.

Local level

The Executive Yuan established Chang-Yun-Cha, Haomeiliao, and Peimen Coastal Reserve in 1984, in line with the Nature Environment Protection Plan for Taiwan's coastal areas. Hsingchu, Miaoli County and Tainan City Governments have also established small mangrove reserves. These reserves do not enjoy the same level of protection as reserves under the CHPL, as their management has been desultory.

Lack of effective protective management

Designating nature preserves and coastal protected areas is only the starting point for mangrove conservation; the key issues include the ensuing proposals, detailed plans, and concrete management practices, with reforms of any inappropriate practices. However, no effective protective management serves Taiwan's mangrove reserves. The present management policy simply involves regular patrols to prevent mangroves from being destroyed and to protect them from certain activities that are harmful to their habitats.

Lack of database for individual mangrove ecosystems

Many scientific efforts and investigations have focused on the ecology of Tanshui Nature Preserve since the 1970s. However, baseline background data on local mangrove reserves or unprotected areas remains unavailable. An inventory report on each mangrove ecosystem should therefore be prepared as soon as possible to provide baseline information to integrate policies for Taiwan's mangrove resources.

Photo 5.
Development of numerous prop roots with superior growth on three year-old *Rhizophora stylosa* seedling grown in 50 cm PVC pipes. August 2001. Photo K.-C. Fan.

Lack of coordination among agencies

Coordination involves horizontal and vertical cooperation and consultation among government agencies and between government and other organizations. Taiwan has so far lacked a national policy on mangrove protection. Moreover, no particular agency manages and preserves mangroves. Various administrative departments handle mangrove affairs at local government level. For example, several different projects were found to overlap in the same protected areas due to poor coordination among agencies.

Restoration of mangroves in Taiwan

More recently, urban and aquatic development world-wide has diminished mangrove forests, and caused concerns in every country for the conservation of these natural resources and their restoration. Mangrove forests have been restored to achieve various objectives, including commercial uses (silviculture), protection of fisheries habitats and shorelines and restoration of balanced ecosystems (Kaly, Jones, 1998; Ellison, 2000). This section briefly reviews the history and problems of mangrove restoration in Taiwan.

The concept of restoration/ rehabilitation for a mangrove ecosystem

Some scientists have emphasized the different meanings given to terms such as restoration and rehabilitation. Field (1998) makes a distinction between rehabilitating an ecosystem, which he defines as the partial or full replacement of the ecosystem's structural and functional characteristics, and total restoration of an ecosystem, which aims to bring an ecosystem back to its original condition. According to this interpretation, restoration is one possible result of a successful rehabilitation effort. Non-scientific organizations generally have no clear definitions of restoration. Restoration managers have therefore frequently emphasized mangrove planting as the primary approach in restoration (Ellison, 2000). Similarly, in Taiwan, scientists, government officials and conservationists have carried out mangrove restoration projects that also involved planting mangrove propagules, seedlings, or even saplings in selected places. However, this report employs the term "restoration" to avoid confusion.

Table III.
Mangrove afforestation projects during 1945-1975 in Taiwan.

Location	Year	Area (ha)	Species	Remarks
Hungmaokang, Hsinchu County	1945	4	*A. marina* *K. candel*	Spread to 5.3 ha
Lungching, Taichung County	1952	10	*K. candel*	All died before 1980
Hanpao, Changhua County	1952-1954	12	*A. marina* *K. candel*	All died before 1980
Tungshiao, Miaoli County	1957-1960	5-6	*K. candel*	All died before 1980
Chinglo, Penghu County	1958	2.9	*A. marina*	All died before 1980
Chiku, Tainan County	1962	24.5	*K. candel* *R. stylosa*	All died before 1980
Chingshui, Taichung County	1975	8	*K. candel*	All died before 1980

Sources: Lee *et al.*, 1977; Huang, Hsu, 1982; Hsueh, 1995.

Mangrove restoration in Taiwan

The mangroves along the west coastal line are all artificial plantations dating from 1945-1975 (Lee *et al.*, 1977; Huang, Hsu, 1982), except *K. candel,* which is native to Taiwan (Liu, Lai, 1982).

1945-1975

Mangrove reforestation projects were initiated in the 1940s, and most projects were carried out between 1945 and 1975 by the Taiwan Forestry Bureau, with funding from the Council of Agriculture (table III). Government officials employed labor to plant seedlings of *K. candel, A. marina* (the major planting species) and *R. stylosa* (in small quantities). Most planting areas were very small; the largest covered 25 ha at Chiku in Tainan County in 1962. These projects aimed primarily to protect the coast. However, unsuitable environmental conditions and human impacts killed all planted mangrove seedlings before 1980 (Huang, Hsu, 1982). The only exception was in Hungmaokang in Hsinchu County, where *K. candel* and *A. marina* grew well and the restored area expanded to 5.3 ha. In 1988, the County government established a local mangrove reserve to protect the mangrove ecosystem.

1976-1993

After 1975 the government directed no mangrove restoration projects; all major work during this period focused on protecting mangroves. During that time, some local people and fishermen planted mangrove seedlings to protect fish ponds, so that mangroves were planted sporadically along the western coastal area of Taiwan.

1994-present

In 1994, former president Lee visited the mangroves of Indonesia and realized the protection value of mangroves. He suggested that the government should establish mangroves on a large scale along the coastal area. Since then, almost every county in western Taiwan has launched mangrove planting projects. In most cases, the four mangrove species were planted in an uncontrolled manner in a small area (1-5 ha). Only a few mangrove restorations have been a partial success, and some mangrove saplings have survived and grown well up to now. However, these projects are rarely documented. The following section (points ▪) gives limited information obtained from personal communication with government officials and researchers.

▪ Haomeiliao restoration project in Chiayi County (1993-1994; 3.0 ha).
Executive agency: Taiwan Endemic Species Research Institute.
Goal: increase biodiversity of the mangrove ecosystem.
Planting methods: *R. stylosa*, *L. racemosa* and *K. candel* propagules and seedlings planted within mixed stand of *Casuarina* and *A. marina*.
Planters: paid workers planted all seedlings and propagules.
Current status: the mangrove is reported to have grown very well, especially *R. stylosa* and *L. racemosa*, which have reached over 2 m after four years. The current status of this project is unknown.

▪ Kaoping River restoration project in Kaohsiung County (1994-2000; 4.5 ha).
Executive agency: Kaohsiung County Government.
Goal: establish a mangrove ecosystem park.
Planting methods: *R. stylosa*, *L. racemosa*, *K. candel* and *A. marina* were planted in a new wetland along the bank of the Kaoping River.
Planters: mainly local students and members of the public.
Current status: a wetland was created by constructing breaching dikes along the river. Several petrochemical plants are near the planting site. According to field observations in September 2001, the mangrove growing area diminished to less than 2 ha, growth of the mangrove seedlings was disappointing, and many creeping plants were encroaching on mature *A. marina* trees. In such circumstances, the future status of the project is uncertain.

▪ Shuangchun restoration project in Tainan County (1995-present; 3.5 ha, and the planting work is continuing).
Executive agency: Tainan County Government.
Goal: replace the degraded *Casuarina* windbreak and create a coastal recreation park including a plantation of mangrove species.
Planting methods: mixed planting of four mangrove species after removing the degraded *Casuarina* stand.
Planters: employed workers for most seedlings, with community families and children.
Current status: The author visited the site in September 2001. The habitat, including favorable tidal inundation flows, is suitable for mangrove growth and canals within the wetland appear to have been dug to assist water flow. The venture has successfully established 75 000 mangrove seedlings in the degraded *Casuarina* stand, and has become the most successful mangrove restoration project in Taiwan (photo 3).

▪ Chinglo restoration project in Penghu County (1994-1995; 1.5 ha).
Executive agency: National Pingtung University of Science and Technology and Penghu County Government.
Goal: restore the mangrove ecosystem that was destroyed for aquaculture in 1974.
Planting methods: *R. stylosa*, *A. marina* and *K. candel* were directly sowed with propagules, and *L. racemosa* were planted with one-year-old seedlings. The site has very high salinity and no fresh water.
Planters: employed workers.
Current status: The survival rate and growth of all four mangrove species progressed very well during the first two years of the project. However, growth was arrested by stresses from the harsh environment, including high salinity, heavy low-nutrient soil (fish farmers removed the fertile silt), strong winds and heavy salt spray during the winter. The author visited the site in August 2001, when only 15 *R. stylosa* saplings had survived, and the *K. candel* samples also gradually declined and died. The salt tolerant *A. marina* is the dominant species but a dwarf mangrove form (seven years old) is present, with a sapling height of only 35-70 cm (photo 1). Most of the *L. racemosa* seedlings survived, but these have not grown significantly in height either.

▪ Anping Harbor restoration project at Tainan City (1996-present; 4.6 ha).
Executive agency: National Pingtung University of Science and Technology.
Goal: restore the *R. stylosa* and *L. racemosa* mangrove species, destroyed by harbor construction, using polyvinyl chloride (PVC) planting pipes to restore mangroves in flooded areas.
Planting methods: *R. stylosa*, *L. racemosa*, *K. candel, Myoporum bontioides* and *Thespesia populnea* propagules and seedlings planted in an urban wetland.
Planters: university students planted most seedlings, but employed workers planted a few.

Photo 6.
Three year-old *Rhizophora stylosa* seedlings grown in 150 cm PVC pipes developed several prop roots but did not reach down to the bottom soil. March 2001.
Photo K.-C. Fan.

Photo 7.
A magnificent view of *Rhizophora stylosa* and *Lummitzera racemosa* seedlings in the flooded area. November 2001.
Photo K.-C. Fan.

Current status: *A. marina* trees already occupy the habitat, which is suitable for mangrove growth (1.5 ha). The remaining areas have unfavorable hydrodynamics or have been degraded by damaging environmental impacts. This project has involved several mangrove replanting trials. Directly sowing *R. stylosa* propagules among *Avicennia* trees has given a survival rate of only 30%. The high mortality rate is due to polluted soil, algal damage and heavy water turbulence. However, some saplings have grown very strongly. With abundant prop roots on the favorable fringe sites near the waterway, the plants reached a mean height over 200 cm, with many propagules emerging (photo 4). Ten month old *L. racemosa* seedlings planted in May 1998 had a survival rate of 62.4% in the first year. The seedlings grew to a height of 110 cm and flowered. However, three years after planting, the sapling height was only 160 cm, mainly because the flourishing canopy of *A. marina* suppressed the saplings by limiting available sunlight.

The author used PVC planting pipes to restore mangroves in a flooded area of 1.0 ha. The PVC pipes had an inside diameter of 10 cm, and were cut to lengths of 150 and 50 cm. Workers drilled five to ten small holes along the whole length of each pipes to allow water exchange. In July 1998, the 150 cm pipes were driven into the soil to a depth of 50 cm in the deepwater area. The 50 cm PVC pipes were placed (with 20 cm inserted into the soil) in a small flood area where the highest flooding was approximately 50 cm. Each pipe was filled with muddy sediment from the surface, creating an artificial bottom, and the *R. stylosa* propagules with new roots were then planted into the top of the PVC pipes.

Unfortunately, due to serious multiple stresses, the seedling survival rate for this experiment was less than 5% after two months. The area was replanted several times during November 1998 and November 1999 with *R. stylosa* propagules and *L. racemosa* seedlings. Recent field investigations show that some vigorous *R. stylosa* seedlings grew extremely well in 50 cm PVC pipes, with a seedling height of 85-110 cm. The proliferating prop roots were established in muddy soil, which provides stability and essential nutrients, and the first propagule was noted on the seedlings three years after planting (photo 5).

The *R. stylosa* container seedlings replanted in the 150 cm PVC pipes in November 1998 also grew well, reaching a height of 75 cm and producing several prop roots. However, they had not yet reached the bottom soil (photo 6).

The survival rate of *L. racemosa* seedlings grown in 150 cm PVC pipes was around 80%, and the seedlings produced fruits in the first year. However, the seedling height was only 60 cm throughout the first three years. These results are primarily explained by the seedlings' shallow root systems and lack of prominent aerial roots to adapt to flood stress. However, the view over the *R. stylosa* and *L. racemosa* seedlings in the flooded area is magnificent (photo 7).

This research has shown that PVC pipes may be an effective, cheap and easy method for planting mangroves. However, there are still many problems. For example, in June 2001, over 70% of the seedlings grown in the flooded area were attacked and eaten by herbivorous caterpillars. Recently, many fish habitats have been in the tray circle (photo 8), affecting seedlings grown in PVC pipes.

Problems of mangrove restoration

In Taiwan, most projects have been designed and implemented by governmental officials and organizations. However, the lack of basic knowledge and experience in mangrove restoration have caused projects to fail or only partially achieve their goals.

There are no reports or documentation illustrating silvicultural techniques for mangrove restoration in Taiwan. Although methods for planting individual mangroves species are familiar and have been developed in many countries (FAO, 1994; FIELD, 1996), they may not be appropriate for the small restoration area in Taiwan.

Restoration of mangroves does not appear to be especially difficult – mangroves may in fact be among the easiest marine systems to reconstruct (KALY, JONES, 1998; ELLISON, 2000). As long as habitats have the right hydrological conditions, mangroves can grow

Photo 8.
The deepwater area at low tide for numerous fish habitats. August 2001.
Photo K.-C. Fan.

in a variety of coastal environments, approaching the biomass, stand structure, and productivity of natural forests within two decades. Unfortunately, some conservation organizations in Taiwan have convinced the public that mangrove seedlings seldom survive and that a mangrove forest is difficult to establish.

Furthermore, in the restoration projects managed by County government and local organizations, volunteer groups and school children are invited to take part in planting. They usually enjoyed the job, but they also damaged planting stock or handled it improperly, which lowered the seedling survival rate. In fact, most Taiwanese people do not know enough about mangrove ecology and ecosystem restoration, and lack concepts for subsequent management, maintenance and remedial work. For example, when mangrove seedlings have survived or grown moderately well for as little as 3-5 years, government officials and conservationists have been too quick to introduce ecotourism into the mangrove restoration areas, not realizing the need for continuing silvicultural work such as thinning to control forest density, and pest and disease control to prevent defoliation or death of mangrove trees.

Otherwise, scientists themselves sometimes argue against restoration projects in Taiwan's coastal area for the following reasons:

▪ Most restoration areas are located at the mouth of a river or on river banks. Mangroves that proliferate too vigorously, like *Kandelia candel* at the Kellung and Tanshui River, can cause drainage problems in those areas. Furthermore, mangrove species planted to protect coastal areas may compete with native plant species and produce negative effects in the near future.

▪ Excessive replanting of mangroves in western coastal areas gradually destroys the habitat of *Uca formosensis* (an endemic species in Taiwan). Excessive replanting of mangroves may drive this unique crab to extinction because its habitat is hard clay mud on spacious flatlands without mangroves (Shih, 1997).

Conclusion and prospects

Mangrove areas in Taiwan are very small and attention is presently focused on conserving mangrove habitats. Conservation legislation, especially the Cultural Heritage Preservation Law (CHPL), prohibits any interference or human activity in mangrove reserves. Accordingly, mangroves may proliferate excessively, causing serious flooding and pest problems. Therefore, the efforts of different institutions in various regions should be better coordinated, especially those of ecologists and foresters who have been disregarded until now. Firstly, the protective legislation must be revised again and strictly enforced, and secondly, appropriate and practical management guidelines must be developed for mangrove reserves, to ensure sustainable development of mangroves in Taiwan.

Almost every county in western Taiwan has undertaken mangrove restoration since 1994. Unfortunately, many projects have failed because of unsuitable habitats and participants' lack of basic knowledge and experience in mangrove restoration. A few mangrove restorations have been partially successful, and some mangrove saplings have survived and grown well. This valuable experience urgently needs to be integrated with technology to develop practical guidelines for mangrove restoration in Taiwan. The Anping Harbor mangrove restoration project, in particular, is the first attempt to restore a mangrove ecosystem in an urban area. This restoration site is very small compared to the world's other restoration sites, and the areas involved are affected by unfavorable hydrodynamic conditions and too many negative environmental impacts. Nevertheless, this project has included several mangrove replanting trials, which have been successful in some places and unsuccessful in others. All of these experiences may be valuable for other mangrove restoration projects.

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