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THE DISTRIBUTION, ECOLOGY, POTENTIAL IMPACTS AND MANAGEMENT OF EXOTIC PLANTS, *Sonneratia apetala* AND *S. caseolaris*, IN HONG KONG MANGROVES

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MASTER OF PHILOSOPHY

CITY UNIVERSITY OF HONG KONG

SEPTEMBER 2009

CITY UNIVERSITY OF HONG KONG
香港城市大學

The Distribution, Ecology, Potential Impacts and Management of Exotic Plants, *Sonneratia apetala* and *S. caseolaris,* in Hong Kong Mangroves
香港外來的紅樹林植物—無瓣海桑及海桑的分布、生態、潛在影響及其管理

Submitted to
Department of Biology and Chemistry
生物及化學系
in Partial Fulfillment of the Requirements
for the Degree of Master of Philosophy
哲學碩士學位

by

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September 2009
二零零九年九月

Declaration

I declare that this thesis represents my own work, except, where due acknowledgement is given, and that it has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for a degree, diploma or other qualification

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Abstract of thesis entitled

The Distribution, Ecology, Potential Impacts and Management of Exotic Plants, *Sonneratia apetala* and *S. caseolaris*, in Hong Kong Mangroves

submitted by

Tang Wing Sze

for the degree of Master of Philosophy at the City University of Hong Kong

in September 2009

Invasion is now considered as a global threat to biodiversity as it is more pervasive than loss of natural habitats and anthropogenic pollution. Mangroves in Hong Kong were invaded by two exotic plants, namely *Sonneratia apetala* Buch.-Ham and *S. caseolaris* (L.) Engl. The present study investigated the distribution, abundance, reproduction, dispersion and germination of these two species, aiming to evaluate their invasive potential and to examine different removal methods. A territory wide baseline survey of *Sonneratia* was conducted in 2005 and 2006 to provide the first geographical record in Hong Kong. A total of 1,693 mature individuals (> 1.5m) were found distributing in 14 mangrove stands in Hong Kong. The relative distribution of *S. apetala* and *S. caseolaris* was 25.6% (434 individuals) and 74.4% (1,259 individuals), respectively. In terms of geographical location, 99.4% (1,683 individuals) were distributed in Deep Bay area, 0.5% (9 individuals) in Lantau area, and only 0.1% (one individual) in Tolo area, the eastern side of Hong Kong. The survey also showed that both *Sonneratia* species produced fruits all year round but the peak fruiting seasons varied between two species. *S. apetala* had two peak fruiting seasons, that is, from September to November and April to June; while the peak fruiting season for *S. caseolaris* was from July to March. Both species produced more fruits per mature tree and more seeds per fruit in autumn than spring. The greenhouse experiment showed that both species had a

significantly higher unfurling numbers in the autumn batch. Comparing with the native mangrove species, *Sonneratia* had a longer fruiting period and faster germination rate.

A desktop analysis was conducted to estimate the spread and the dispersal rate of *Sonneratia* seeds and to predict the potential affected mangrove stands. Results showed that seeds released from January to April and September to December had a higher tendency to escape from Deep Bay area and flow southward. For seeds released from May to August, they would remain in Deep Bay area for at least one month as there was no net ebbing tide in the first month. The seeds would have a higher chance to strand within Deep Bay area or reached the mangrove stands in the outer Deep Bay. These findings revealed that the spread of *Sonneratia* would depend on the time of seed released as well as the tidal flow. Greenhouse experiment proved that more than half of the seeds remained viable in 35 parts per thousands (ppt) for more than one month and thus seeds from Deep Bay area could spread to southern part of Hong Kong.

Germination experiments showed that both *Sonneratia* species were salinity sensitive and germination was significantly lower when the salinity was higher than 15 ppt. Both species were sensitive to light intensity but showed no preference to substrate type. Tidal level was another factor affecting germination of *S. caseolaris* with significantly higher budding and unfurling numbers at high than low tidal levels; but the germination numbers of *S. apetala* were similar at all tidal levels. Cold period was a factor affecting germination of *S. caseolaris*, with significantly higher budding and unfurling numbers at 0 hour (without cold treatment) than 48 hours cold treatment; but the budding and unfurling numbers of *S. apetala* were similar among all cold treatments. The results of the greenhouse experiments were consistent with the current distribution of *Sonneratia* in Hong Kong, with most

colonized in the western (less saline) than the eastern sides of Hong Kong such as Deep Bay and Lantau areas, and were mainly found on the open mudflat (higher light intensity) and absent under closed canopy.

A series of field trials comparing the effectiveness of seven removal methods showed that "cut only" method was not reliable as there was 25% of the cut individuals re-sprouted. The non-intrusive "hand pulling" method was most effective in terms of time and money to remove seedlings and saplings with height less than 1.5 m. For the larger saplings and adult trees, "cut and covered by mud" was the best method as it could successfully prevent *Sonneratia* from re-sprouting and all individuals were dead at the end of the monitoring period. "Cut and apply glyphosate" was the second most effective method, however, the application of herbicide should be avoided due to its uncertain impact to the native flora and fauna. The "cut and covered by plastic bag" method was also effective but it has a disadvantage of putting man-made material into the natural environment and the bags must be removed. "Ring barking" as well as the "frill and apply glyphosate" methods were not recommended as both failed to kill the plants.

In summary, the study revealed that the exotic *Sonneratia* have a high potential to become invasive. It is likely that *Sonneratia* will be more and more in Hong Kong, these exotic plants must be carefully controlled and monitored. Battle against *Sonneratia* requires long term commitment, sufficient resources must be allocated for continuous management work.

Acknowledgements

This thesis could not have been written with the support, advice and help from my supervisors, colleagues, family and friends. I am indebted to Prof. Tam, Fung-yee Nora for her guidance and valuable advice for my project. The Agriculture, Fisheries and Conservation Department, the Hong Kong Special Administrative Region (AFCD) supported the survey of the distribution of *Sonneratia* and the removal trials. I would like to express my deepest appreciation all those contributed their expertise, advice and encouragement in this project, in particular, Dr. Kwok, Pik-wan Winnie (AFCD). I would like to thank all the staffs from AFCD in particular Chow, Ka-lai who provided support in my field work. I am grateful for the support of my lab-mates Leung, Ka-kin and the final year project student, Chan, Lei-yuk Esther, who worked with me in taking care of seedlings in the greenhouse. Grateful the industrial attachment scheme student helpers Lo, Chi-leung Marcus and Lau, Kai-chi Victor for their efforts in the field work during the summer of 2005 and 2006 respectively. Last but not least, I must express my gratitude to my parents for their concern and support during my study.

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LIST OF ABBREVIATIONS

AFCD	Agriculture, Fisheries and Conservation Department of the Hong Kong Special Administrative Region
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
CEDD	Civil Engineering and Development Department of the Hong Kong Special Administrative Region
CG	Cut and apply glyphosate
CM	Cut and covered by mud
CO	Cut only
CP	Cut and covered by plastic bag
DDT	Dichloro-Diphenyl-Trichloroethane
EPD	Environmental Protection Department of the Hong Kong Special Administrative Region
FG	Frill and inject glyphosate
FIA	Flow injection analyzer
FMFNR	Futian Mangrove Forest Nature Reserve
HKSAR	Hong Kong Special Administrative Region
HK-SWC	Hong Kong-Shenzhen West Corridor
HP	Hand pulling
IUCN	The International Union for Conservation of Nature
MDC	Kam Tin Main Drainage Channel
MPMNR	Mai Po Marshes Nature Reserve
ppt	Part per thousand
RB	Ring barking
SPSS	Statistics Package for Social Science
TKN	Total Kjeldahl nitrogen
TOM	Total organic matter of oven dried weight
USEPA	United States Environmental Protection Agency
WWFHK	The World Wide Fund for Nature, Hong Kong

CHAPTER 1

GENERAL INTRODUCTION

1.1 Exotic and invasive species

Human intervention accelerates the rate of species invasions (IUCN, 2000). The spread of human and the development of trading links help the plant and animal out of their native range to mix and spread (Dudgeon & Corlett, 2004). Invasions are now considered as a global threat to biodiversity as it is more pervasive than the loss of natural habitats and pollution by human activities (Cronk & Fuller, 1995; Luken & Thieret, 1997). As once exploitation or pollution stops, the ecosystem can sometimes slowly recover. Unfortunately, the invasive species cannot be easily and completely eradicated; they can spread, consolidate, posing pervasive and even irreversible threat to the ecosystem (Cronk & Fuller, 1995; Dudgeon & Corlett, 2004). In America, biological invasions are second only to land use change (Wilcove *et al.,* 1998).

Exotic species is not equivalent to invasive species. Exotic species is defined as the species that is capable to disperse outside of its native range by human direct and indirect introductions (Cronk & Fuller, 1995; IUCN, 2000; Vermeji, 1996). The synonymous term of exotic is ‘non-native’, ‘alien’, ‘introduced’ and ‘non-indigenous’ species (Smith, 1998). Exotic species can be introduced deliberately or accidentally, most of the exotic species have undetectable or even no impact to the ecosystem. Not all the exotic species are unwelcomed, for instance, human are benefit from the introduction of varieties of crops, ornamentals and livestock. Exotic plants are most likely introduced accidentally, transport through the seeds in the substrate, cultivation or afforestation. Once introduced, some plants are able to establish themselves and form self-sustaining populations in natural and semi-natural ranges. In some cases, it becomes an invasive species. The definition of invasive exotic species is a species outside of

its active range that can spread naturally without the assistance of human in natural or semi-natural habitats, to produce a significant change in terms of composition, structure, diversity or ecological relationship of native species (Cronk & Fuller, 1995; Smith, 1998). Difficulty arises when a line is needed to draw between exotic and invasive plant, in particular, it is at the early stage of the introduction without the support of scientific research. For the species that the detrimental effects have not yet determined, “naturalized exotic species” are used. These are the species that might have interactions with the native flora and fauna and may potentially threaten the native biodiversity of Hong Kong (Dudgeon & Corlett, 2004).

1.2 Exotic plants in Hong Kong

Many species of plants have introduced into Hong Kong accidentally or deliberately and some have later established their own population. In Hong Kong, there are approximately 2,130 species of wild vascular plants including of at least 160 naturalized exotic species (Dudgeon & Corlett, 2004; Ng & Corlett, 2002). Among the naturalized exotic species, 252 have been documented in a recent checklist (Ng & Corlett, 2002). Of these, slightly over half was probably introduced from tropical America, about 20% from Northern Europe and China, 15% from Africa and Madagascar while only 10% are contributed by the tropical and subtropical Asia (Dudgeon & Corlett, 2004). The percentages from Asia are underestimated because it is hard to tell whether the species is native or exotic from its geographical distributions unless the exotic species is recently introduced.

Wetlands have been strongly invaded in many parts of the world but they are mostly referring to floating aquatics, submerged aquatics and plants of seasonally flooded low-lying areas in the freshwater area. Same case occurs in Hong Kong, most of the exotic plants are confined to lowland species especially the habitats that are frequently disturbed by human, such as wastelands,

cultivated areas, abandoned cultivation and forest margins (Corlett, 1992; Ng & Corlett, 2002). Exotic plants dominate the spontaneous plant communities near human settlement (Corlett, 1992) but rarely a significant problem in natural vegetation (Leung *et al.*, 2009). Only a few exotic plant species have been reported to invade naturally disturbed habitats, including *Sonneratia apetala* Buch.-Ham. in the brackish habitat of the Mai Po Marshes Nature Reserve (MPMNR) and *Tridax procumbens* L. at the back of sandy beaches (Corlett, 1992; Ng & Corlett, 2002).

1.3 Mangroves in Hong Kong

Mangrove refers either the constituent plants of tropical intertidal forest communities or to the community itself (Morton & Morton, 1983; Tam & Wong, 1997; Tomlinson, 1994). Mangroves are evergreen plants that belong to several families, they are highly specialized in conditions of high salinity, extreme temperatures, anaerobic and unstable substrates. Mangroves are found in sheltered tropical and subtropical areas, with freshwater input from streams or rivers and regular tidal flushing (Tam & Wong, 2000). In the world, there were around 17,000,000 ha of mangrove area and the area was declining due to coastal development, exploitation and climate change (Tam & Wong, 2000).

Mangroves in Hong Kong represent the northerly distribution in the world. Excluding the exotic mangrove *Sonneratia* species, there are eight species of true mangroves. The most dominant species in Hong Kong is *Kandelia obovata* Sheue, Liu & Young sp. nov. (formerly as *Kandelia candel* (L.) Druce), followed by *Aegiceras corniculatum* (L.) Blanco, *Excoecaria agallocha* L., *Avicennia marina* (Forssk.) Vierh and *Bruguiera gymnorrhiza* (L.) Poir., *Acanthus ilicifious* L., *Lumnitzera racemosa* Willd. and *Heritiera littoralis* Dryand. ex Ait. are comparatively rare and occur in few mangrove stands in Hong Kong. As Hong Kong is situated in subtropical region and has a relatively

cold winter, mangrove trees are characterized by their dwarf sizes (Tam & Wong, 2000).

According to the most updated ecological survey done by Agriculture, Fisheries and Conservation Department (AFCD), there are 63 mangrove stands in Hong Kong which occupy 510 hectare (AFCD, 2007a) (Fig. 1.1). Most of them are distributed in Deep Bay area, the northwest of Hong Kong. Mangrove stands in this area are remarkable and characterized by the soft substrate. On the contrary, on the eastern side of Hong Kong, mangrove stands in Sai Kung and Northeast New Territories areas are characterized by narrow fringe or belts of dwarf trees, the substrate is mostly sandy and covered with stones and pebbles. The most fascinating piece of mangroves in Hong Kong is the MPMNR in Deep Bay, with the largest areas and the high diversity of avifauna.

Mangrove is one of the chronically disturbed habitats, the instability condition of the substrate excludes most of the invasive plant species from the mangrove area (Teo *et al.*, 2003). However, *Sonneratia*, the commonly used exotic species for afforestation in Mainland China such as Futian Mangrove Forest Nature Reserve (FMFNR), Shenzhen Bay has been rapidly and widely spread in Hong Kong mangrove stands. It is almost impossible to prevent the establishment of this exotic species in our area.

1.4 Pathways of *Sonneratia* introduction

Overexploitation, industrialization, urbanization and reclamation destroyed the mangrove areas in the world (Lock & Cheung, 2004, Tam & Wong, 2000). Planting and replanting of mangroves are one of the methods to convert the bare mudflat back to mangroves. Two fast growing species, *Sonneratia apetala* Buch. -Ham. and *S. caseolaris* (L.) Engl., were introduced to the FMFNR from Dongzhaigang Mangrove Nature Reserve of Hainan Island in 1993 for afforestation. The plants were successfully established after a year and started to produce flowers and fruits in 1996 (Li *et al.*, 1998; Zan *et al.*, 2003).

Chapter 1: General Introduction

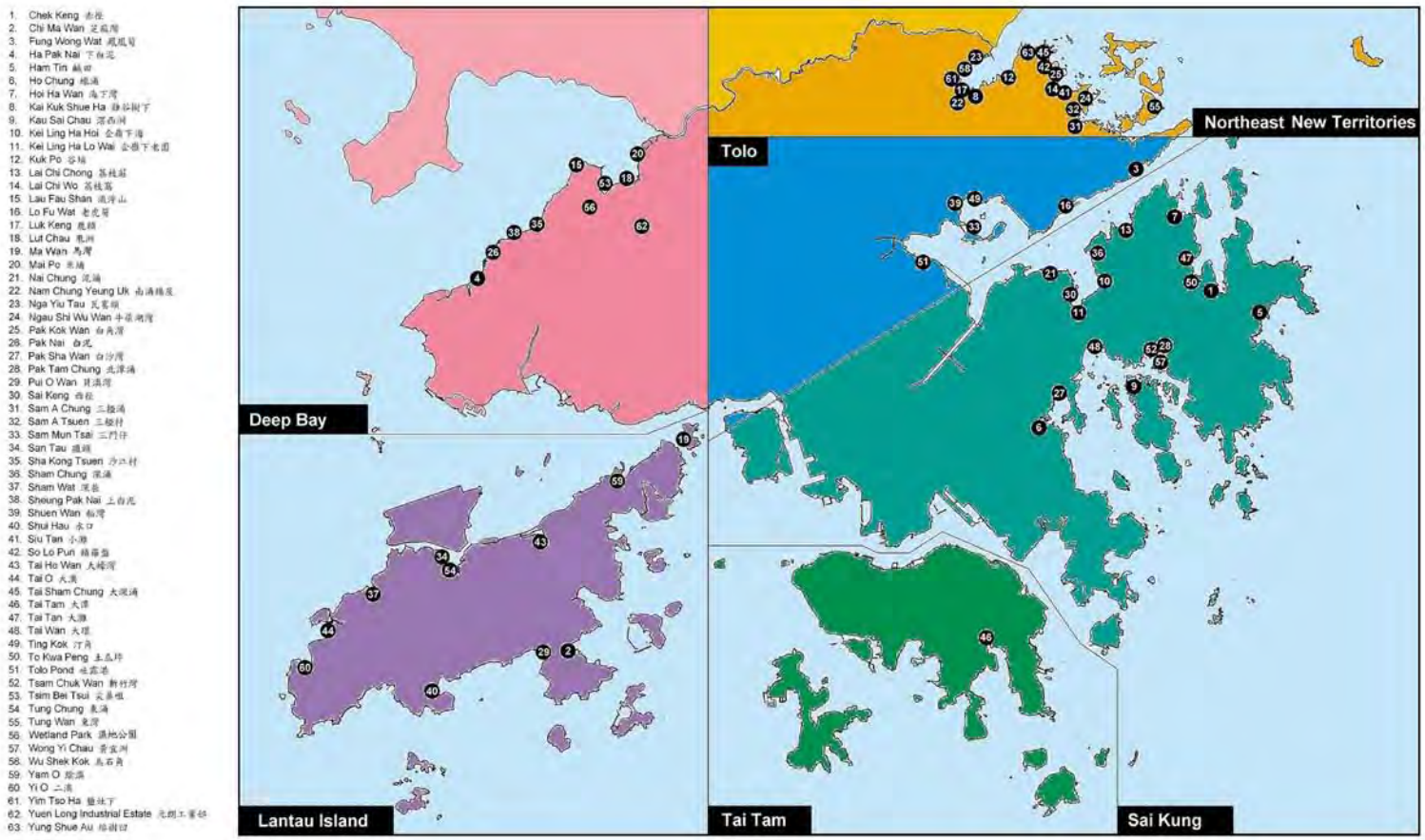


Fig. 1.1 Distribution of mangrove stands in Hong Kong (AFCD, 2007a)

S. apetala is naturally distributed in South Asia such as India, Bangladesh and Malaysia, and was originally introduced to Dongzhaigang from Sundarban, the southwest of Bangladesh in 1985 (Liao *et al.*, 2004; Zan, *et al.*, 2003). *S. caseolaris,* distributed from South East Asia to the north of Australia, is a native species and naturally found in the Hainan Island (Liao *et al.*, 1997b; Zan *et al.*, 2003). Both species were appreciated for their fast growing nature and are useful to stabilize the bare mudflat within a relatively short period of time (Zan *et al.*, 2003). They are easily grown and their seed germination requirements are not specific. They can also tolerate fluctuations of temperature, pH and salinity (Liao *et al.*, 1997a). Both *Sonneratia* species are exotic to Hong Kong.

In early 2000, some extraordinary mangrove plants were found by staff from AFCD on the exposed mudflat close to the mouth of Sham Chun River in Deep Bay area. They were later identified as the exotic mangrove species belonging to the genus *Sonneratia*. In 2001, individuals of *Sonneratia* were also found among the native mangrove species, including *A. corniculatum*, *K. obovata* and *A. ilicifolius* along the embankment of the downstream section of the Kam Tin Main Drainage Channel (MDC). The 13 ha mangroves along the MDC were planted in 1998 as a mitigation measure to compensate the mangrove lost due to the MDC project, and seedlings of *Kandelia, Aegiceras* and *Sonneratia* were introduced. Being fast growing, *Sonneratia* could easily be recognized among other planted mangroves by their height. As the number of *Sonneratia* in the MDC was surprisingly high and their occurrence among the native mangrove trees suggested that they might become invasive species. Although the potential impact of the exotic species on the native mangrove communities was still unknown, precautionary measure were taken to remove the exotic mangrove. Therefore, in April 2002, the then Territory Development Department (now renamed as Civil Engineering and Development Department, CEDD) who commissioned the original planting project was asked to clear the *Sonneratia* plants found along the MDC. AFCD has also started to conduct regular *Sonneratia* removal exercises since 2001.

1.5 Impacts of *Sonneratia*

Few papers have reported the impacts of the two *Sonneratia* species, *S. apetala* and *S. caseolaris*, on native mangrove plants. The results of the limited reports and studies were controversial. There were studies showing that the niche of *Sonneratia* species did not overlap with the native one and therefore unlikely to replace the indigenous mangrove species (Zan *et al.*, 2003). Some studies showed that *Sonneratia* species could improve the quality of the substrate in the mudflat by increasing the salinity, nitrogen, potassium, calcium, and organic materials, reducing the pH, and even promoting the growth of native species (Li e*t al.*, 2003). Yet there is no ecological study to consider the role, the status and the invasive potential of *Sonneratia* species in Hong Kong. The impact of the exotic *Sonneratia* on the mangrove habitats in Hong Kong is also unknown. More information of *Sonneratia* species is certainly needed.

1.6 Research aim and objectives

The present study aims to assess the distribution, ecology and potential impacts of the *Sonneratia* species on native mangroves in Hong Kong.

The comprehensive and representative floristic data of *Sonneratia* is potent in disclosing at least some associations between the exotic species and native flora. Different measures to control the spread of *Sonneratia* species was also explored in this study. Results from the present study provide baseline information which helps Hong Kong government to predict the impacts and draft the management plan of these exotic species.

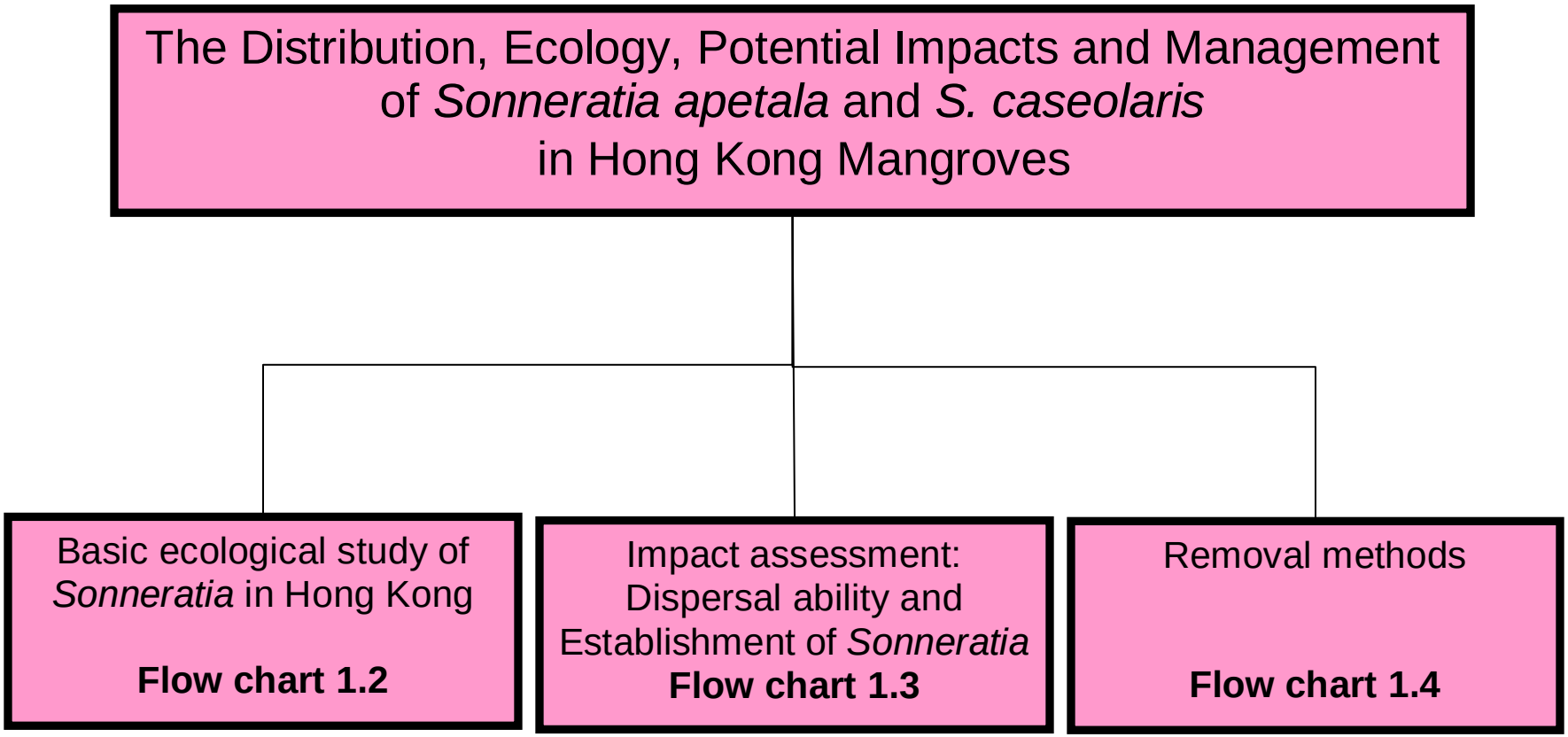
The specific objectives of the study include:

1) Investigate the biology of *Sonneratia apetala* and *S. caseolaris*, including their morphology and reproduction, in particular, seasons of flowering and fruiting and abundance of fruits and seeds.

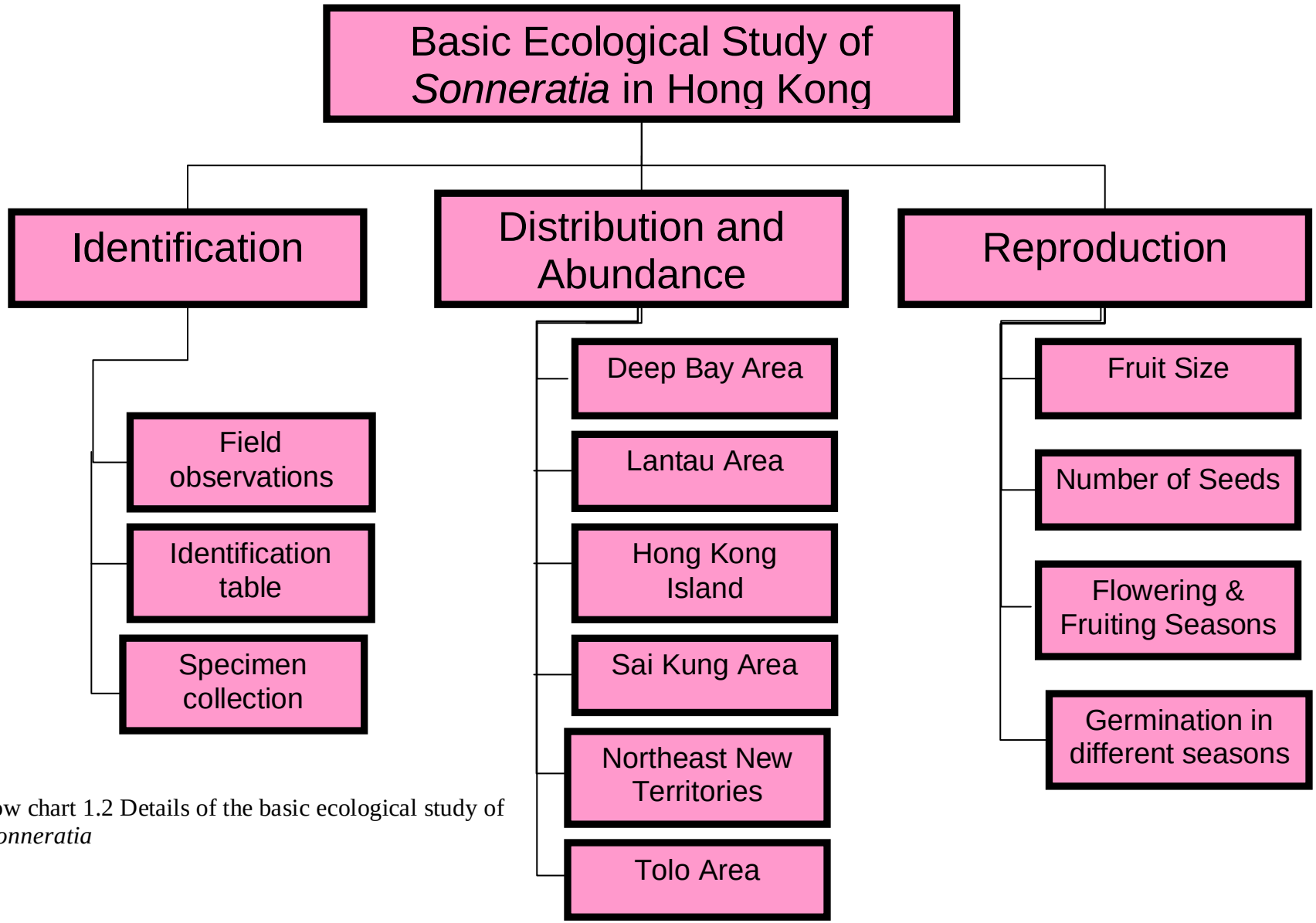
2) Carry out a territorial-wide baseline survey to determine the abundance and distribution of the two *Sonneratia* species. Different mangrove stands in Hong Kong were visited, and locations of *Sonneratia* were mapped out.
3) Compare the seed vigor in different fruiting seasons, aiming to identify the best season for removal.
4) Use a computer model to predict the dispersal of *Sonneratia* propagules from Deep Bay area to different mangrove stands in Hong Kong.
5) Conduct greenhouse experiments to test the viability of seeds under different salinities during dispersal phrase, examine the germination requirements of *Sonneratia* species, and find out the limiting factors and hence predict their potential impacts.
6) Evaluate different physical and chemical removal methods, and determine the most effective way to clear *Sonneratia*.

1.7 Research plan

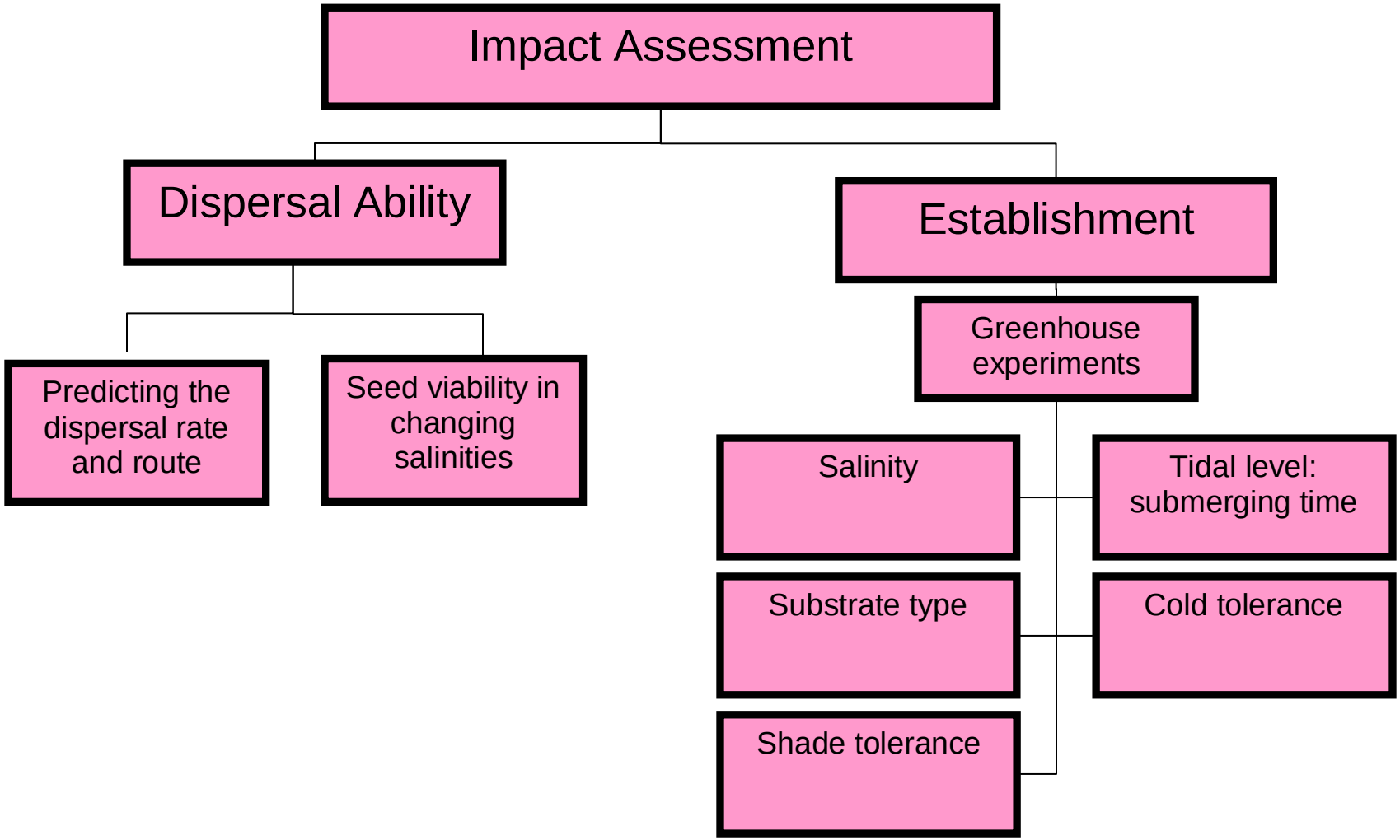
The study was divided into three sections, namely Basic ecological study, Impact assessment and Removal methods (Flow chart 1.1). The Basic ecological study (Flow Chart 1.2) includes species identification and the reproductive biology of *Sonneratia*. To evaluate the abundance and distribution of *Sonneratia* in Hong Kong, a territorial-wide baseline survey was conducted in 2005 and 2006. Twenty-nine mangrove stands from six areas of Hong Kong were visited. The distribution and abundance of *Sonneratia* in each stand was counted. For the impact assessment study (Flow chart 1.3), the possibility of *Sonneratia* in Deep Bay to disperse and establish in other mangrove stands was evaluated. For the dispersal assessment, a computer model was used to predict the dispersal rate and direction, and predict the mangrove stand that may be potentially affected. In the establishment phase, the germination conditions for the *Sonneratia* were assessed. For the removal study (Flow chart 1.4), the most effective method to remove *Sonneratia* was identified through field trials, a preliminary management plan was then proposed for management consideration.



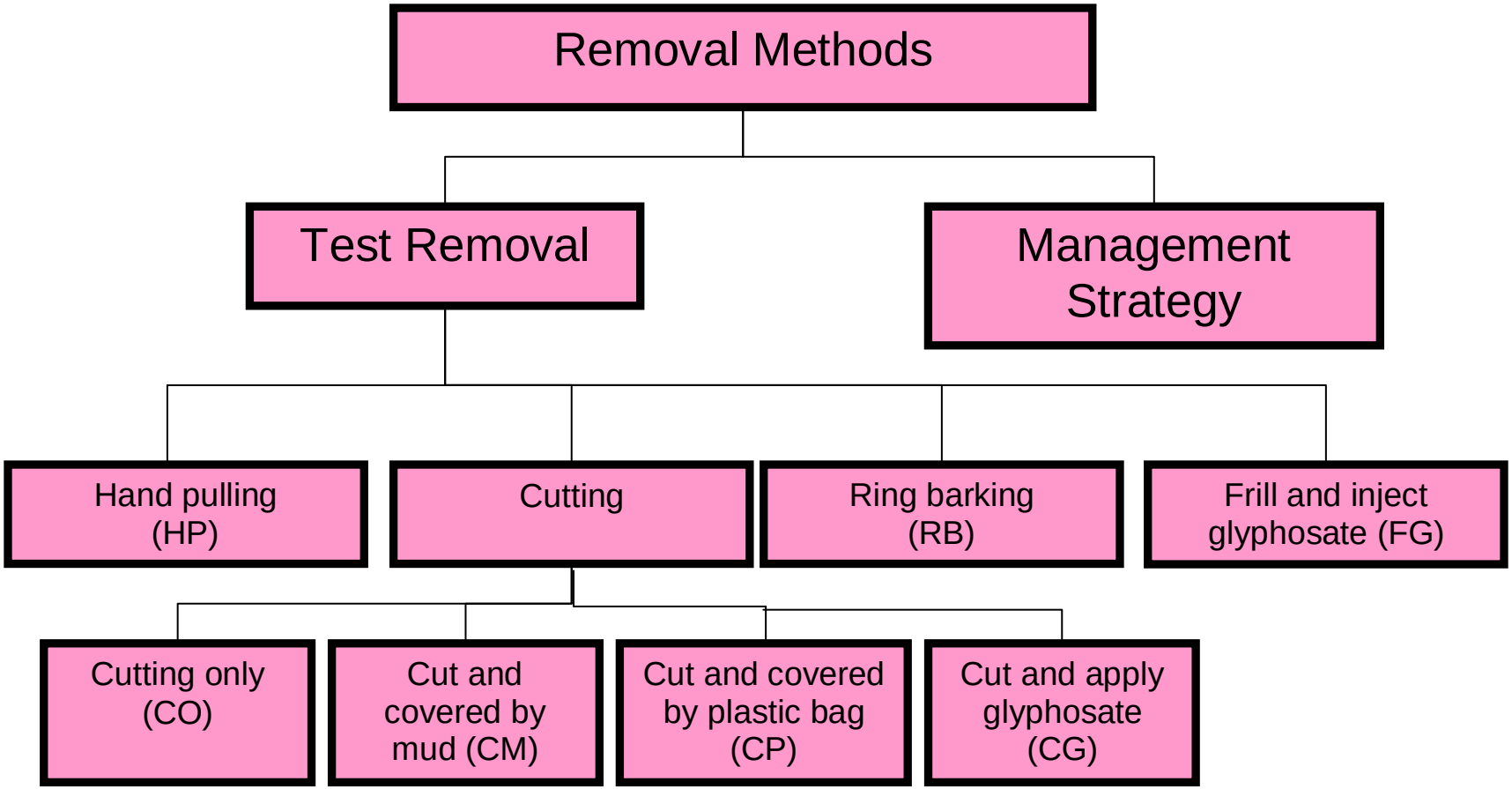
Flow chart 1.1 Research plan of the *Sonneratia* study



Flow chart 1.2 Details of the basic ecological study of *Sonneratia*



Flow chart 1.3 Details of impact assessment of *Sonneratia*



Flow chart 1.4 Details of the *Sonneratia* removal study

CHAPTER 2

BASIC ECOLOGICAL STUDY OF *SONNERATIA* IN HONG KONG

2.1 Introduction

2.1.1 Identification of *Sonneratia* species

Accidental introductions are much more difficult to predict, in some cases, the origin and identity of the alien plants are often not clearly known. Correct identification of the species is essential before assessing the distribution and understanding its biology. Identification of *Sonneratia* into species level is difficult as this genus has uniform vegetative features, and hybrids can occur among the members, examples are *S. alba* x *S. ovata* and *S. alba* x *S. caseolaris* in Borneo and Queensland, respectively (Tomlinson, 1994). In 2000, the *Sonneratia* specimens found in Deep Bay area were formerly misidentified as *Sonneratia alba* J. Smith (杯萼海桑) by the Agriculture, Fisheries and Conservation Department (AFCD). Based on the keys published by Hogarth (1999), the previously mis-identified *Sonneratia* in Hong Kong might belong to two species –*Sonneratia apetala* Buch.-Ham (無瓣海桑) and *Sonneratia caseolaris* (L.) Engl. (海桑). The present study therefore aims to conduct more detailed field observations on their morphology and reproduction, as well as collecting specimens for further identification.

2.1.2 Distribution and abundance of *Sonneratia*

One of the crucial steps of nature conservation or ecosystem restoration is an assessment of the distribution. Accurate recording the distribution of *Sonneratia*

species is essential to assess the extent of the problems and their impacts, decide the control measures and prioritize the areas for removal. Such data can also act as a baseline for the success of any control program if needed.

The composition of mangrove plants in Hong Kong has been described by several scientists (Duke & Khan, 1993; Morton & Morton, 1983; Tam & Wong, 1997; Young, 1993), none of them recorded *Sonneratia*. Due to the close proximity of the Mai Po mangrove stand in Hong Kong to Futian Mangrove Forest Nature Reserve (FMFNR) (Fig. 2.1), it is likely that the *Sonneratia* in Hong Kong was originated from Futian where the two *Sonneratia* species had been used for afforestation since mid 90's.

According to the recent ecological survey conducted by the Coastal Community Working Group of the AFCD from 2002-2005, a total of 63 mangrove stands was identified in Hong Kong (Fig. 1.1 in Chapter 1), covering a total area of 510 ha (AFCD, 2007a). They are distributed in six areas: Deep Bay, Lantau, Hong Kong Island, Sai Kung, Northeast New Territories and Tolo.

Deep Bay

Deep Bay is situated on the northwest of the New Territories. There are ten mangrove stands in Deep Bay Area, namely Mai Po, Tsim Bei Tsui, Kam Tin River, Yuen Long Industrial Area, Wetland Park, Lau Fau Shan, Sha Kong Tsuen, Sheung Pak Nai, Pak Nai and Ha Pak Nai.

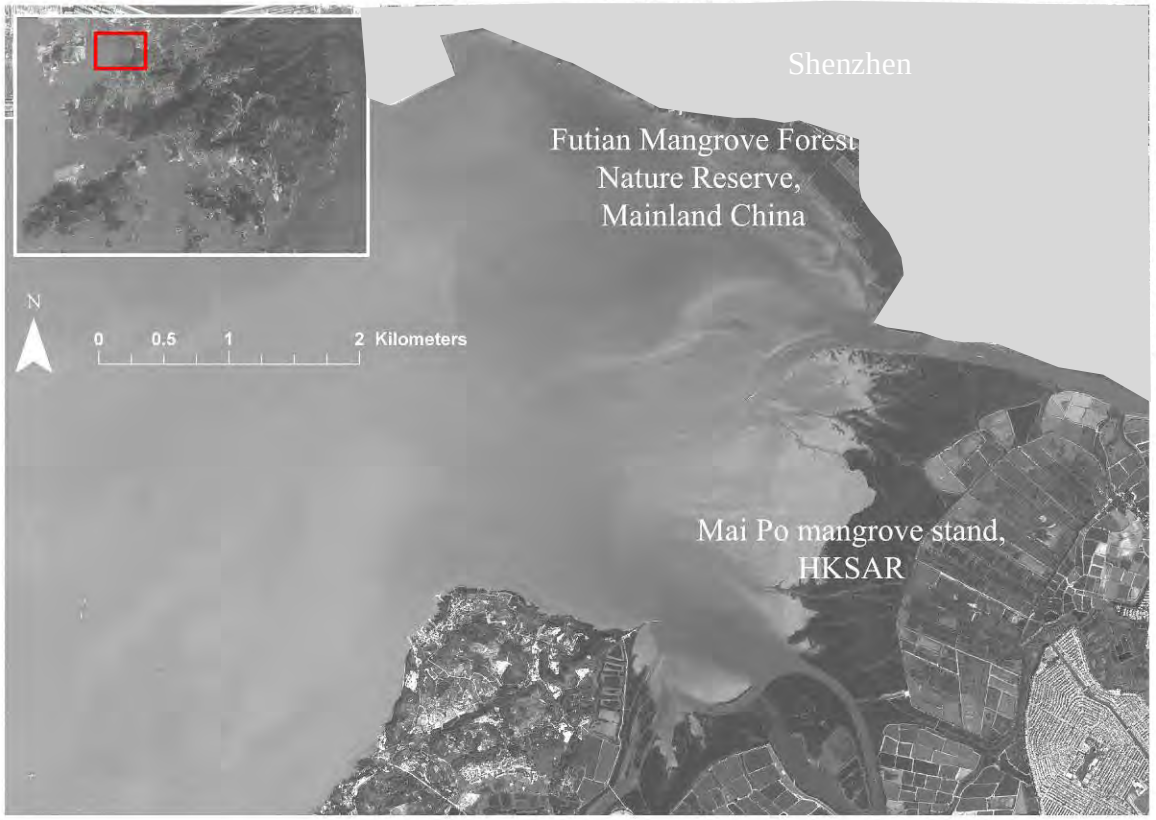


Fig. 2.1 Map showing the locations of Futian Mangrove Forest Nature Reserve (FMFNR) and Mai Po mangrove stand

Deep Bay area is closest to the FMFNR where *Sonneratia* was planted for afforestation in mid 90's and hence it may be the most vulnerable to the invasion. Deep Bay area is influenced by the highly seasonal discharge from the Sham Chun and Pearl Rivers. Apart from freshwater, river carries tones of sediments to Deep Bay every year (Irving and Morton, 1988). Substrate in this area is extremely soft and muddy.

Lantau Area

Lantau Area is situated on the southwest of Hong Kong. There are 11 mangrove stands in this area. Five mangrove stands, Ma Wan, Yam O, Tai Ho Wan, Tung Chung, San Tau on the northern coast, Sham Wat, Tai O and Yi O on the western coast while another three mangrove stands on the southern coast, they are Shui Hau, Pui O and Chi Ma Wan.

Hong Kong Island

Tai Tam mangrove is the only mangrove stand on Hong Kong Island. It is a small mangrove stand on the southeastern part of Hong Kong Island.

Northeast New Territories, Tolo and Sai Kung

The other 41 mangrove stands are distributed in the Northeast New Territories, Tolo and Sai Kung areas. Substrates in these stands are generally sandy. These

mangroves are far from the Pearl River Delta and generally receive higher salinity sea water.

Sonneratia is dispersed exclusively by ocean currents, the fruit and seed have some initial ability to float (Tomlinson, 1994). The process of invasion can be divided into three successive stages: arrival, establishment and integration (Vermeij, 1996). The study of the arrival phase can assess the dispersibility which is an important step for any invaded species. The tidal flow generated by the program Digital Tidal Stream Atlas 2006 shows that the ebbing tides (Fig. 2.2) carry the seeds from Inner Deep Bay to Outer Deep Bay. With the supplement of the outflow of the Pearl River, the stream passes through the Urmston Road and hits the Chek Lap Kok and North of Lantau Island. The stream is further diverged into two routes: one heading to Ma Wan Channel and Rambler Channel and moving southward to the West and East Lamma Channels, reaching the south of Hong Kong Island. Another route is flowing from Chek Lap Kok to the Lantau West and then moving eastward to the Lantau South. Figure 2.3 shows that the flowing tide moves in an opposite direction, from south-east to north-west, flowing back to inner Deep Bay. According to this tidal flow pattern, the floating *Sonneratia* seeds have a higher chance to establish in Deep Bay and Lantau areas. The present study will therefore focus on Deep Bay and Lantau areas.

In order to obtain enough floristic data that can represent a general picture of the distribution of the exotic *Sonneratia* species in Hong Kong mangroves, a baseline survey of *S. apetala* and *S. caseolaris* was carried out in 2005 and 2006.

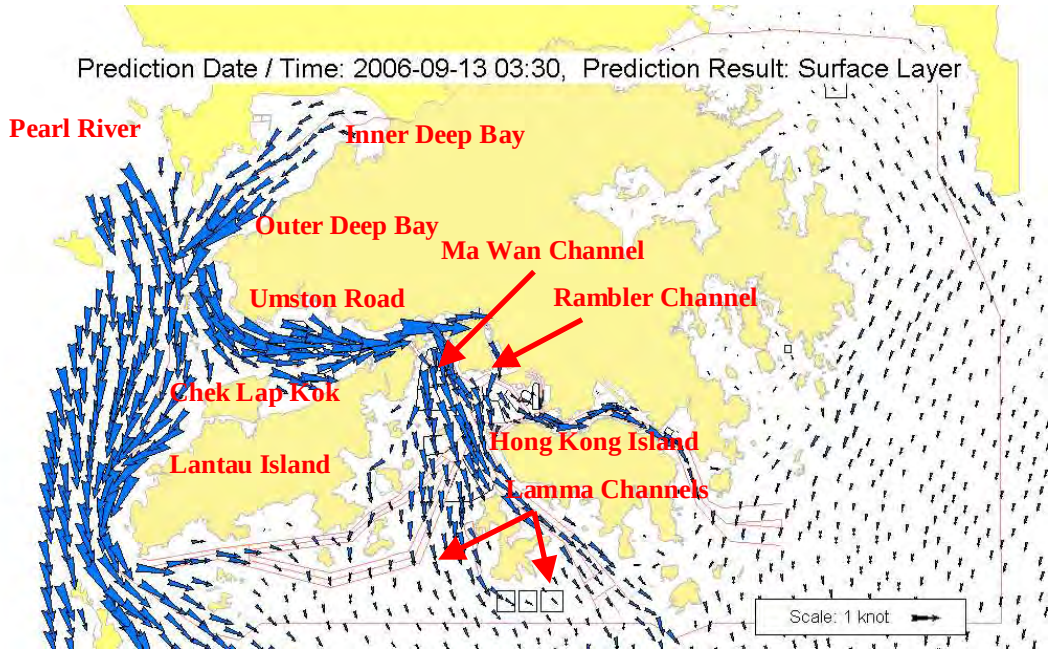


Fig. 2.2 The tidal cycle in Hong Kong: Ebbing tide (Hong Kong Digital Tidal Stream Atlas 2006 (Version 1.01), Hydrographic Office, Marine Department, the Government of the Hong Kong Special Administrative Region)

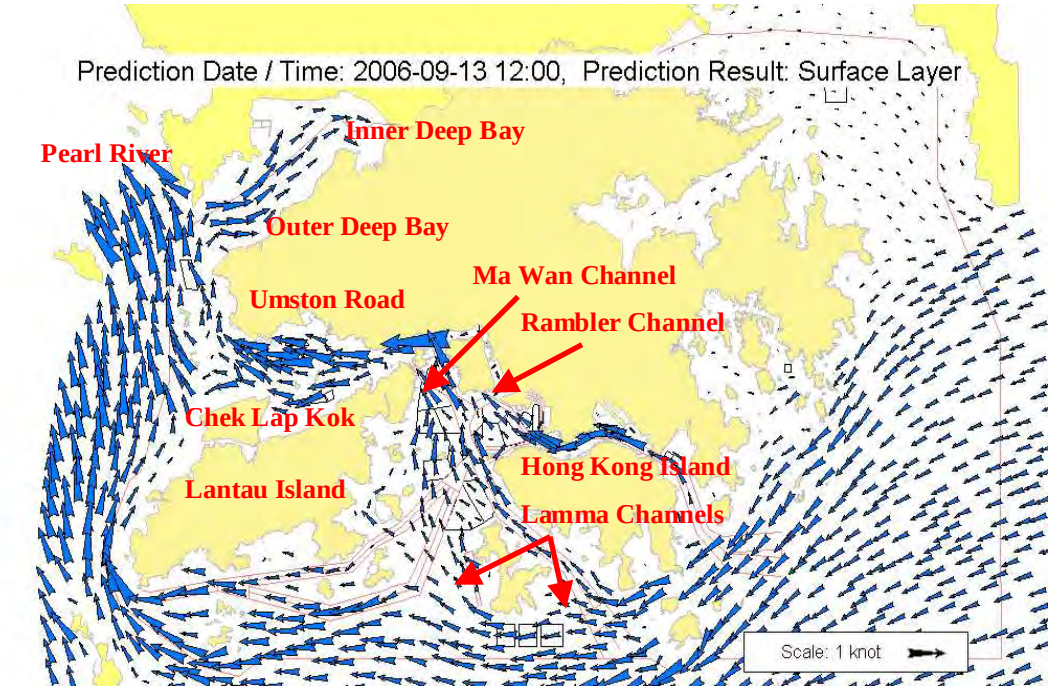


Fig. 2.3 The tidal cycle in Hong Kong: Flowing tide (Hong Kong Digital Tidal Stream Atlas 2006 (Version 1.01), Hydrographic Office, Marine Department, the Government of the Hong Kong Special Administrative Region)

2.1.3 Reproductive biology of *Sonneratia* species

Seed ecology includes the seasonality of flowering and fruiting, and the seed viability in different fruiting periods. The timing of flowering and fruiting is determined by the availability of energy and nutrients, flowering usually occurs in a fixed point of the growth cycle while fruiting links to the availability of dispersal agents (Dudgeon & Corlett, 1994). Tam & Wong (2004) gave a comprehensive account on the fruiting seasons and the characteristics of propagules of the eight true native mangrove species in Hong Kong. Identify the fruiting period and testing the seed viability in different fruiting periods are important for the management of *Sonneratia*, and such information can help managers to decide the best timing for removal. Huang & Zhan (2003) reported that *S. apetala* started to reproduce three years after transplanting to Dongzhaigan, Hainan Island in 1985, they also found that this species were able to flower one year later and produced fruit in alternate year when it was transplanted from Hainan to Zhanjiang, Guangdong. These results showed that *S. apetala* were more adaptable in Guangdong than Hainan Provinces. Zan *et al.* (2003) also found that the *S. apetala* and *S. caseolaris* were able to flower and produce fruit two years later after transplanting to FMFNR. The present study aims to determine the signs of fruit maturity, the peak fruiting season, fruit size and seed numbers of *S. caseolaris* and *S. apetala* in Hong Kong, and test the viability and vigor of seeds harvested from different fruiting seasons.

2.2 Materials and methods

2.2.1 Identification of *Sonneratia* species

The differences between the two *Sonneratia* species were identified based on field observations and the key published by Hogarth (1999). Samples from four mature trees of each species were collected from two locations, namely Tsim Bei Tsui and Mai Po in the summer, 2005. The samples were then sent to Royal Botanic Gardens of Kew in Britain for confirmation.

2.2.2 Distribution and abundance of *Sonneratia*

2.2.2.1 Study sites

All the ten mangrove stands in Deep Bay area were visited, which included Mai Po, Tsim Bei Tsui, Kam Tin River, Yuen Long Industrial Area, Wetland Park, Lau Fau Shan, Sha Kong Tsuen, Sheung Pak Nai, Pak Nai and Ha Pak Nai (Fig. 2.4). All 11 mangrove stands in Lantau area were surveyed, which included Ma Wan, Yam O, Tai Ho Wan, Tung Chung, San Tau, Sham Wat, Tai O, Yi O, Shui Hau, Pui O and Chi Ma Wan. In Hong Kong Island, the only mangrove site, Tai Tam, was also surveyed. For Sai Kung, Northeast New Territories and Tolo areas, two mangrove stands from each area were randomly selected. They were Chek Keng and Kei Ling Ha Lo Wai from Sai Kung area; Lo Fu Wat and Tolo Pond from Tolo area; Lai Chi Wo and Tai Shum Chung from Northeast New Territories area.

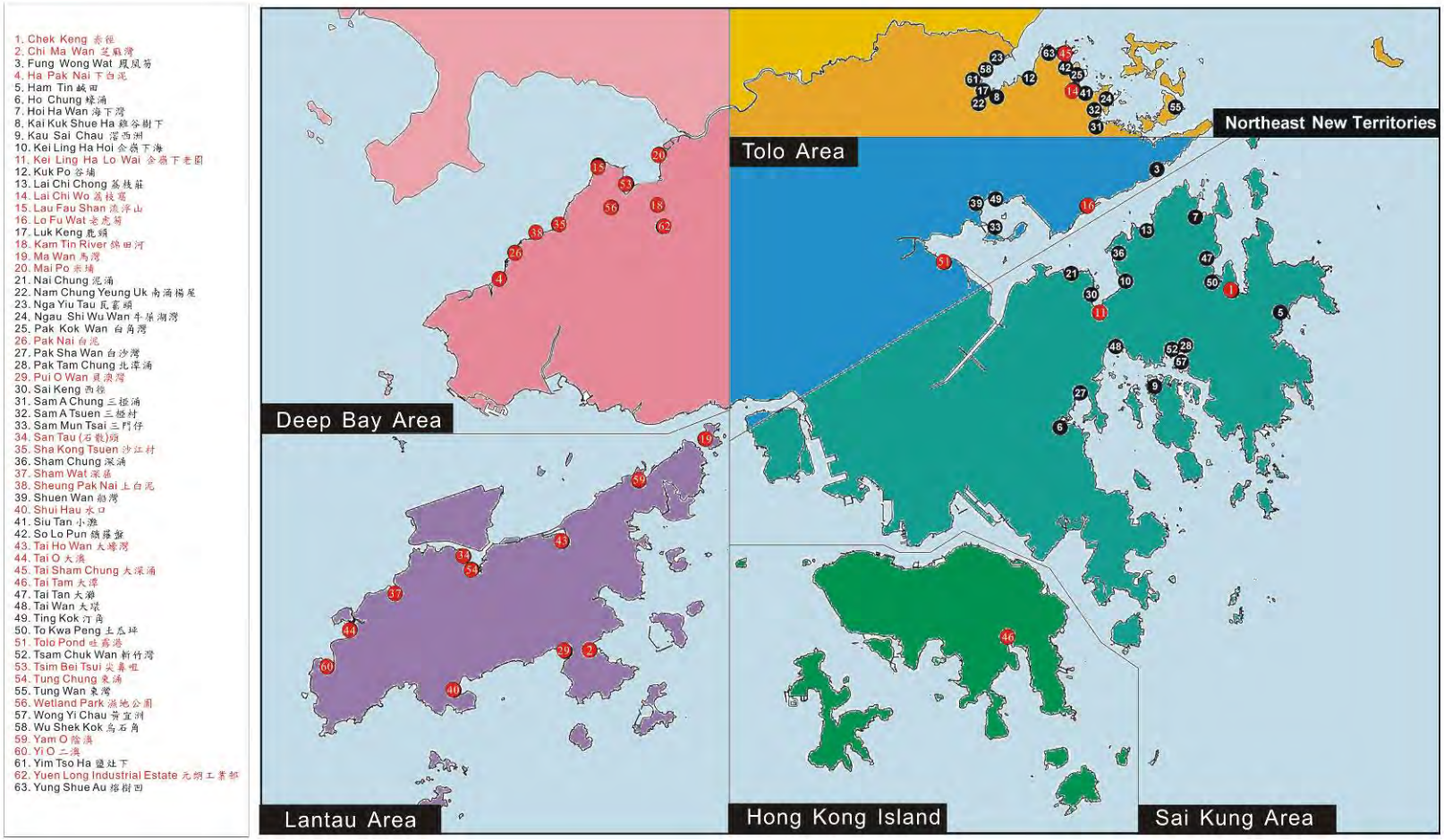


Fig. 2.4 Distribution of 63 mangrove stands in Hong Kong and the 28 stands surveyed in the present study (Red colour indicates the surveyed stands)

2.2.2.2 Distribution of *Sonneratia* in different mangrove stands in Hong Kong

A total of 20 field visits were made to the selected mangrove stands in Hong Kong in 2005 and 2006. To attain the maximum exposure of the mangrove areas, the stands were visited in the low ebb period (<1.2 m). Walking on the soft and muddy substrate in Deep Bay area was dangerous and inefficient, mud surfer was used for the survey. The mud surfer was driven to the edge of the mangroves and the individual trees of *Sonneratia* in the stand were counted. The coordinates of the *Sonneratia* individuals were recorded by Global Positioning System (GPS) (Garmin^{TM} eTrex ®). If the individual was far way from the edge, the location of the mud surfer was taken as the reference coordinate, the distance between the mud surfer and the targeted individual was measured by the laser rangefinder (Leica Pinmaster Rangefinder) and the direction was measured by a compass (Fig. 2.5). The exact coordinate was then calculated by trigonometry. For the channels in large mangrove areas such as Tsim Bei Tsui and Mai Po, where the mud surfer could not drive in, a motor boat was used during the floating tide (> 2.5 m). The number and location of *Sonneratia* individuals along the channels were recorded. Aerial photographs were taken in April 2006 to assist in locating the *Sonneratia* individuals in the heavily infested areas such as the patches close the Sham Chun River and Tsim Bei Tsui (Photo 2.1). For the mangrove stands other than Deep Bay area, they could be accessed by foot. Photos were taken for references. Only individuals with height >1.5 m were recorded.

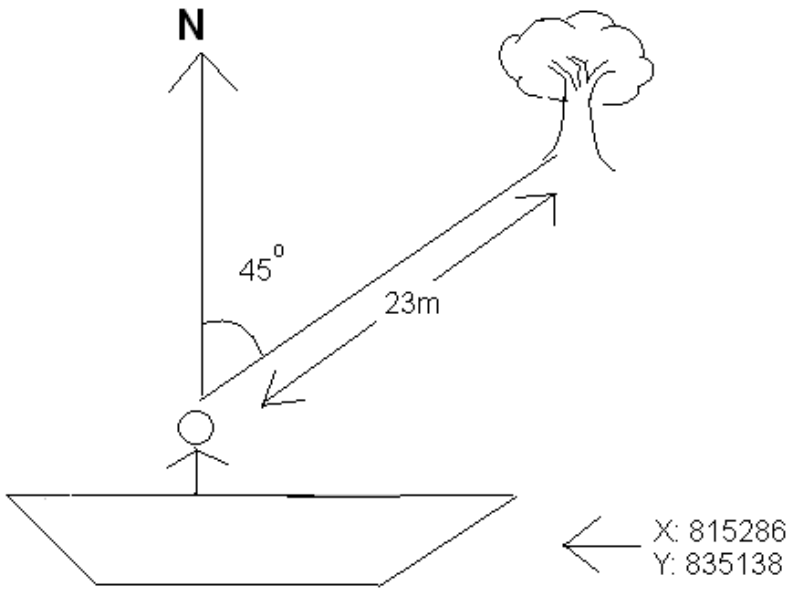


Fig. 2.5 Measurement for the distant *Sonneratia* individual



Photo 2.1 Aerial photograph of Mai Po mangrove stand showing *Sonneratia* individuals that appeared differently from the native mangrove plants (Red circles indicate the location with high density of *Sonneratia* individuals)

The ecological information was entered into the Geographic Information System (GIS) ArcGIS Desktop 9.1 (ESRI, China (HK)) for further analysis. Map was generated for each mangrove stand, and the density of *Sonneratia* was calculated according to the following equation,

$$\text{Density} = \frac{\text{Number of } \textit{Sonneratia} \text{ individuals}}{\text{Area of a particular mangrove stand}}$$

The area of a particular mangrove stand was determined by ArcGIS Desktop 9.1, the boundary of each mangrove stand was marked on the aerial photograph and analyzed by the program. The area was expressed in term of hectare.

2.2.3 Reproductive biology of *Sonneratia* species

2.2.3.1 Flowering and fruiting seasons

Five individuals of each *Sonneratia* species in Tsim Bei Tsui (22°28'37''N, 114°01'24''E) were visited monthly between August 2005 and December 2006. The presence of flowers or fruits was recorded. Peak fruiting season was defined as more than ten mature fruits could be found under the canopy of a parent plant. Based on field observations, the mature signs were recorded in terms of the colour, size and aromatic smell of the fruit.

2.2.3.2 Productivity and seed vigor in different fruiting seasons

Experiments were conducted to compare the productivity and germination percentages in two peak fruiting seasons: spring and autumn (based on findings from the previous studies). Ten individuals (4-10 m) were randomly chosen for

counting the number of fruits produced from each mature tree in the two peak fruiting seasons in Tsim Bei Tsui (22°28'40"N 114°01'22"E) and Sheung Pak Nai (22°26'52"N 113°57'15"E). Fruits of *S. apetala* were collected in May to June and October to November while *S. caseolaris* were collected in February to March and August to October to represent the spring and autumn batches. At least five fruits of each *Sonneratia* species were collected from each site. The average diameter of fruit and number of seeds per fruit were measured and counted. The average number of seeds per tree was calculated by

= Average number of fruits per mature tree x Average number of seeds per fruit

Mature fruits were collected and soaked in water. After one to four days, the soft fruits were quashed, pulps were removed and seeds were filtered out. Seeds were then stood in freshwater for two days to let the remaining pulp sunk before planting (Zhong *et al.*, 2003). The collected seeds were rinsed by tap water and stored in room temperature (20±3℃). The seeds were planted within three days.

Substrate collected from Tsim Bei Tsui mangrove stand (22°28'40"N 114°01'22"E) were flushed with running tap water to remove the salt and then transferred to the tray in size of 17.5 cm x 25 cm x 19 cm in 7 cm depth. Two layers of green fine mesh were placed at the bottom to prevent leakage of fine substrate (Fig. 2.6). The tray was then put in a larger plastic tank, with a size of 32 cm x 23 cm x 11.5 cm and containing 8 L of tap water. The water was replaced once a week. 30 seeds were sowed at around 1 mm depth at a density of 1 cm x 1 cm. The tanks were placed in an environmental chamber at 30°C with light dark cycle of 12 hours light and 12 hours dark. Three replicates were prepared for each treatment. The germination was recorded daily by counting the numbers of seeds with budding (Photo 2.2) and first pair of leaf unfurling (Photo 2.3) for 30 days.

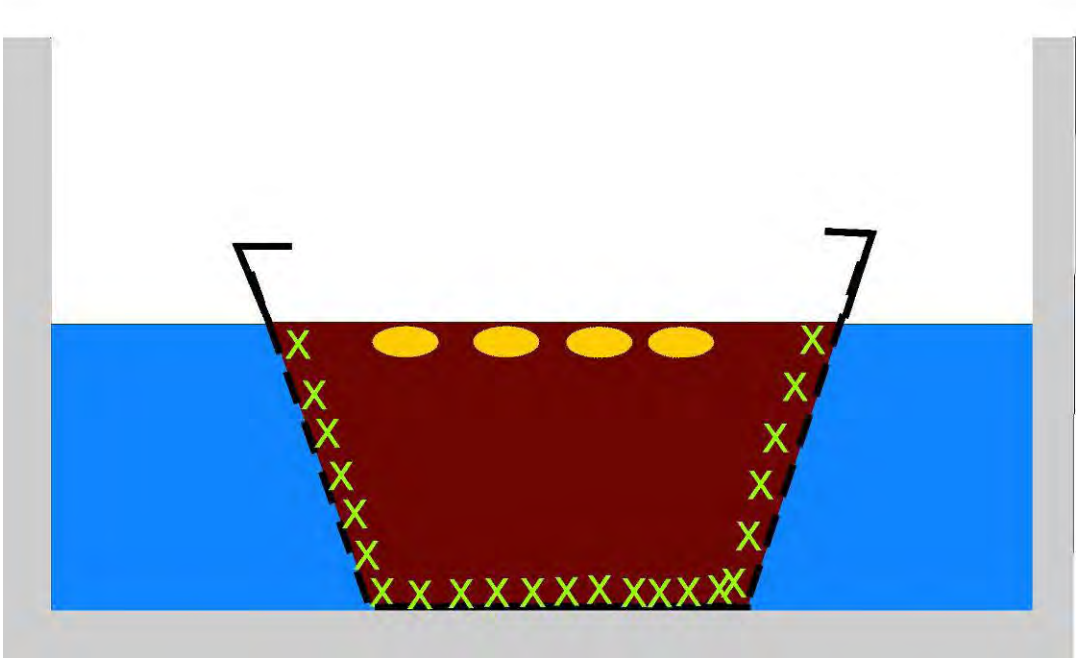


Fig. 2.6 The experimental setup (Yellow oval indicates the *Sonneratia* seeds, brown area indicates the substrate, green cross represents the layer of green mesh placed underneath the substrate, and the black outline indicates the perforated trays while the grey outline indicates the plastic tank)



Photo 2.2 A budding seed



Photo 2.3 First pair of leaf unfurling

2.2.3.3 Data treatment

Mean and standard deviation values of the triplicate of each treatment were calculated. To test for the different germination rate, one-way analysis of covariance (ANCOVA) was employed to compare the effects of different treatments on the budding and unfurling numbers of both *S. apetala* and *S. caseolaris* at the level of $p<0.05$. Time after planting was regarded as the covariate, season as a cofactor and logarithmic transformed numbers of budding and unfurling as a dependent variable. Tukey test was employed for multiple comparisons if ANCOVA result was significant at the level of $p<0.05$. To test for the cumulative germination number at the end of the experiment, one-way

analysis of variance (ANOVA) followed by the Tukey test were employed to compare the effects of different treatments on the budding and unfurling numbers. In case there were less than two treatments (i.e. seasons, spring and autumn), the difference between the treatments were evaluated by student t-test at the level of $p<0.05$. All the statistical tests were performed by the computer program called Statistics Package for Social Science (SPSS 13.0 for Windows, SPSS Inc, Illinois, U.S.A.).

Graphs of germination for both species were plotted with the time after planting against the cumulative budding and unfurling percentages calculated as follow:

The cumulative budding percentages at time t were equaled to:

$$\frac{\text{Cumulative number of budding at time t}}{\text{Number of seeds planted}} \times 100\%$$

The cumulative unfurling percentages at time t were

$$\frac{\text{Cumulative number of unfurling at time t}}{\text{Total number of seeds budded}} \times 100\%$$

2.3 Results

2.3.1 Identification of *Sonneratia* species

The specimens were sent and confirmed by the Royal Botanic Gardens of Kew in Britain as *Sonneratia apetala* Buch.-Ham and *Sonneratia caseolaris* (L.) Engl. A set of specimen for each species was kept in Hong Kong Herbarium for reference. The morphological features of these two species were summarized in Table 2.1. These two species can be easily distinguished in the flowering and fruiting seasons. The flowers and fruits of *S. caseolaris* were comparatively larger than that of *S. apetala*. Fruits of *S. caseolaris* can grow up to 8.5 cm while that of *S. apetala* had a maximum size of 3.0 cm. Flower of *S. caseolaris* had red and oblong petals while that of *S. apetala* did not have petals. Style of *S. caseolaris* topped with capitates stigma while that of *S. apetala* topped with mushroom shaped or peltate stigma. Leaves of both *Sonneratia* species are variable. Generally, *S. caseolaris* had broad and ovate leaf, while the leaf of *S. apetala* was narrow and elliptical. The average petiole length of *S. caseolaris* was 0.5 cm (short petiole) while it was around 1 cm in *S. apetala*. A detailed description was published in the book “Flora of Hong Kong Vol. II” by AFCD.

Table 2.1 Morphological characteristics of *Sonneratia apetala* and *S. caseolaris* found in Hong Kong (Kwok *et al.*, 2004)

Species	***Sonneratia caseolaris* (L.) Engl**	***Sonneratia apetala* Buch. -Ham**
Chinese Name	海桑 	無瓣海桑 
Section	*Sonneratia*	*Pseudosonneratia*
Height	up to 15 m	up to 20 m
Natural Distribution	South East Asia to the northern Australia. Native to China where they are naturally found on Hainan Island.	South Asia such as India, Bangladesh and Malaysia.
Leaves	Broad, ovate, opposite leaf, incompletely unrolled to show venation. Apex acute in young plants which becomes round at later stage. Length to width ratio is less than two. Petiole short (0.5 cm) and red. 	Narrow, elliptical, opposite, gradually taper toward the apex. Petiole is longer (~1 cm). 
Flowers	Relatively larger (~5 cm). Bisexual. Stamens red and white distally, standing erect. Style greenish and long, twice the length of stamens, topped with capitate stigma. Usually have 6 sepals. Petals red and oblong. Flowers appear all year round. 	Flower small (1.5-2 cm) and stalked, single or clustered at branch ends. 4 green calyx lobes. Bisexual. Stamens white, standing erect. Style yellow topped with mushroom-shaped or peltate stigma. Flowers appear from May to December. 
Fruits	Compressed and edible fleshy. Large (up to 8.5 cm). Green when young and turns yellowish green and aromatic when mature. Produces 800-1,300 seeds per fruit. Fruits appear all year round. 	Oval berry. Distinctively smaller (1.5-2.5 cm) than *S. caseolaris*. 4-5 calyx lobes. Green when young and becomes grayish when mature. Each fruit produces 100-130 seeds. Fruits appear from August to early Spring. 

2.3.2 Distribution and abundance of *Sonneratia apetala* and *S. caseolaris* in Hong Kong

Twenty field surveys conducted in 2005 and 2006 showed that there were 1,693 individuals of *Sonneratia* distributing in 14 mangrove stands in Hong Kong , with 434 (25.6%) *S. apetala* and 1,259 (74.4%) *S. caseolaris* individuals (Table 2.2). In term of geographical location, 1,683 (99.4%) distributed in nine mangrove stands in Deep Bay area, nine individuals (0.5%) distributed in four mangrove stands in Lantau area, and only one individual (0.1%) in Tolo Pond in Tolo area. Three out of six areas did not have any *Sonneratia*, they were Hong Kong Island, Sai Kung area and Northeast New Territories. The average density of *Sonneratia* in Hong Kong mangrove was 3.5 individuals per hectare. Both *S. apetala* and *S. caseolaris* were found in Deep Bay area, while only *S. caseolaris* was found in Lantau and Tolo areas.

2.3.2.1 Distribution of *Sonneratia* in Deep Bay area

Over 99% of *Sonneratia* individuals were found in the Deep Bay area of Hong Kong. The average density in Deep Bay area was 4.3 individuals per hectare and the density of *Sonneratia* per stand varied from 0.0 to 23.5 individuals per hectare, with the highest density in Kam Tin River. The distribution and density of *Sonneratia* in each stand in Deep Bay area were summarized in the following sections.

Table 2.2 Abundance and distribution of *Sonneratia* species in the surveyed mangrove stands in Hong Kong (*S.a.* = *Sonneratia apetala, S.c.*= *Sonneratia caseolaris*, Density = Total number of *Sonneratia* / hectare, % of Hong Kong total *Sonneratia* population= number of *Sonneratia* in each mangrove stand / total number of *Sonneratia* in Hong Kong x 100, *= only the surveyed stands were included in this area)

Site name	Man-grove Area (hectare)	No. of *S. a.*	No. of *S. c.*	% of *S. a.*	% of *S. c.*	Total no. of *S.*	Density	% of HK total *S.* population
Deep Bay area								
Mai Po	260.0	249	665	27.2	72.8	914	3.5	54.0
Kam Tin River	12.5	63	230	21.5	78.5	293	23.5	17.3
Yuen Long Industrial Estate	3.5	0	0	0.0	0.0	0	0.0	0.0
Tsim Bei Tsui	93.6	98	293	25.1	74.9	391	4.2	23.2
Wetland Park	3.2	1	2	33.3	66.7	3	1.0	0.2
Lau Fau Shan	5.0	2	1	66.7	33.3	3	0.6	0.2
Sha Kong Tsuen	6.9	8	32	20.0	80.0	40	5.8	2.4
Sheung Pak Nai	6.2	11	20	35.5	64.5	31	5.0	1.8
Pak Nai	4.7	2	5	28.6	71.4	7	1.5	0.4
Ha Pak Nai	0.5	0	1	0.0	100.9	1	2.2	0.1
Subtotal (10 stands)	**396.3**	**434**	**1,249**	**25.8**	**74.2**	**1,683**	**4.3**	**99.4**
Lantau area								
Ma Wan	0.1	0	1	0.0	100.0	1	18.0	0.1
Yam O	0.2	0	0	0.0	0.0	0	0.0	0.0
Tai Ho Wan	2.4	0	0	0.0	0.0	0	0.0	0.0
Tung Chung	3.6	0	0	0.0	0.0	0	0.0	0.0
San Tau	2.3	0	0	0.0	0.0	0	0.0	0.0
Sham Wat	0.7	0	1	0.0	100.0	1	1.4	0.1
Tai O	7.0	0	3	0.0	100.0	3	0.5	0.2
Yi O	0.9	0	0	0	0.0	0	0.0	0.0
Shui Hau	0.7	0	4	0.0	100.0	4	5.5	0.2
Pui O Wan	1.8	0	0	0.0	0.0	0	0.0	0.0
Chi Ma Wan	0.1	0	0	0.0	0.0	0	0.0	0.0
Subtotal (11 stands)	**19.8**	**0**	**9**	**0.0**	**100.0**	**9**	**0.5**	**0.5**
Hong Kong Island								
Tai Tam	0.2	0	0	0.0	0.0	0	0.0	0.00
Subtotal (1 stand)	**0.2**	**0**	**0**	**0.0**	**0.0**	**0**	**0.0**	**0.0**
Sai Kung area*								
Chek Keng	1.0	0	0	0.0	0.0	0	0.0	0.0
Kei Ling Ha Lo Wai	2.4	0	0	0.0	0.0	0	0.0	0.0
Subtotal (18 stands)	**28.2**	**0**	**0**	**0.0**	**0.0**	**0**	**0.0**	**0.0**
Tolo area*								
Tolo Pond	2.0	0	1	**0.0**	**100.0**	1	0.50	0.1
Lo Fu Wat	1.1	0	0	0.0	0.0	0	0.0	0.0
Subtotal (6 stands)	**15.1**	**0**	**1**	**0.0**	**0.0**	**0**	**0.1**	**0.1**
Northeast New Territories*								
Lai Chi Wo	3.5	0	0	0.0	0.0	0	0.0	0.0
Tai Sham Chung	0.6	`0	0	0.0	0.0	0	0.0	0.0
Subtotal (17 stands)	**25.8**	**0**	**0**	**0.0**	**0.0**	**0**	**0.0**	**0.0**
Total	**484.3**	**434**	**1,259**	**25.6**	**74.4**	**1,693**	**3.5**	**100.0**

2.3.2.1.1 Mai Po (22°30'N, 114°02'E)

Mai Po mangrove is one of the components of the Mai Po and Inner Deep Bay Ramsar Site (Fig. 2.7). It had 260 ha mangroves which was the largest mangrove stand in Hong Kong and the sixth largest in all of China (Lock & Cheung, 2004; Young, 1994). It is also the greatest wildlife resource of Hong Kong. Large numbers of local and migratory birds use the stand for feeding and roosting. There are eight species of true mangrove plants. The stand was dominated by *Kandelia obovata* which grow close to the border fence, followed by *Avicennia marina* and *Avicennia corniculatum* in the mid-shore, scattered with *Bruguiera gymnorrhiza*. *Excoecaria agallocha*, *Lumnitzera racemosa* and *Heritiera littoralis* were present at the backshore. *Acanthus ilicifolius*, situated in the foreshore, acts as the major pioneer species and accounts for the rapid forward growth in Deep Bay in recent years (Morton & Morton, 1983). Mangrove plants are also distributed in the *Gei Wais*, the traditional shrimp ponds at the backshore of the mangrove.

In Mai Po, 914 individuals of *Sonneratia* were found which accounts for more than half of the *Sonneratia* in Hong Kong. Of which, 249 (27.2%) and 665 (72.8%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Mai Po was 3.5 individuals per hectare. Most of them were distributed in the outlets of streams and channels where the salinity was relatively lower. They were also found in the outermost region of the mangrove forests or in isolated 'gaps' within the mangrove stand where light penetrated. The highest density of *Sonneratia* was found in the outlets of Sham Chun River as it is closest to the FMFNR replanting site. Another hotspot was located at the channel out of *Gei Wai* Pond 5, in which 158 mature individuals with an average height of 7 m were found; while 251 individuals of mature *Sonneratia* with an average of 8 m were found in areas outside *Gei Wai* Ponds 11 and 12.

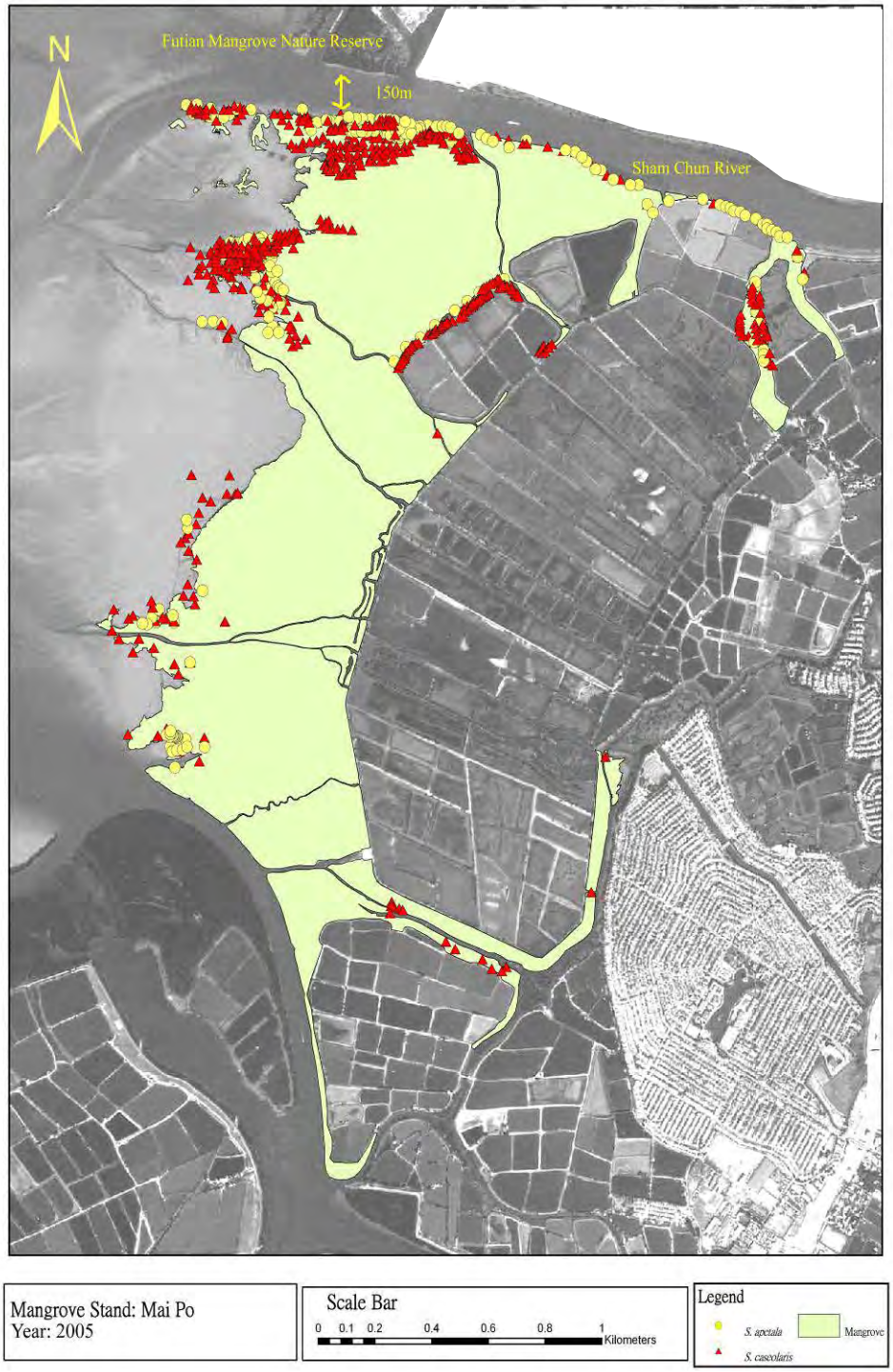


Fig. 2.7 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Mai Po, part of the Mai Po and Inner Deep Bay Ramsar Site. (yellow arrow represents the closest distance between Mai Po mangrove stand and Futian Mangrove Forest Nature Reserve)

2.3.2.1.2 Tsim Bei Tsui (22°28'N, 114°00'E)

Tsim Bei Tsui had the second largest pieces of mangroves in Deep Bay, with an area of 93.6 hectares (Fig. 2.8). The stand was part of the Mai Po and Inner Deep Bay Ramsar site. It consisted of two patches of mangroves. The large patch developed between the two sizable freshwater rivers, Kam Tin River and Tin Shui Wai Drainage Channel. It was located on the eastern side of the drainage channel. The mangrove on the western side was developed along the border fence. Behind the fence, the mangroves were connected to ponds. The mangrove was dominated by *K. obovata* with few individuals of *A. corniculatum* and *B. gymnorrhiza*.

There were 391 individuals of *Sonneratia*, accounted for 23.2% of all the *Sonneratia* in Hong Kong. Of which, 98 (25.1%) and 293 (74.9%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Tsim Bei Tsui mangrove was 4.2 individuals per hectare. The densest part was adjacent to Kam Tin River, receiving the freshwater from the river. As Kam Tin River had an extraordinary high density of *Sonneratia* (Fig. 2.9), the seeds may be carried out by the ebbing tide and stranded on Tsim Bei Tsui mangrove stand. There were some *Sonneratia* individuals sparsely distributed on the outermost region of the mangrove stand and the channels between mangrove patches.

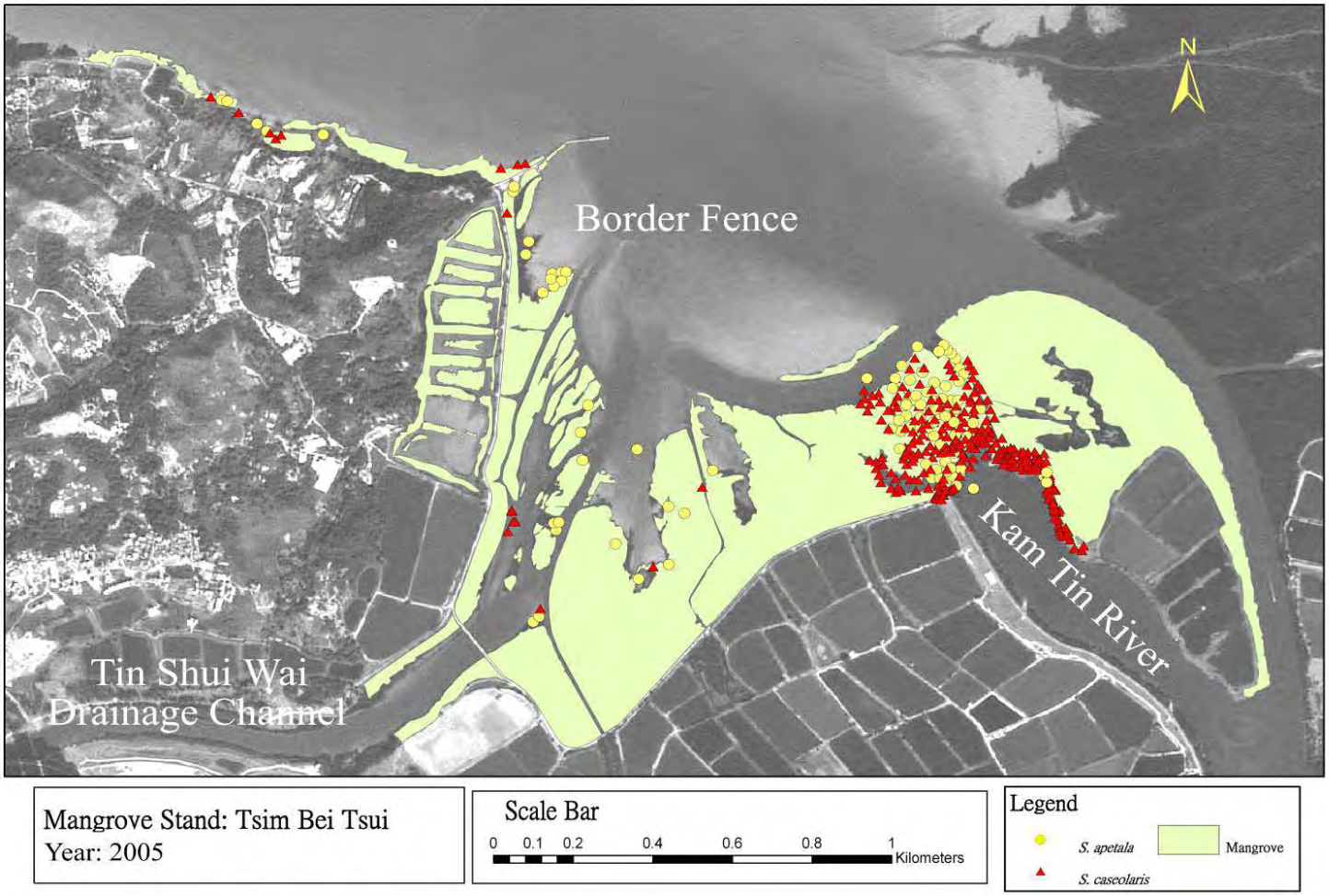


Fig. 2.8 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Tsim Bei Tsui, part of the Mai Po and Inner Deep Bay Ramsar Site

2.3.2.1.3 Kam Tin River (22°28'N, 114°01'E)

After construction of the drainage channel in Kam Tin River (formerly called Kam Tin Main Drainage Channel), four fringes of mangroves were developed on both sides of the channel with a total area of 12.5 hectares (Fig. 2.9). The four fringes of mangroves along the drainage channel were planted with mangrove species in 1998 as a mitigation measure for the mangrove lost due to the drainage project. In Kam Tin River, a total of 293 individuals of *Sonneratia* were recorded, accounting for 17.3% of all the *Sonneratia* in Hong Kong. Of which, 63 (21.5%) and 230 (78.5%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Kam Tin River mangrove was 23.5 individuals per hectare, the densest place of *Sonneratia* in Hong Kong. They were mainly distributed on the western bund of the Kam Tin River. The surprisingly high numbers of *Sonneratia* in the Kam Tin River and their well mixing within the native mangrove suggested that they were mistakenly planted with the native species.

The number of *Sonneratia* recorded in this survey represented the minimum number in this area as some *Sonneratia* individuals (unknown numbers) were already removed by Civil Engineering Development Department (CEDD) in 2004 and 2005. Moreover, *Sonneratia* found along the channel were cleared by the Territory Development Department (now renamed as CEDD) in April 2002. Flowers and fruits of both species were observed during the survey, indicating that they could establish after clearance and possibility self-sustain.

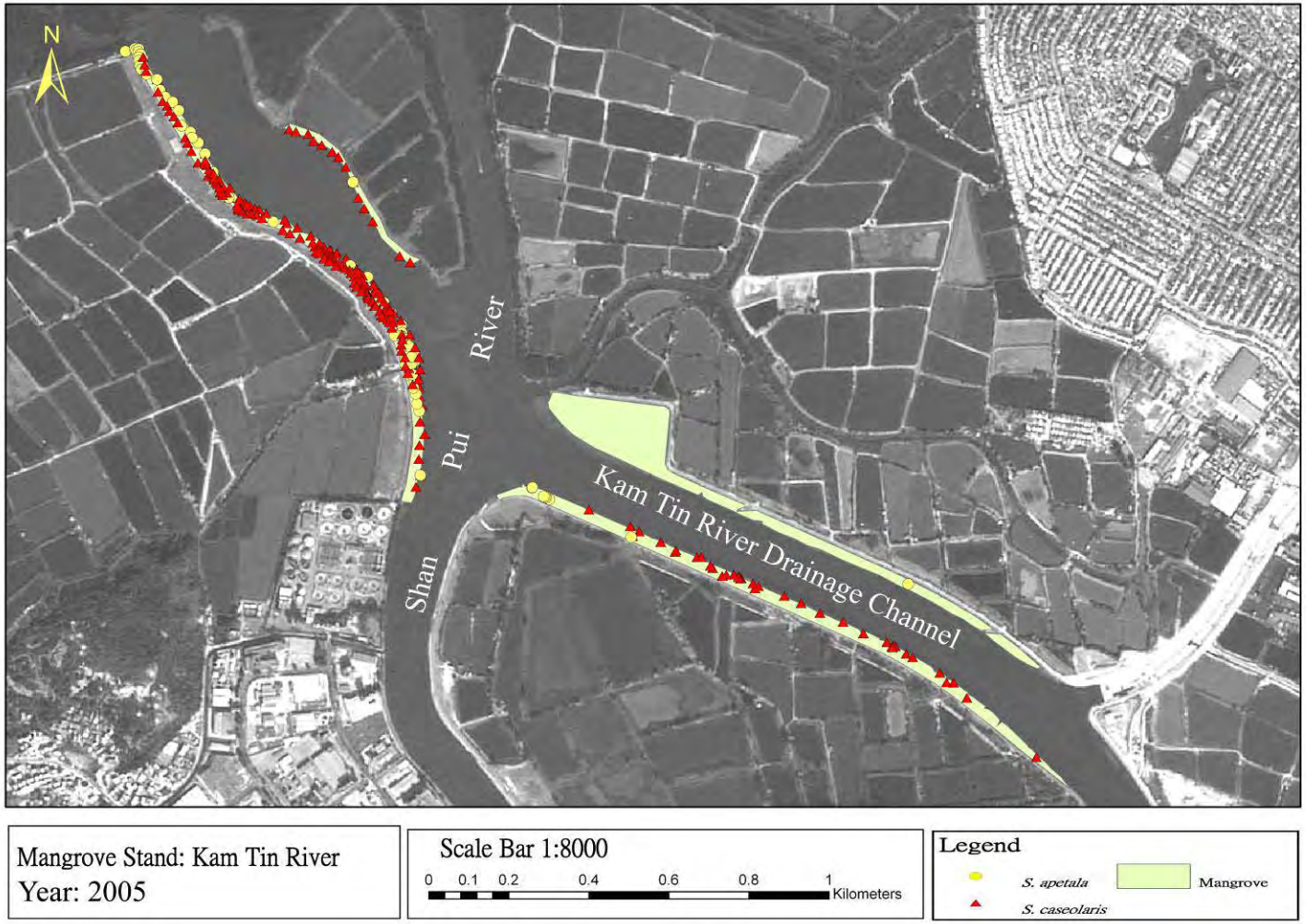


Fig. 2.9 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Kam Tin River

2.3.2.1.4 Yuen Long Industrial Estate (22°27'N, 114°02'E)

Yuen Long Industrial Estate was located on the eastern side of Shan Pui River (Fig. 2.10). The mangrove area recorded in 1997 was 7.2 hectares (Tam & Wong, 1997). Due to the dredging and channelization of Shan Pui River, the mangrove stand diminished to 3.5 hectares in 2005. It was heavily polluted, the dominant species was *K. obovata*, following by *A. corniculatum*, and *E. agallocha* was the least abundant species. No *Sonneratia* was found in this mangrove site.

2.3.2.1.5 Wetland Park (22°28'N, 114°00'E)

Wetland Park with mangrove coverage of 3.2 hectares laid on the sides of the nullah originated from Tin Shui Wai Town (Fig. 2.11). Five species of mangroves were recorded. The dominant species was *K. obovata*, followed by *A. corniculatum*, and *B. gymnorrhiza* and *Acrostichum aureum* with decreasing abundance. *H. littoralis* was planted by the staff of Wetland Park for habitat enhancement. Receiving outflow of the channel, the substrate in Wetland Park was muddy. The number of *Sonneratia* species in Wetland Park was low. Only three individuals of *Sonneratia* were found in the mangrove, accounted for 0.2% of all the *Sonneratia* population in Hong Kong. Of which, one (33.3%) and two (66.7%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Wetland Park mangrove was 1.0 individual per hectare which was one of the lowest density in Deep Bay area. The low number and density were the results of two removal projects in the past. The first removal dated back to September 2001, with 251 *Sonneratia* removed from the nullah. Another one was conducted in October 2006, 20 *Sonneratia* seedlings were removed.



Fig. 2.10 Distribution of native mangrove in Yuen Long Industrial Estate

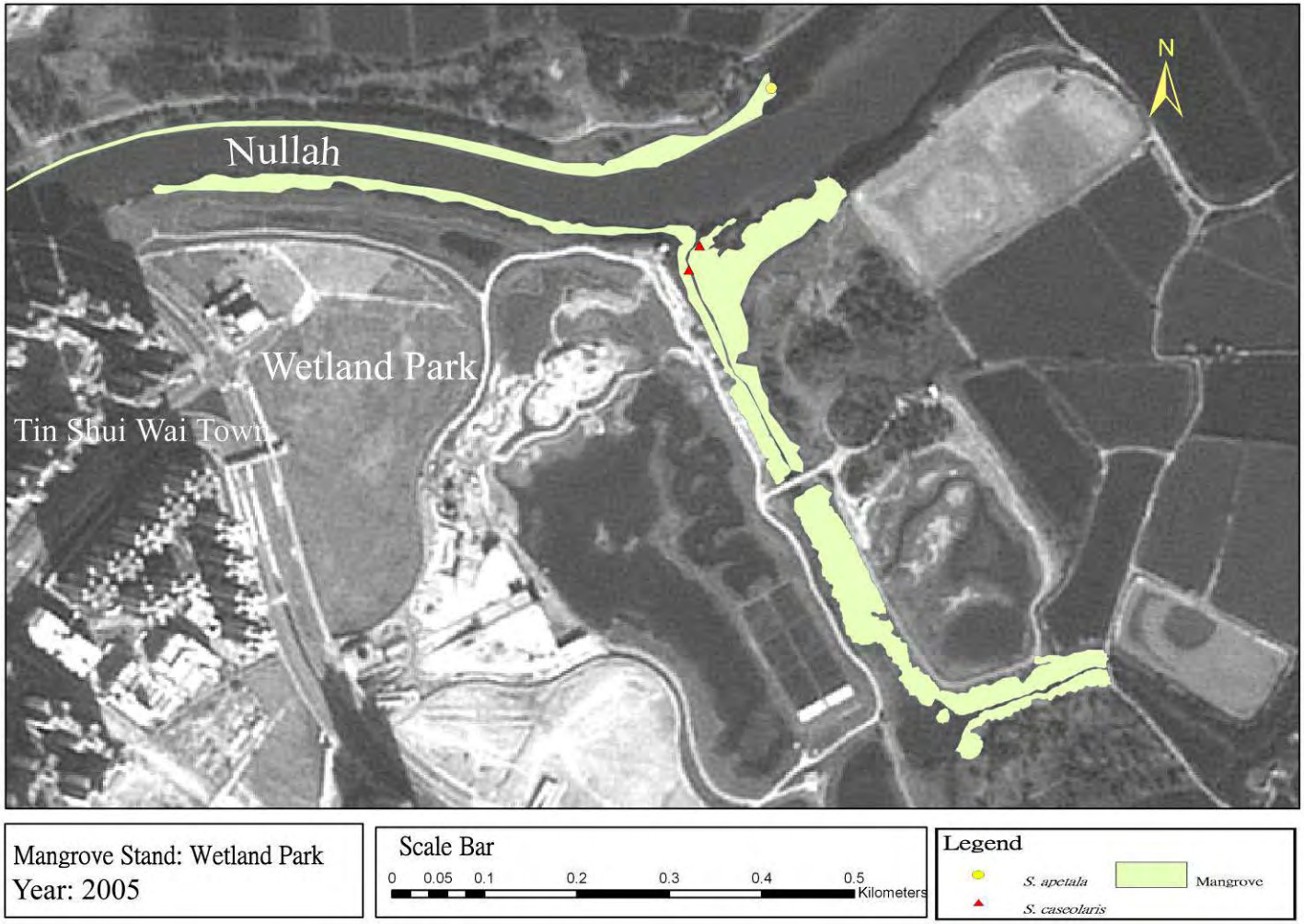


Fig. 2.11 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Wetland Park

2.3.2.1.6 Lau Fau Shan (22˚29'N, 113˚59'E)

Mangrove in Lau Fau Shan distributed along 2.2 km coastline, from Nam Sha Po to Lau Fau Shan with an area of 5 hectares (Fig. 2.12). The stand consisted of fringes of mangrove trees dominated by *K. obovata*. The substrate was muddy.

There were three individuals of *Sonneratia* in Lau Fau Shan mangrove, accounted for 0.2% of all the *Sonneratia* population in Hong Kong. Of which, two (67.8%) and one (33.3%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Lau Fau Shan mangrove was 0.6 individual per hectare which accounted to 0.2% of all *Sonneratia* in Hong Kong.

2.3.2.1.7 Sha Kong Tsuen (22˚27'N, 113˚58'E)

Mangrove in Sha Kong Tsuen had an area of 6.9 hectares, spreading over 2 km of the coastline (Fig. 2.13). Sha Kong Tsuen village was located at the back of the mangrove. The substrate was muddy. It consisted of dwarf mangroves with an average height <2 m. The mangrove stand was dominated by *K. obovata*.

There were 40 individuals of *Sonneratia* in Sha Kong Tsuen, accounted for 2.4% of all the *Sonneratia* population in Hong Kong. Of which, eight (20%) and 32 (80%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Sha Kong Tsuen mangrove stand was 5.8 individuals per hectare, a relatively high density in Deep Bay area.

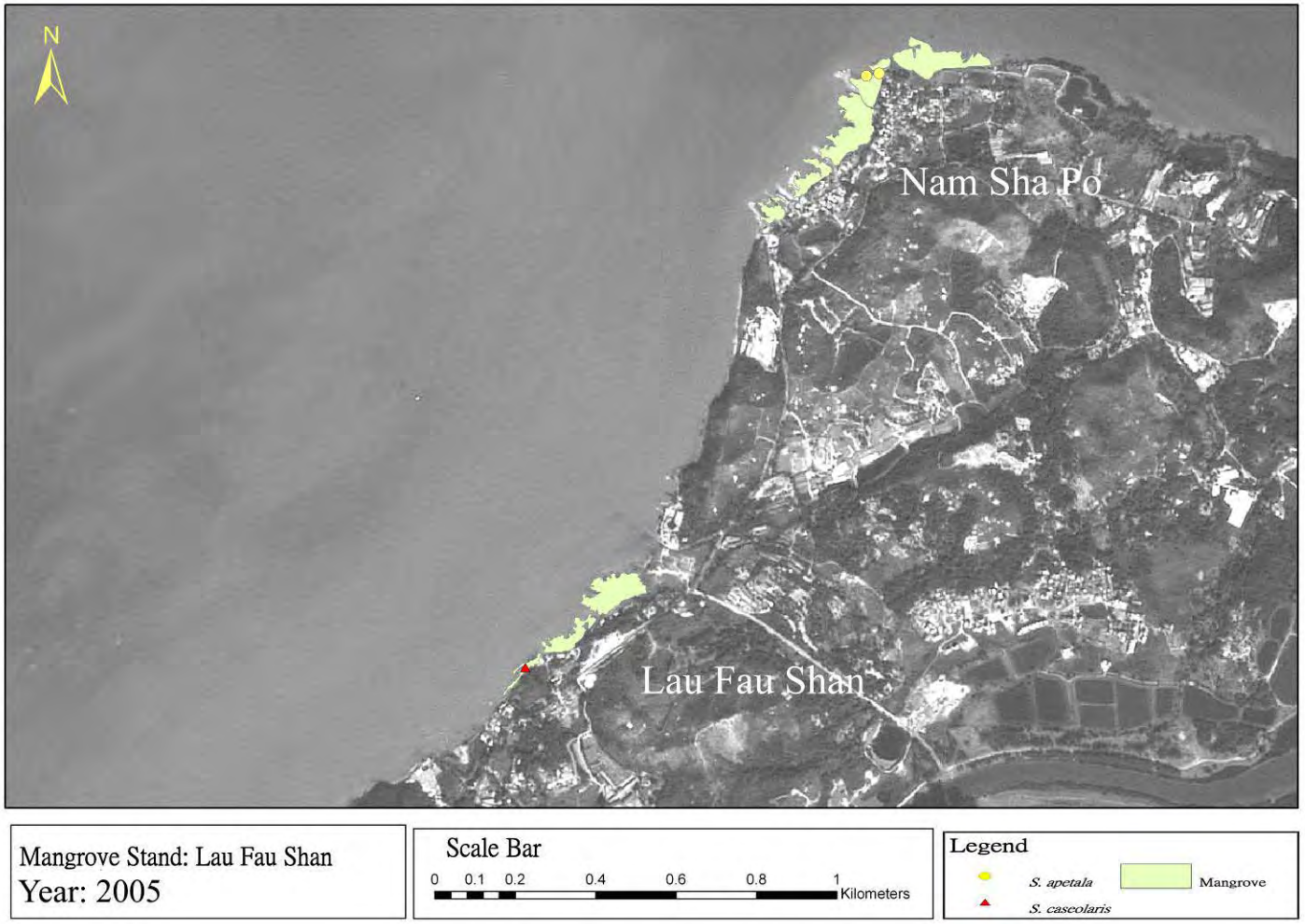


Fig. 2.12 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Lau Fau Shan

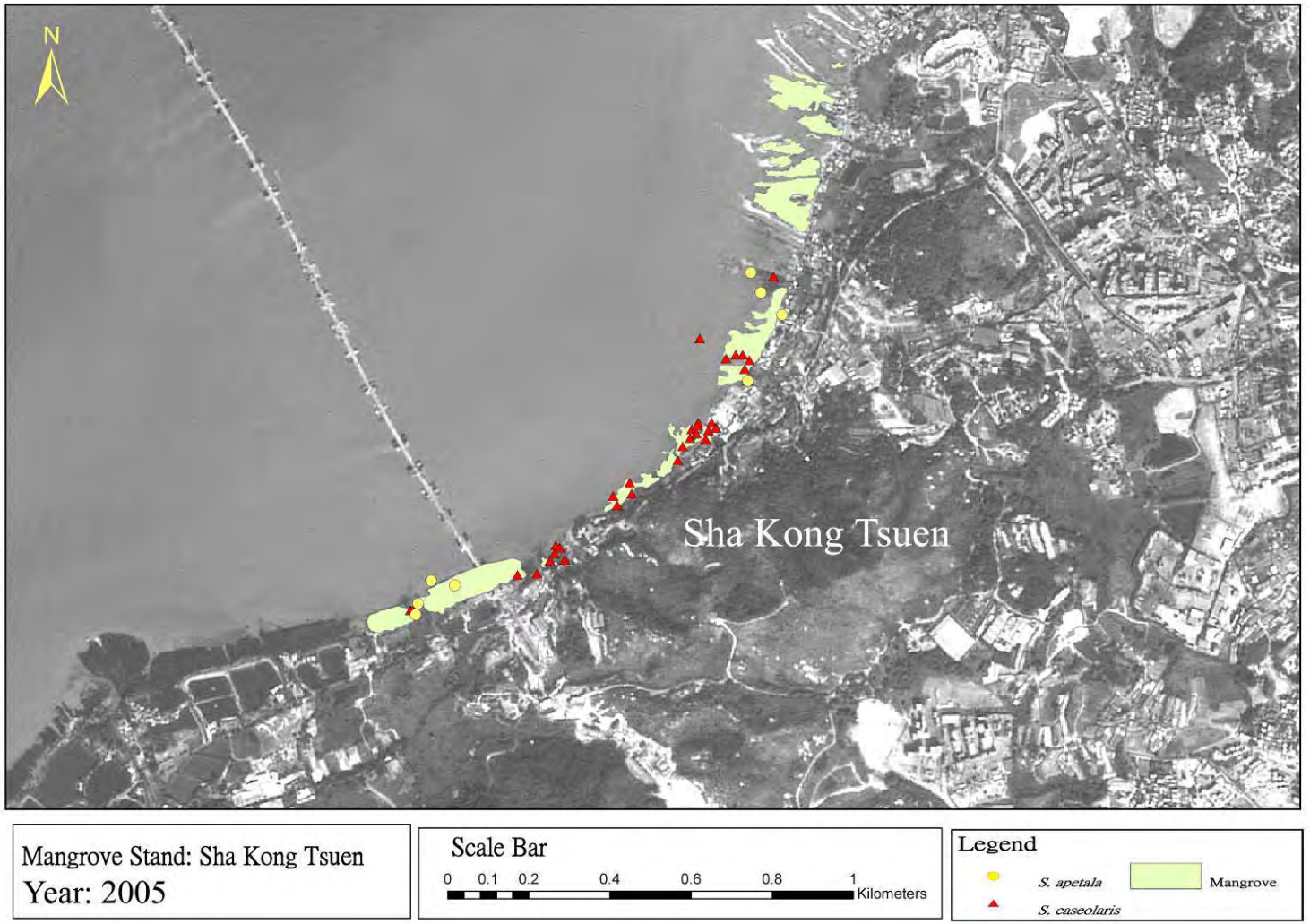


Fig. 2.13 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Sha Kong Tsuen

2.3.2.1.8 Sheung Pak Nai (22˚27'N, 113˚57'E)

Mangrove in Sheung Pak Nai had an area of 6.2 hectares, spreading over 1.8 km of the coastline. Fish ponds and villages were located at the back of the mangrove (Fig. 2.14). There were two patches of mangroves, both dominated by *K. obovata*, the patch on the eastern side was planted about 25 years ago by local farmers while the western patch was natural mangroves (personal communication with villager). The substrate was mainly muddy, a small sandy beach was present between the two patches with remarkably decrease in number of mangrove plants.

There were 31 individuals of *Sonneratia* in Sheung Pak Nai, accounted for 1.8% of all the *Sonneratia* population in Hong Kong. Of which, 11 (35.5%) and 20 (64.5%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Sheung Pak Nai mangrove was 5.0 individuals per hectare. One 2 m tall *S. apetala* was found on the sandy beach, suggested that this species could adapt to different soil type. Other *Sonneratia* plants were mainly distributed on the edge of the mangrove.

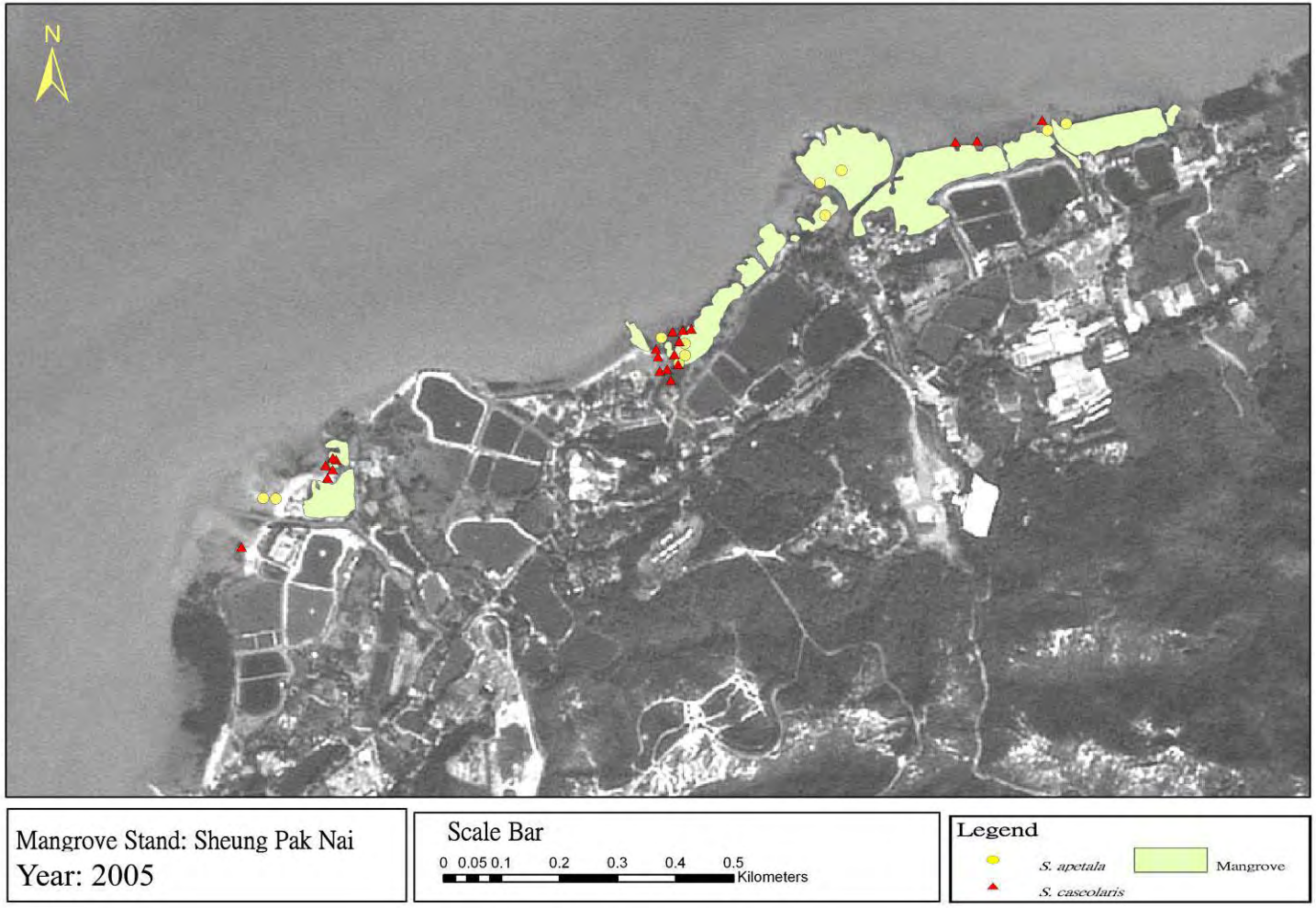


Fig. 2.14 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Sheung Pak Nai

2.3.2.1.9 Pak Nai (22˚27'N, 113˚57'E)

Mangrove in Pak Nai had an area of 4.7 hectares (Fig. 2.15). There were two patches of mangroves, both laid on the seaward edge of the fish ponds. The substrate was very soft and deep. The stand was dominated by *K. obovata*.

There were seven individuals of *Sonneratia* in Pak Nai, accounted for 0.4% of all the *Sonneratia* population in Hong Kong. Of which, two (28.6%) and five (71.4%) were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Pak Nai mangrove was 1.5 individuals per hectare.

2.3.2.1.10 Ha Pak Nai (22˚25'N, 113˚56'E)

Mangrove in Ha Pak Nai was located behind a sand bar (Fig. 2.16). Due to the reclamation and land filling activities near Tai Shui Hang, the mangrove patch on the southern side was destroyed. The size of the stand shrunk from 0.7 hectare (Tam and Wong, 1997) to 0.5 hectare in 2005. The stand did not look healthy, only few dwarf *K. obovata* individuals were found.

Only one individual of *S. caseolaris* was found in Ha Pak Nai, accounted for 0.1% of all the *Sonneratia* population in Hong Kong. This individual was developed on the outlets of the stream. The density of *Sonneratia* in Ha Pak Nai mangrove was 2.2 individuals per hectare.

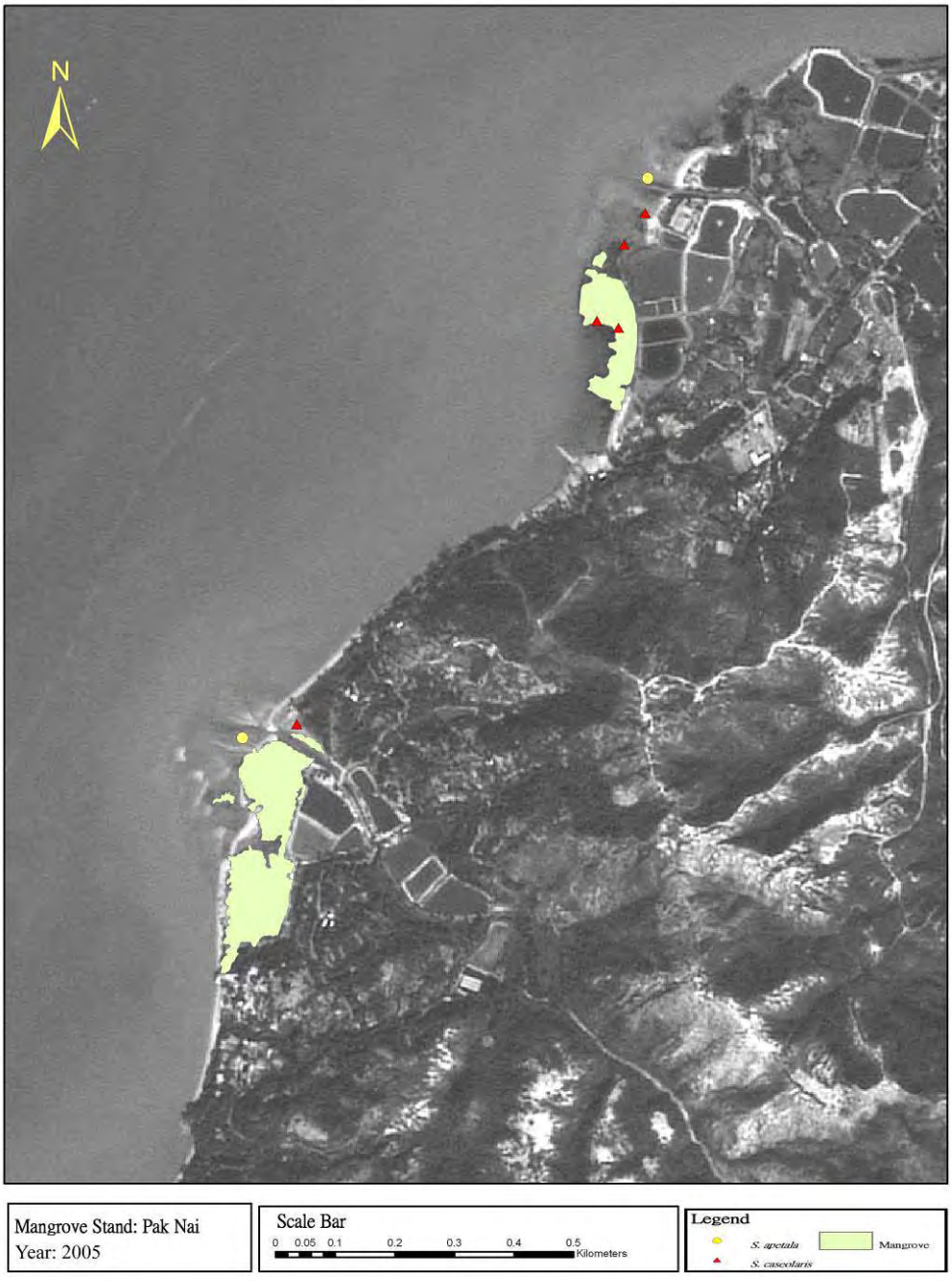


Fig. 2.15 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Pak Nai

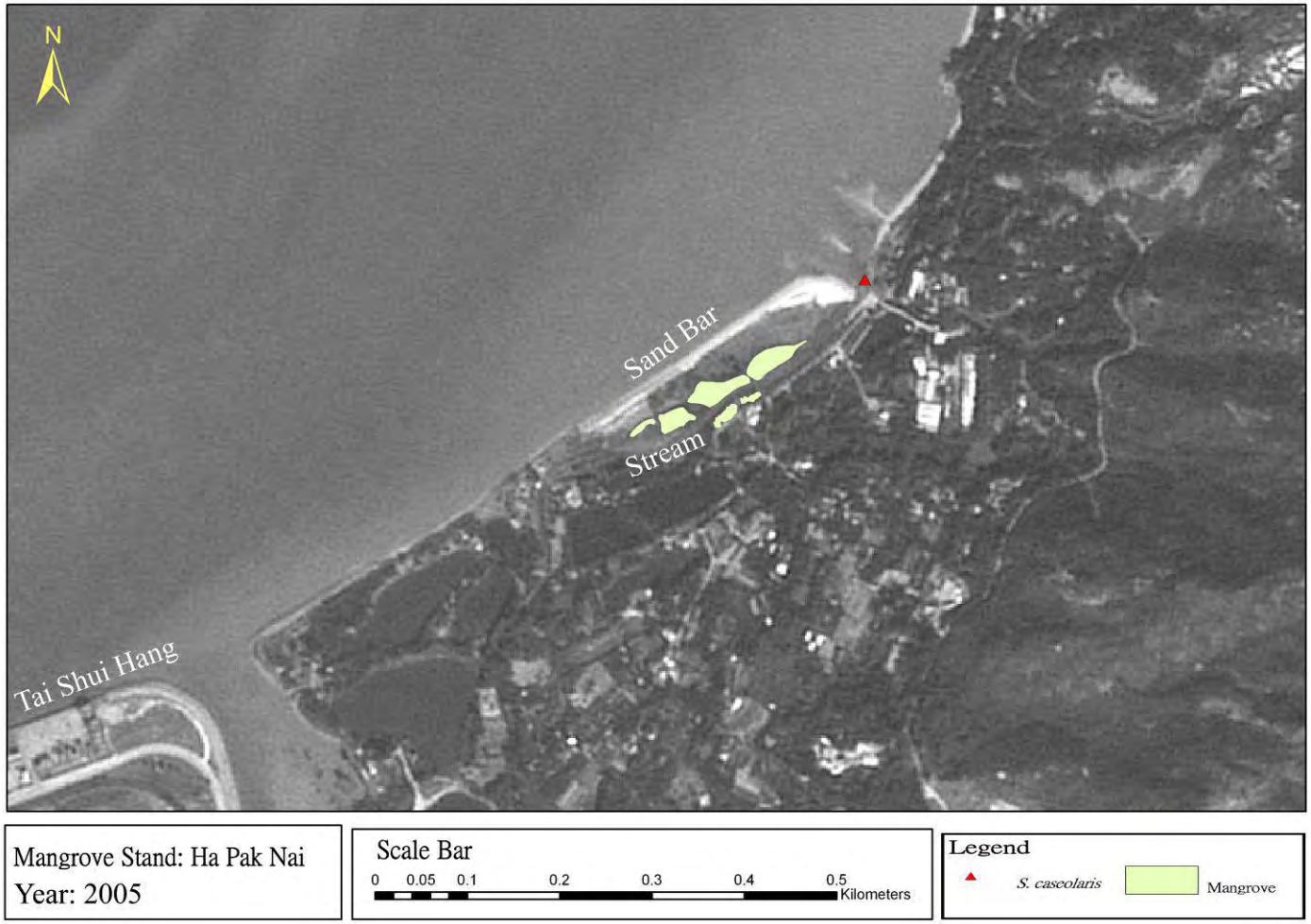


Fig. 2.16 Distribution of native mangrove and *Sonneratia* (>1.5 m) individual in Ha Pak Nai

2.3.2.2 Distribution of *Sonneratia* in Lantau Area

Mangrove stands in Lantau area were characterized by narrow belts of mangroves. The substrate was generally shallow with a thin soil layer and the surfaces were covered by sands, pebbles or stones. Only nine individuals of *S. caseolaris* were found in Lantau area. The average density was 0.5 individual per hectare. The 11 mangrove stands in this area were described in the following sub-sections.

2.3.2.2.1 Ma Wan (22°20'N, 114°03'E)

Mangrove stand in Ma Wan had an area of 0.1 hectare (Fig. 2.17) and was located behind a seawall. The substrate was compact sandy mud and became muddier at the foreshore area. The bay was utilized as a typhoon shelter and several houses were located in the northern part of the bay. A transplantation experiment was carried out in 2001, *B. gymnorrhiza* and *A. marina* were planted on the foreshore but both were dead within two years (Tam & Wong, 2004). Three species were found in the survey, they were *K. obovata*, *A. corniculatum* and *E. agallocha*.

Only one individual of *S. caseolaris* was recorded in the mangrove edge, adjacent to *K. obovata*, accounted for 0.1% of all the *Sonneratia* population in Hong Kong. It was 1.5 m tall and located at the forest edge. The density of *Sonneratia* in Ma Wan mangrove was 18 individuals per hectare.



Fig. 2.17 Distribution of native mangrove and *Sonneratia* (>1.5 m) individual in Ma Wan

2.3.2.2.2 Yam O (22°19'N, 114°01'E)

Mangrove stand in Yam O had an area of 0.2 hectare (Fig. 2.18). The landward substrate was firm and sandy while the seaward was muddy. There were six species of true mangrove plants, dominated by *K. obovata* and *A. corniculatum*, interspersed with *B. gymnorrhiza, A. marina* and *L. racemosa, E. agallocha* was distributed at the backshore. No *Sonneratia* was found in this survey.

2.3.2.2.3 Tai Ho Wan (22°17'N, 113°58'E)

Mangrove stand in Tai Ho Wan had an area of 2.4 hectares (Fig. 2.19). The substrate in the eastern mangrove was firm; the southern side consisted of mixed sand and mud, while the western side was very fluid. Seven species of true mangrove plants were present, dominated by *A. corniculatum* and *K. obovata*. *A. aureum, A. marina*, *H. littoralis, B. gymnorrhiza* and *E. agallocha* were also found. *Sonneratia* was absent from this stand.



Fig. 2.18 Distribution of native mangrove in Yam O

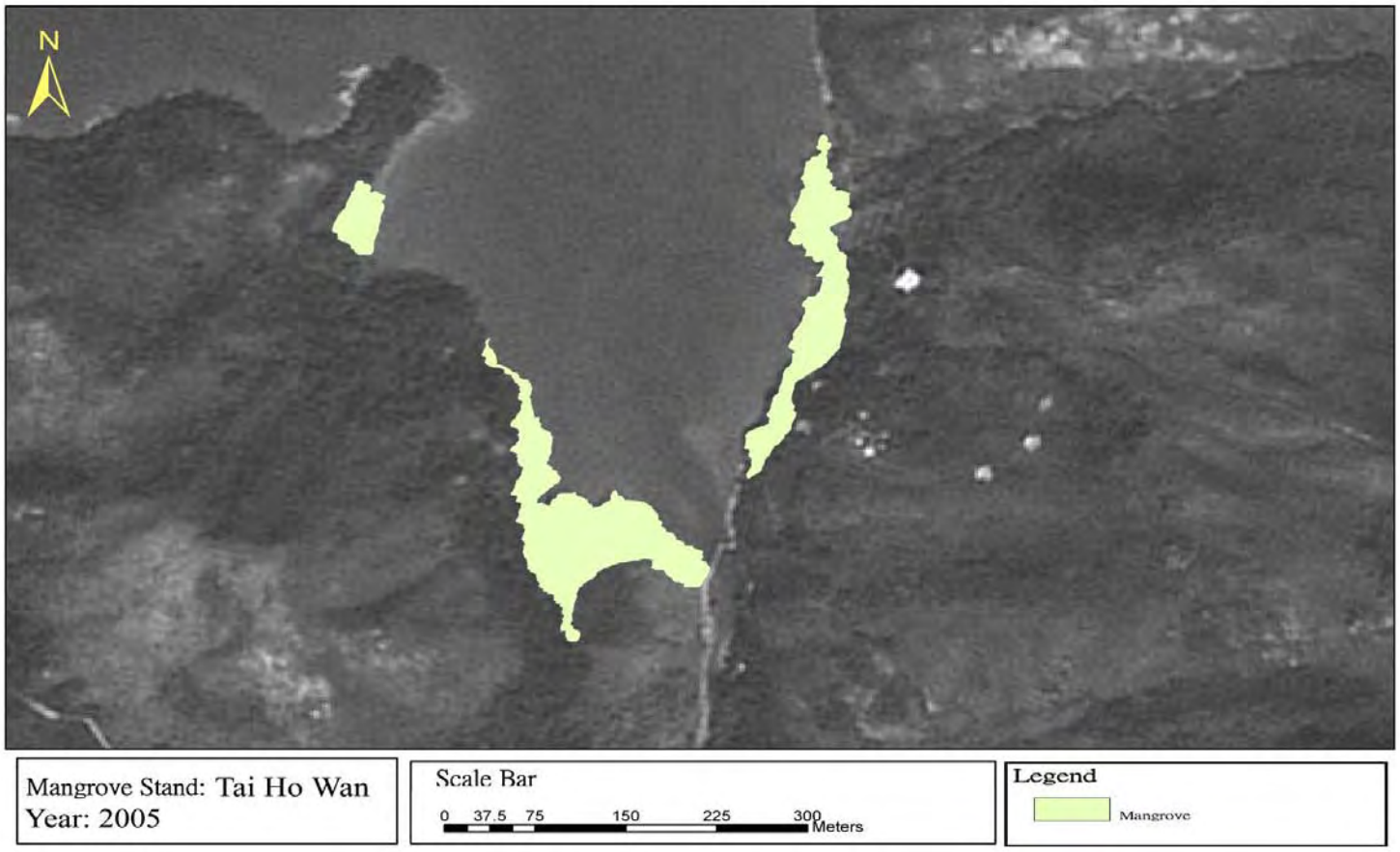


Fig. 2.19 Distribution of native mangrove in Tai Ho Wa

2.3.2.2.4 Tung Chung (22°16N, 113°55'E)

Mangrove stand in Tung Chung had an area of 3.6 hectares (Fig. 2.20). The substrate was sandy in the foreshore but muddy in the seaward side. There were six species of true mangroves, dominated by *A. corniculatum* and *K. obovata* interspersed with *B. gymnorrhiza*. *A. marina* was mainly in the western side of the stand. *Sonneratia* was absent from the stand.

2.3.2.2.5 San Tau (22°17N, 113°55'E)

Mangrove stand in San Tau had an area of 2.3 hectares (Fig. 2.21). The substrate was sandy and became muddy in the seaward side. Seven species of true mangroves were found, dominated by *K. obovata, A. corniculatum* and a healthy patch of *B. gymnorrhiza*. Few individuals of *A. marina*, *L. racemosa*, *H. littoralis* and *E. agallocha* were found but *Sonneratia* was absent.

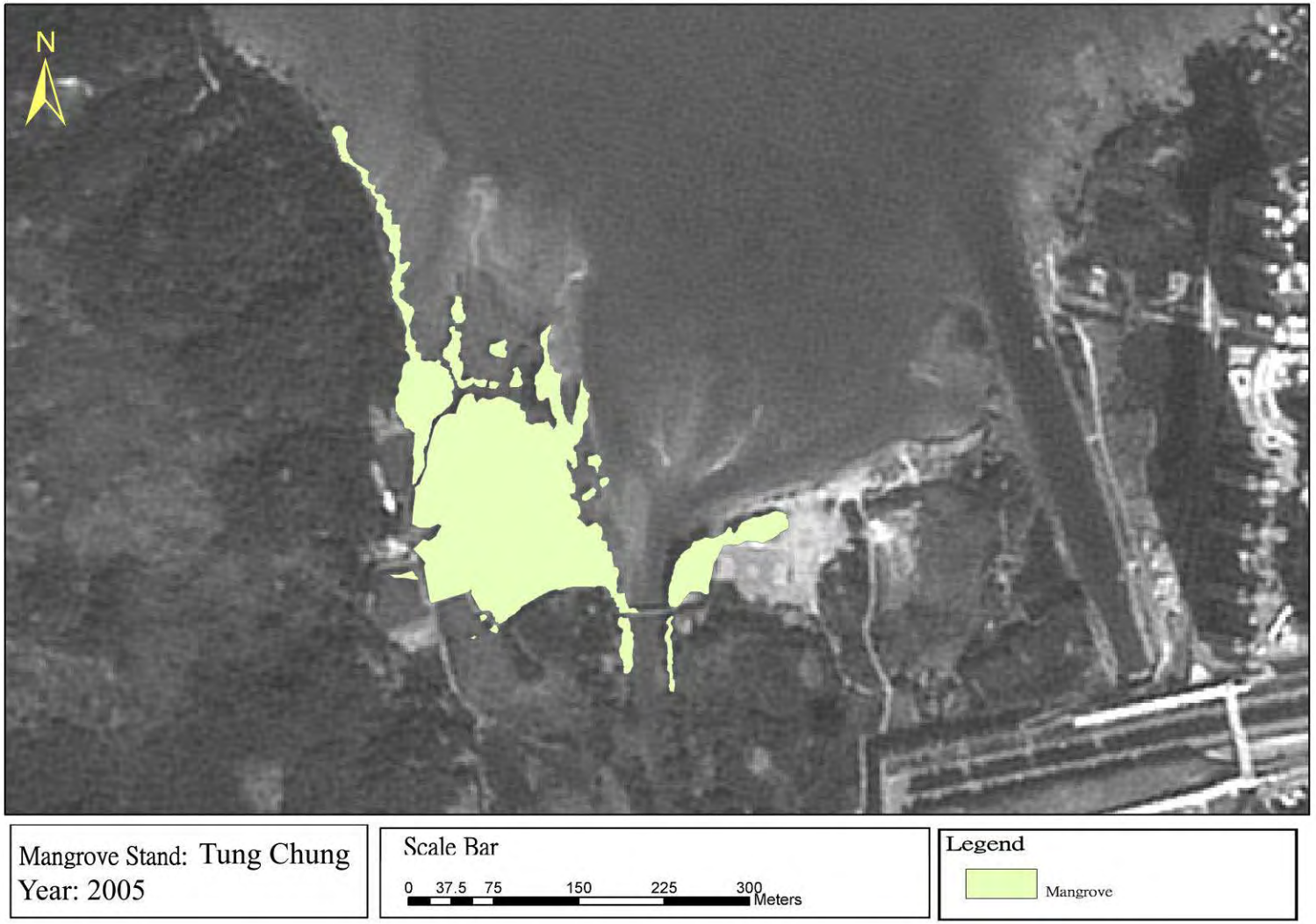


Fig. 2.20 Distribution of native mangrove in Tung Chung

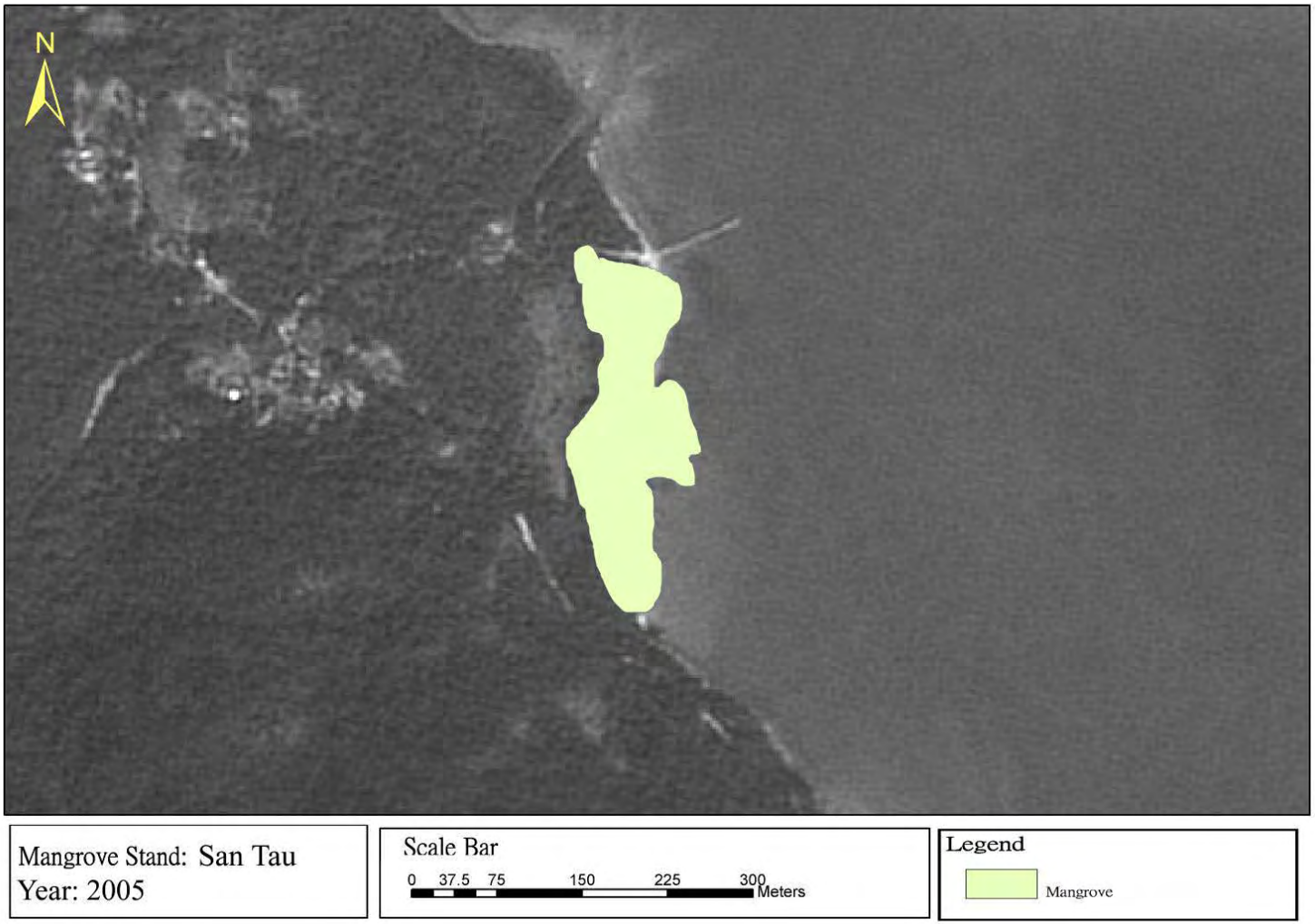


Fig. 2.21 Distribution of native mangrove in San Tau

2.3.2.2.6 Sham Wat (22°16N, 113°53'E)

Mangrove stand in Sham Wat had an area of 0.7 hectare (Fig. 2.22). The substrate at the mangrove stand was mainly sandy and became muddy in the outflow of the stream. Six species of mangroves were recorded, dominated by *K. obovata* and *A. corniculatum*. *A. marina*, *B. gymnorrhiza* and *E. agallocha* were present in a small number. One *S. caseolaris* was found on the outlet of the stream bank. It was 2.8 m tall, the diameter in the breast height was 3.5 cm while the basal diameter was 8.4 cm.

2.3.2.2.7 Tai O (22°15N, 113°51'E)

Mangrove stand in Tai O had an area of 7.0 hectares (Fig. 2.23). Compare with the previous study conducted by Tam & Wong (1997), the area has increased by ten fold in last ten years as the new mangrove boundary included the newly created patch in Tai O Salt Pan. Six species of true mangrove plants were recorded, including *A. marina*, *E. agallocha*, *K. obovata*, *A. aureum*, *A. corniculatum* and *B. gymnorrhiza*. Three individuals of *S. caseolaris* were found in the bay opposite to Tai O Salt Pan, their height ranged from 2.4 to 2.9 m. AFCD had conducted two removal works in 2006 and 2007, with 13 and 10 individuals of *Sonneratia* removed respectively.

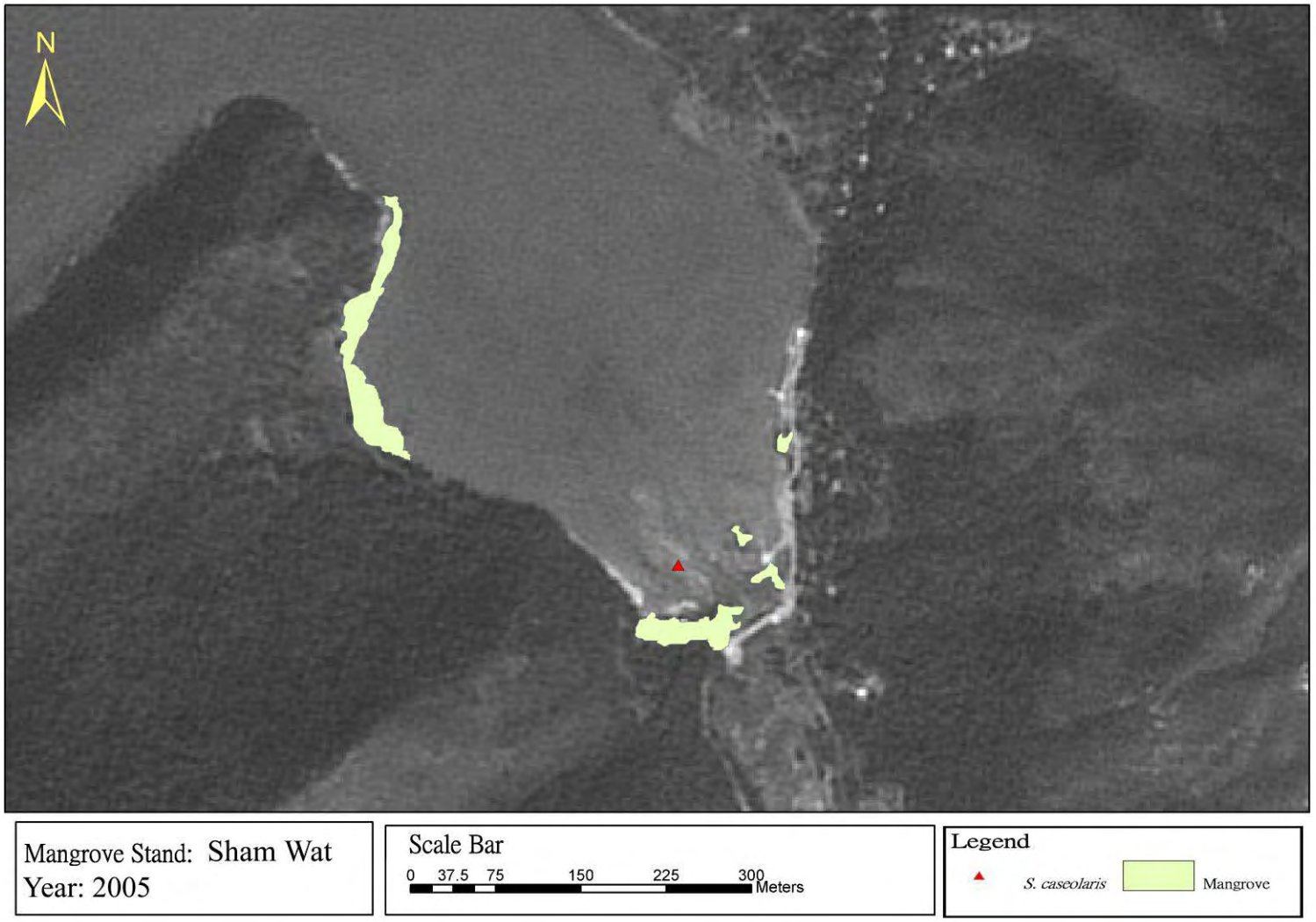


Fig. 2.22 Distribution of native mangrove and *Sonneratia* (>1.5 m) individual in Sham Wat



Fig. 2.23 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Tai O

2.3.2.2.8 Yi O (22°13N, 113°50'E)

Mangrove stand in Yi O had an area of 0.9 hectare (Fig. 2.24). The substrate at the foreshore was sandy and became muddy near the stream. Five species of true mangroves were present, dominated by *A. marina* and *A. corniculatum*, with a few patches of *K. obovata* and *B. gymnorrhiza* at the mid shore. *Sonneratia* was absent from this stand.

2.3.2.2.9 Shui Hau (22°13N, 113°55'E)

Mangrove stand in Shui Hau had an area of 0.7 hectare (Fig. 2.25). The substrate was mainly sandy and became muddy in the stream outlets. Six species of mangroves were present, dominated by *K. obovata, A. corniculatum* and large patches of *A. marina* in the eastern side of the stand. Three individuals of *S. caseolaris* were present, with two grew close to the permanent stream and one on the outer edge of the stand. Their height ranged from 1.5 to 2.2 m.

2.3.2.2.10 Pui O Wan (22°14N, 113°58'E)

Mangrove stand in Pui O had an area of 1.8 hectares (Fig. 2.26). It was a fringe mangrove situated on the stream bank originated from the Pui O village. Three species of true mangroves were present, dominated by *A. corniculatum* interspersed with *B. gymnorrhiza, E. agallocha* was developed at the back shore. No *Sonneratia* was found.

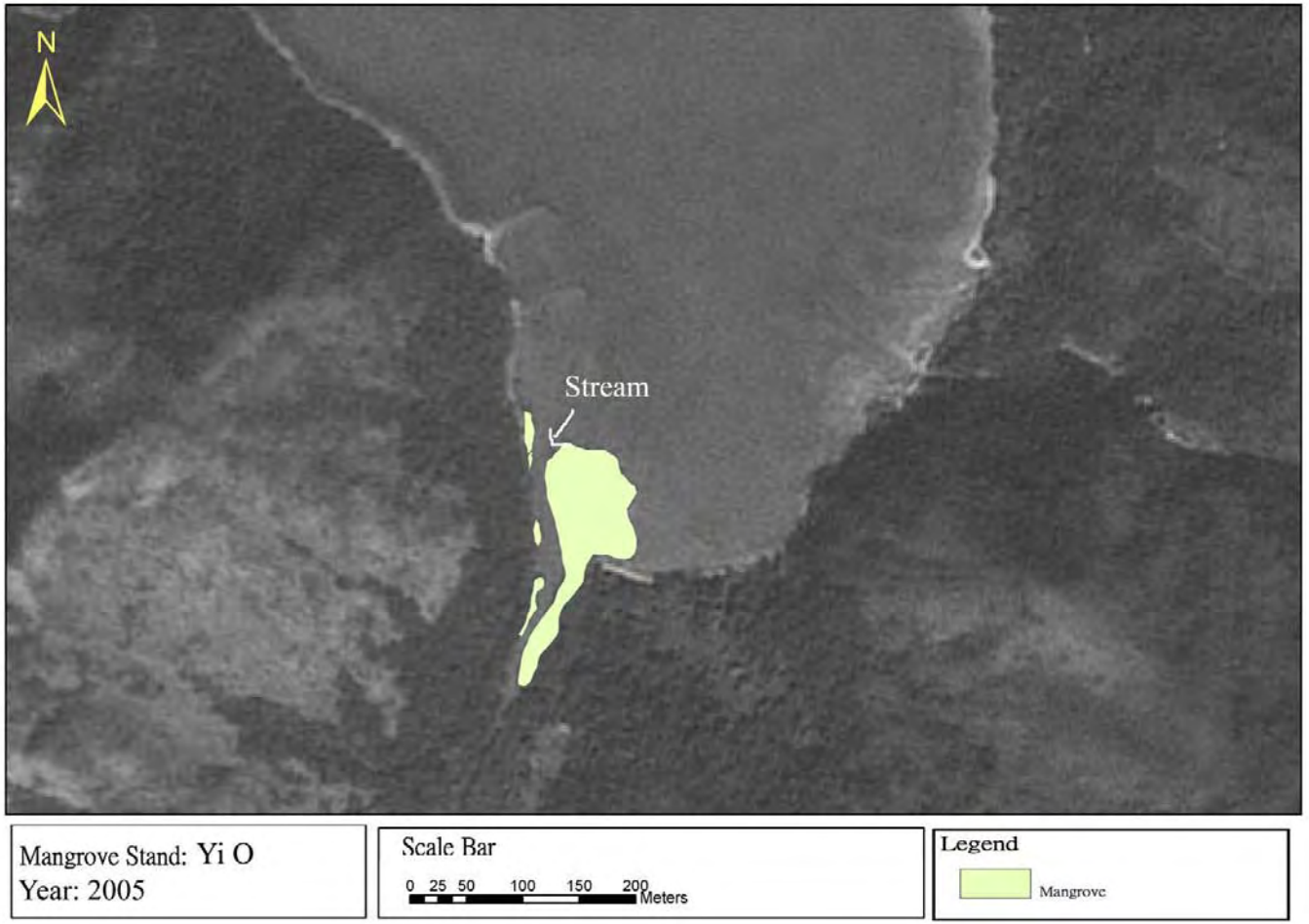


Fig. 2.24 Distribution of native mangrove in Yi O

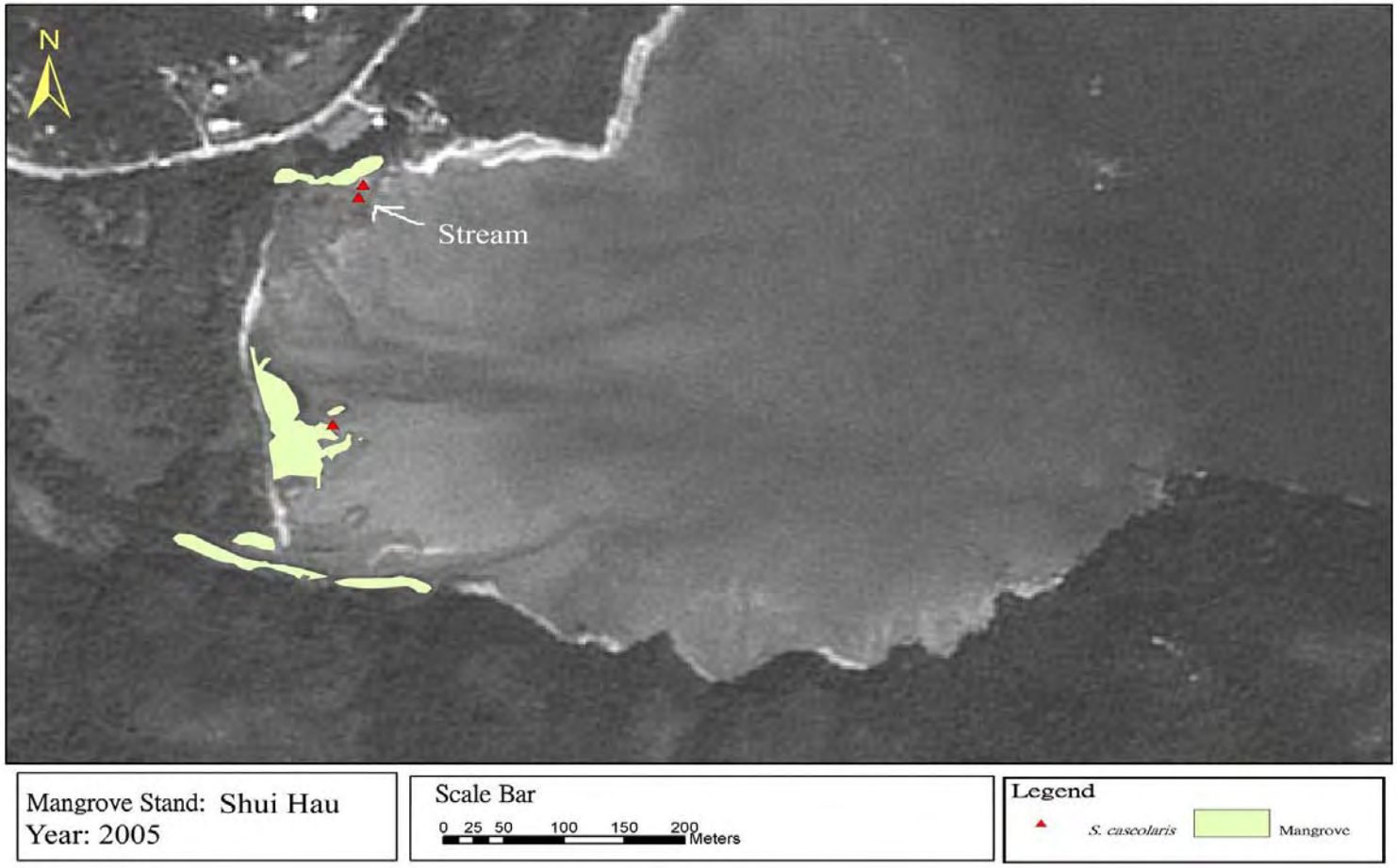


Fig. 2.25 Distribution of native mangrove and *Sonneratia* (>1.5 m) individuals in Shui Hau



Fig. 2.26 Distribution of native mangrove in Pui O Wan

2.3.2.2.11 Chi Ma Wan (22°14N, 113°59'E)

Mangrove stand in Chi Ma Wan had an area of 0.1 hectare situated on the stream bank (Fig. 2.27). The substrate was sandy. Only one species, *A. corniculatum*, was found but all individuals appeared unhealthy with most leaves were dried. *Sonneratia* was absent from this stand.

2.3.2.3 Distribution of *Sonneratia* on Hong Kong Island (Tai Tam 22°14'N, 114°13'E)

Mangrove in Tai Tam had an area of 0.2 hectare (Fig. 2.28). It was a fringe mangrove dominated by *K. obovata*. In the study previously done by Tam & Wong (1997), only *K. obovata* could be found on the site. With the habitat enhancement by replanting of different species, the number of mangrove species increased to seven, they were *K. obovata, A. corniculatum, A. marina, B. gymnorrhiza, H. littoralis*, *L. racemosa* and *E. agallocha*. No *Sonneratia* was found in the stand, probably due to the remote distance between Tai Tam and Deep Bay.

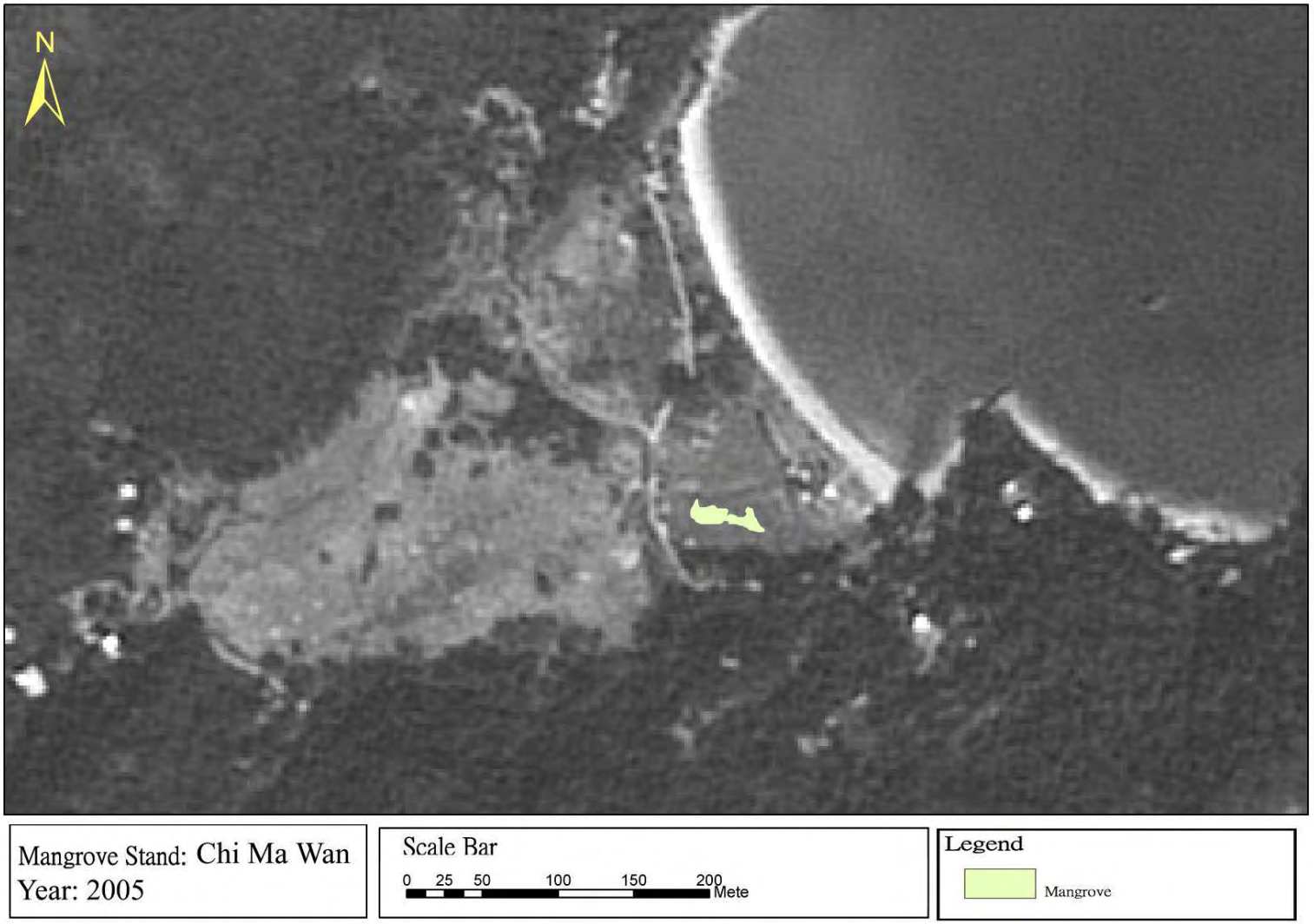


Fig. 2.27 Distribution of native mangrove in Chi Ma Wan

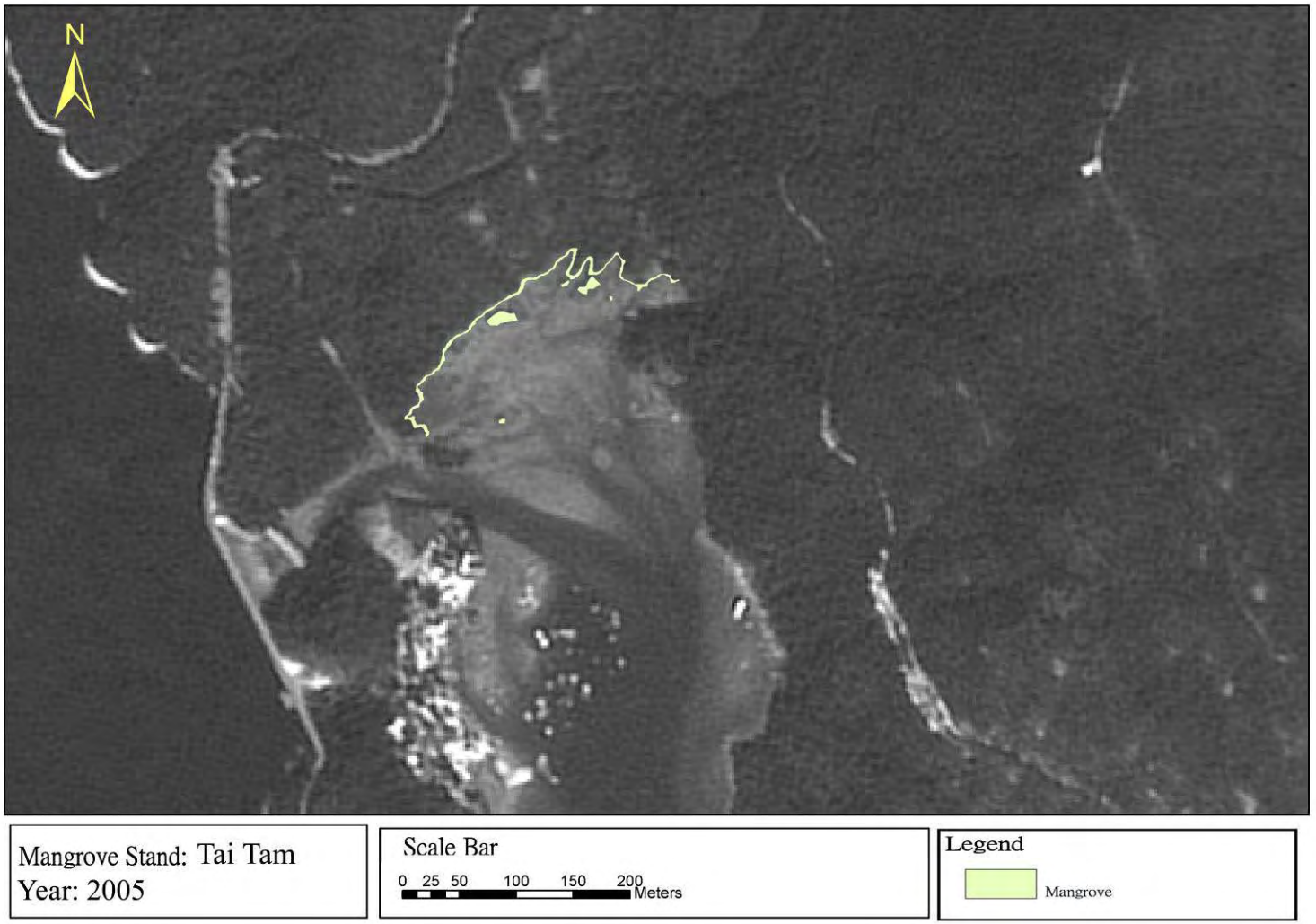


Fig. 2.28 Distribution of native mangrove in Tai Tam

2.3.2.4 Distribution of *Sonneratia* in other mangrove stands

The eastern mangroves in Hong Kong which situated in Sai Kung, Tolo and Northeast New Territories areas are theoretically safeguarded from the invasion of *Sonneratia* as explained before. In fact, there was one extraordinary sighting of *Sonneratia* in Tolo area. One *S. caseolaris* was found in Tolo Pond (22°26'N, 114°11'E) by Mr. Tom Glenwright (Chan & Lau, 2005). The author suggested that this mangrove species may be spreading. It was a 1.2 m tall *S. caseolaris*, partially immersed in the fish pond of Tolo Pond instead of the mangrove stand (Fig. 2.29). The pond belongs to the Kerry Lake Egret Nature Park, formerly named as Tai Po Kau Interactive Nature Centre, and is currently used for recreation activities such as fishing and boating. The possibility of the natural spreading is dim, as the pond is enclosed by a dam and the only passage to the Tolo Pond mangrove is through the sluice gate that opens only when the staff wants to fill up the pond with the flowing tide. *Sonneratia* was not found in the nearby mangroves such as Kei Ling Ha Lo Wai and Lo Fu Wat. The chance for *Sonneratia* seed to travel a long distance and spread from Deep Bay to Tolo Pond is not really possible.

Personal communication with the staff at the Center discovered that there was a transplantation of reed bed from Deep Bay to Tolo Pond few years ago. The seeds of *Sonneratia* may be transported to the fish pond together with the reed (*Phragmites sp.*) accidentally, resulting in the establishment of the single *Sonneratia*.



Fig. 2.29 Distribution of native mangrove and *Sonneratia* (>1.5 m) individual in Tolo pond

2.3.3 Reproductive biology of *Sonneratia* species

2.3.3.1 Flowering and fruiting seasons

Sonneratia apetala, flowered and fruited all the year round while there were two peak fruiting seasons, from April to June and from September to November (Table 2.3). *S. caseolaris* in Hong Kong produced flowers and fruits all year round but there was only one single prolonged peak fruiting period from July to March in the following year. The mature fruit was easily distinguished based on the signs summarized in Table 2.4. Generally, the mature fruits can be easily detached from the tree and the pulp is soft with aromatic smell while the seeds can be easily isolated from the pulp.

2.3.3.2 Productivity and seed vigor in different fruiting seasons

2.3.3.2.1 Productivity of *Sonneratia* species in spring and autumn

Both species of *Sonneratia* produced more fruits per mature tree and seeds per fruit in the autumn batch than that in spring (Table 2.5). *S. apetala* produced 12.7 times more seeds per mature tree in autumn than spring while *S. caseolaris* produced 4.5 times more seeds per mature tree in autumn than spring. *S. caseolaris* were more productive than *S. apetala* in both seasons. In spring, each *S. caseolaris* mature tree produced 5.6 times more seeds than *S. apetala*; while the difference was 2.0 times in autumn.

Table 2.3 Flowering and fruiting seasons of *Sonneratia apetala* and *S. caseolaris* (P: present, M: Peak fruiting season with more than 10 mature fruits could be found under the canopy of a parent plant)

Species	Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Sonneratia apetala	Flowering	P	P	P	P	P	P	P	P	P	P	P	P
	Fruiting	P	P	P	P M	P M	P M	P	P	P M	P M	P M	P
Sonneratia caseolaris	Flowering	P	P	P	P	P	P	P	P	P	P	P	P
	Fruiting	P M	P M	P M	P	P	P	P M	P M	P M	P M	P M	P M

Table 2.4 Signs to show fruit maturity of *Sonneratia apetala* and *S. caseolaris* in Hong Kong

Species	Maturity Indicator
Sonneratia apetala	1. Easy detach from tree when branch is shaken 2. Reach the minimum size of 2 cm 3. Pulp soft with weak aromatic smell 4. Pericarp sticky and apple green in colour 5. Seeds can be easily isolated from the pulp, ovary is 5 to 8 celled
Sonneratia caseolaris	1. Easy to pick from branch by gentle force 2. Reach the minimum size of 6 cm in diameter 3. Pulp soft with strong aromatic smell 4. Pericarp sticky and shiny green in colour 5. Seeds can easily be isolated from the pulp

Table 2.5 Abundance of mature fruits and seeds of *Sonneratia apetala* and *S. caseolaris* in Hong Kong at two peak fruiting seasons (The average number of seeds per tree = Average number of fruits per tree x Average number of seeds per fruit)

Species and Season	Average number of fruits per mature tree	Average fruit size in diameter (cm)	Average number of seeds per fruit	Average number of seeds per mature tree
Sonneratia apetala				
Spring	891	2.4	73	65,202
Autumn	8,299	2.8	100	827,118
Sonneratia caseolaris				
Spring	812	4.4	452	367,078
Autumn	1,566	6.6	1,052	1,647,158

2.3.3.2.2 Germination of *Sonneratia apetala* collected in spring and autumn

Seeds of *S. apetala* collected in autumn were able to start budding in Day 4 while those collected in spring did not bud until Day 9 (Fig. 2.30). Autumn seeds had a faster budding rate than the spring seeds, they could reach 25% at Day 5 and 50% at Day 6, and the budding percentage in Day 30 was 64.44% while the respective percentage for the spring seeds was only 6.67% (Table 2.6). Statistical analysis showed that the budding number was significantly affected by season after controlling the effect of time (Table 2.7).

Seeds collected in spring were unable to unfurl even at the end of the germination experiment (Day 30) (Fig. 2.30). Seeds from autumn started to unfurl in Day 5 and almost 100% were unfurled at the end of the experiment (Table 2.8). Statistical analysis showed that the unfurling number was significantly affected by season after controlling the effect of time (Table 2.7).

At the end of the experiment, Day 30, the numbers of seeds with budding were significantly different between the spring and autumn seasons ($p < 0.05$) and the numbers of unfurling were also significantly different ($p < 0.05$) (Fig. 2.31).

Table 2.6 The budding percentages of *Sonneratia apetala* seeds collected in spring and autumn (NA: Not available)

Season	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
Spring	NA	NA	NA	6.67 %
Autumn	5 days	6 days	NA	64.44 %

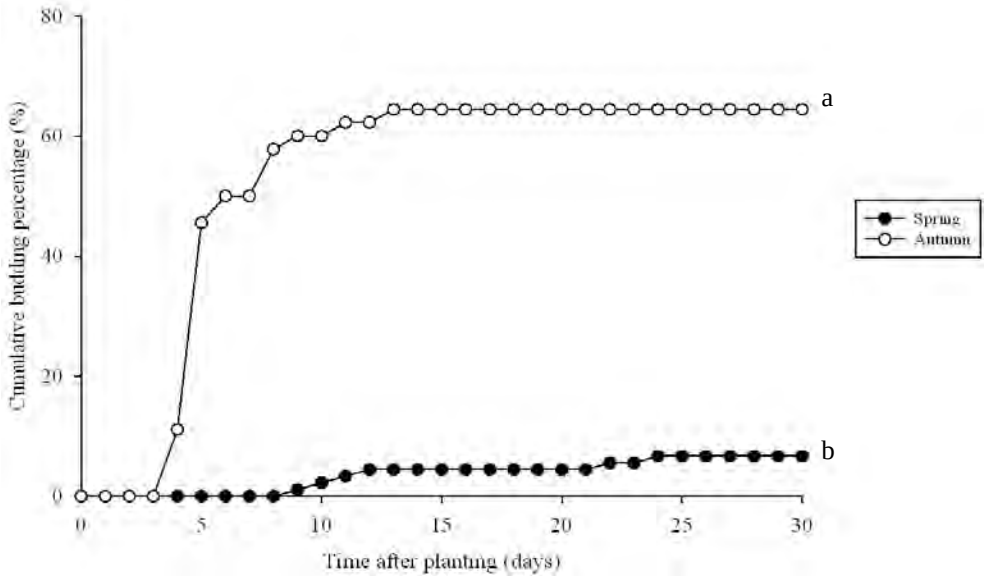
Table 2.7 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia apetala* seeds collected in different seasons. (The variate is the seasons and the covariate is number of days after planting, *= significant difference at $p<0.05$ level)

Parameter	Budding		Unfurling	
	$F(1,182)$	p	$F(1,182)$	p
Season	55.662	0.000*	15.340	0.000*
Day	117.147	0.000*	188.749	0.000*
Seasons x Day	13.373	0.000*	188.749	0.000*

Table 2.8 The unfurling percentages of *Sonneratia apetala* seeds collected in spring and autumn (NA: Not available)

Season	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
Spring	NA	NA	NA	0 %
Autumn	8 days	9 days	16 days	96.82%

Budding



Unfurling

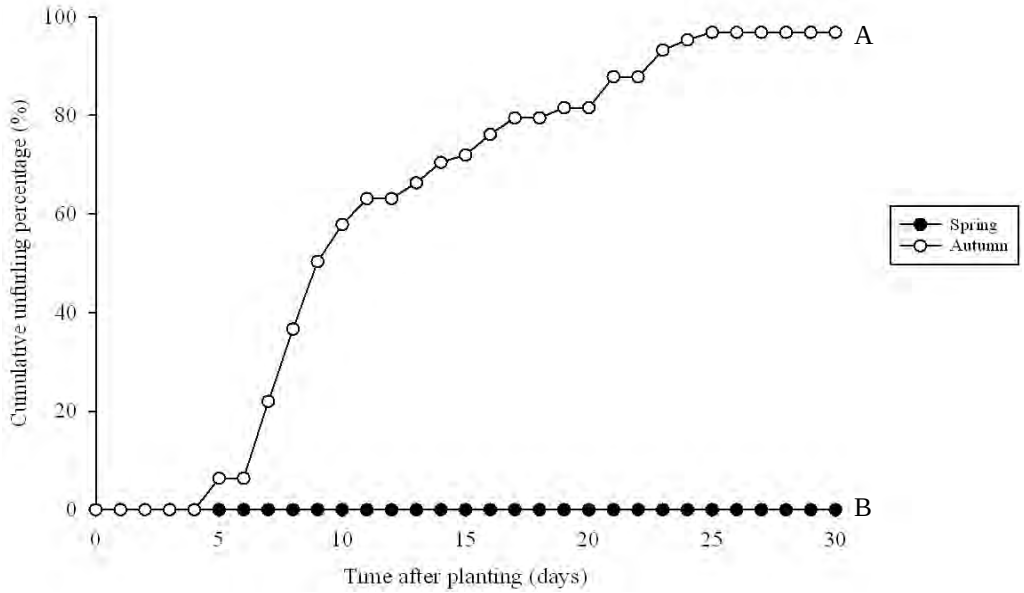


Fig. 2.30 Cumulative budding and unfurling percentages of *Sonneratia apetala* seeds collected in spring and autumn (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

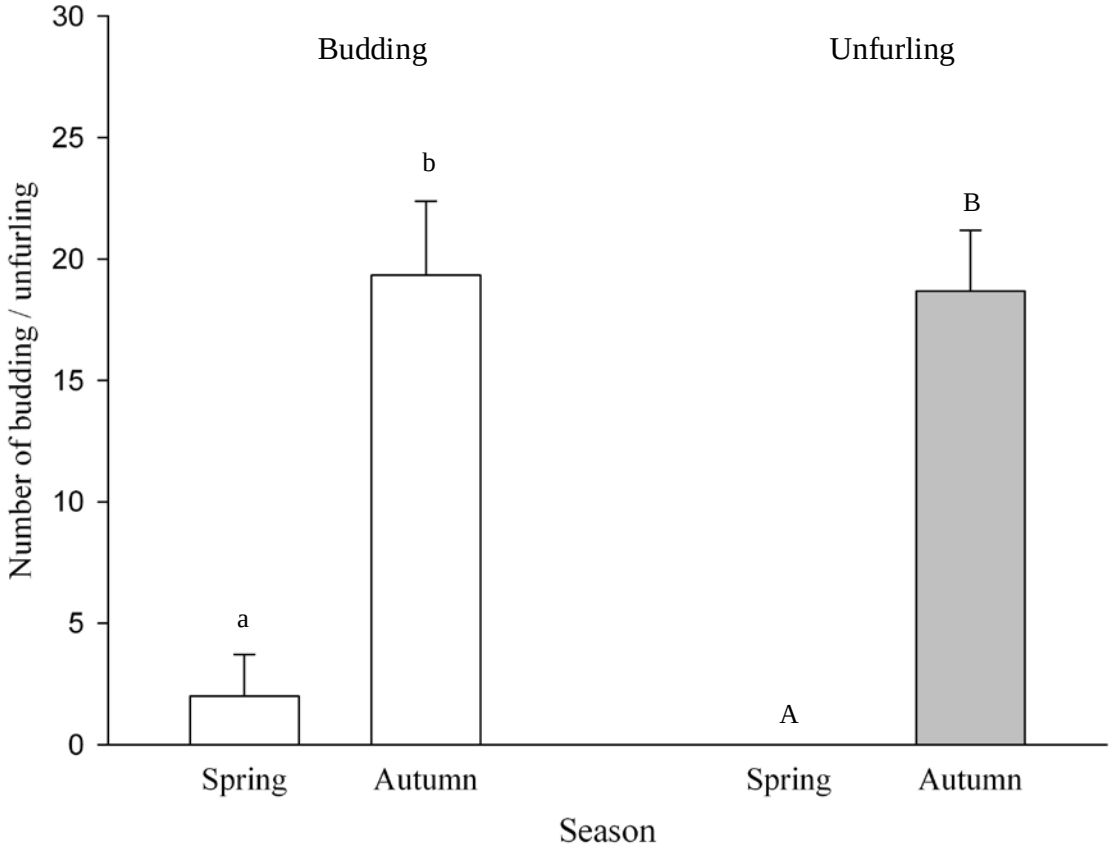


Fig. 2.31 The numbers of budding and unfurling of *Sonneratia apetala* seeds collected in spring and autumn at Day 30 (Mean and standard deviation of triplicates are shown. Means of the same species with different letters are significantly different at $p \leq 0.05$ level according to t-test)

2.3.3.2.3 Germination of *Sonneratia caseolaris* collected in spring and autumn

All seeds of *S. caseolaris* collected were able to bud, irrespective to the seasons. However, the budding time and the rate were faster in the autumn batch, which started to bud in Day 1, while those collected in spring did not bud until Day 3 (Fig. 2.32). Although the budding rates of the autumn seeds were higher than the spring ones at the initial stage, both batches attained around 60-70% budding at the end of the experiment (Table 2.9). At Day 30, seeds collected in spring had budding percentages of 62.33%, while those in autumn had 67.78%. Statistical analysis showed that the budding number was significantly affected by season after controlling the effect of time (Table 2.10).

Seeds from autumn started to unfurl in Day 5 and almost 100% unfurled at the end of the experiment (Table 2.11 and Fig. 2.32). However, seeds collected in spring did not unfurl. Statistical analysis showed that the unfurling number was significantly affected by season after controlling the effect of time (Table 2.10).

At the end of the experiment, Day 30, the numbers of budded seeds were not significantly different between the spring and autumn seasons ($p>0.05$) but their numbers of unfurling were significantly different ($p<0.05$) (Fig. 2.33).

Table 2.9 The budding percentages of *Sonneratia caseolaris* seeds collected in spring and autumn (NA: not available)

Season	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
Spring	14 days	24 days	NA	62.33%
Autumn	2 days	4 days	NA	67.78%

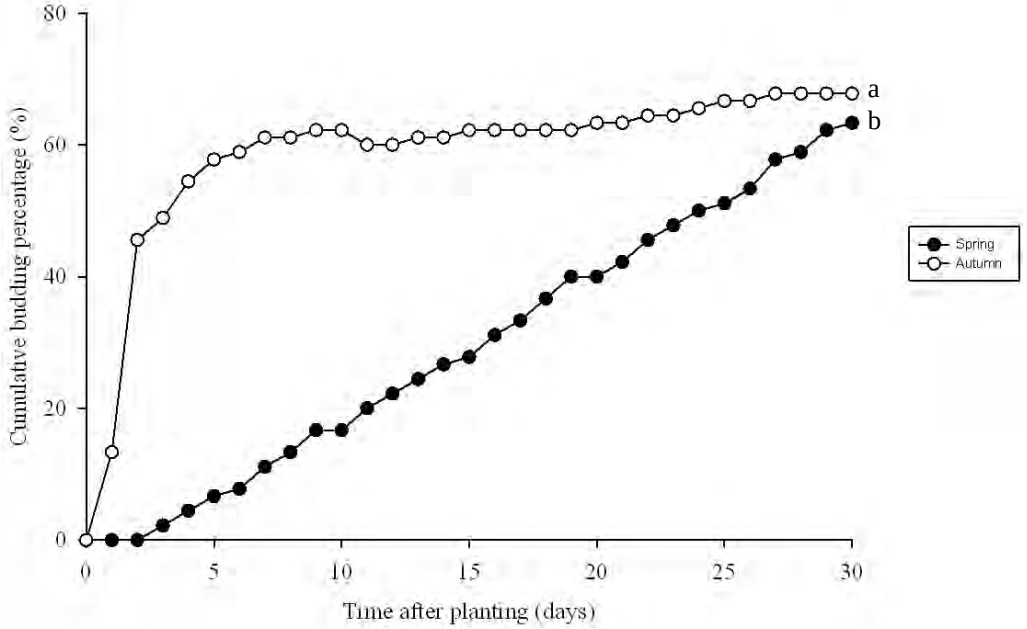
Table 2.10 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia caseolaris* seeds collected in different seasons. (The variate is the season and the covariate is number of days after planting, *= significant difference at $p<0.05$ level)

Parameter	Budding		Unfurling	
	$F(1,182)$	p	$F(1,182)$	p
Season	194.015	0.000*	36.483	0.000*
Day	300.752	0.000*	156.397	0.000*
Season x Day	73.698	0.000*	109.956	0.000*

Table 2.11 The unfurling percentages of *Sonneratia caseolaris* seeds collected in spring and autumn (NA: not available)

Season	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
Spring	NA	NA	NA	3.3 %
Autumn	7 days	9 days	11 days	95.8%

Budding



Unfurling

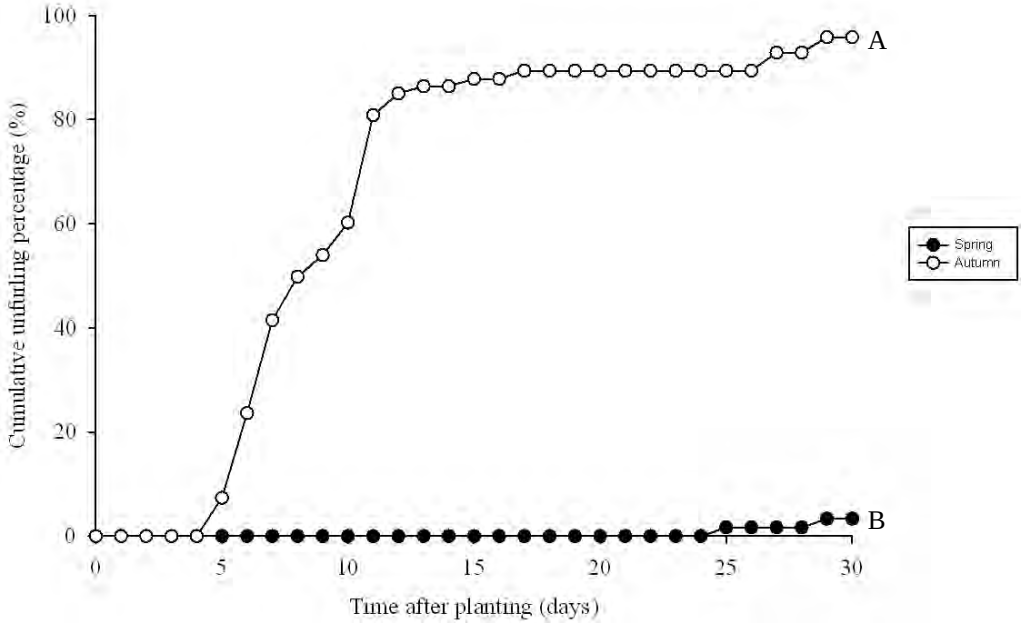


Fig. 2.32 Cumulative budding and unfurling percentages of *Sonneratia caseolaris* seeds collected in spring and autumn (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

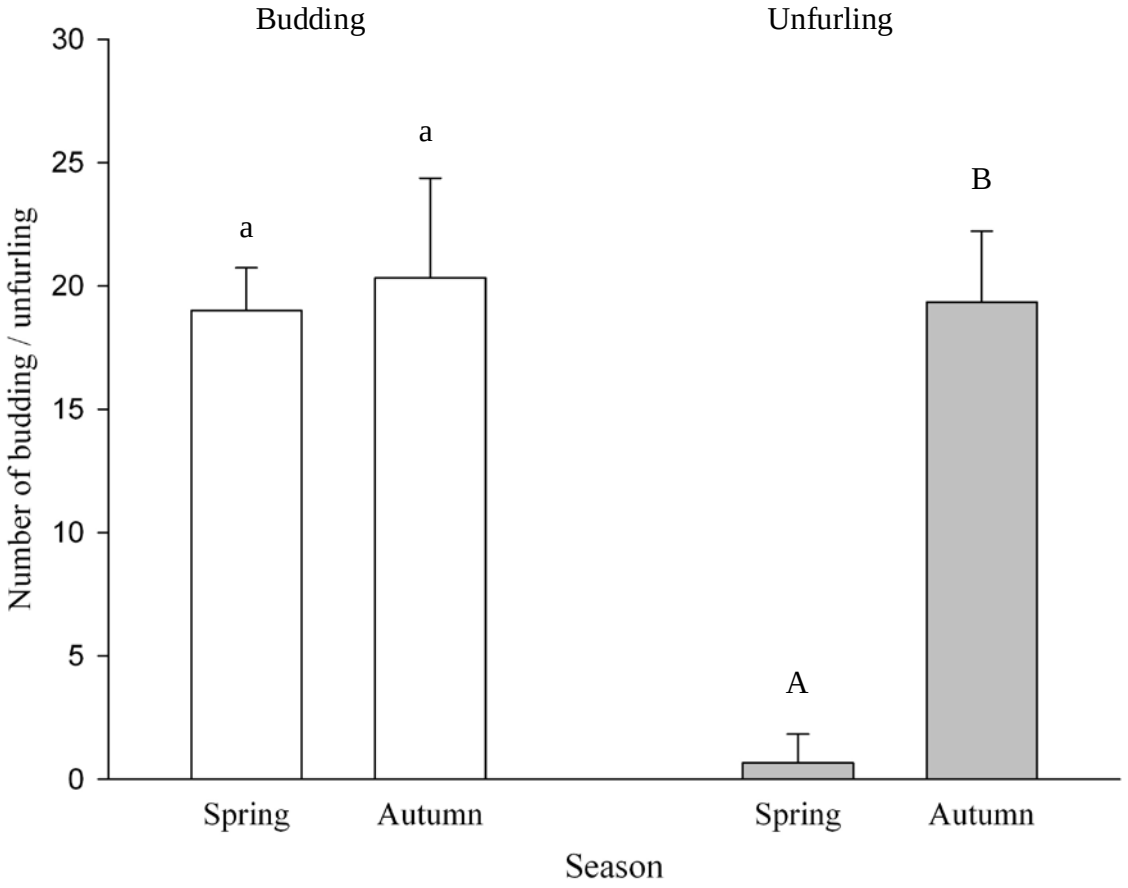


Fig. 2.33 The numbers of budding and unfurling of *Sonneratia caseolaris* seeds collected in spring and autumn at Day 30 (Mean and standard deviation of triplicate are shown. Means of the same species with different letters are significantly difference at $p \leq 0.05$ level according to t-test)

2.4 Discussion

2.4.1 Identification, distribution and abundance of *Sonneratia* species

This study aims to provide an updated distribution map of *Sonneratia* in Hong Kong since it was first discovered in Mai Po Marshes Nature Reserve (MPMNR) in 2000. Such information provided a baseline data for the evaluation of dispersal trend and rate in the future. The distribution maps are crucial for defining hotspots and prioritizing the areas for removal.

The plant samples collected from Tsim Bei Tsui and Mai Po were identified as *Sonneratia apetala* Buch.-Ham and *S. caseolaris* (L.) Engl. Both species belonged to the genus *Sonneratia*. *Sonneratia* is an evergreen tree with open spreading crown which can grow up to 20 m high. Although they do not have buttress or prop roots, they have thick, cone-shaped and upright densely congregated pneumatophores originating from the underground cable roots, similar to the native mangrove species *A. marina* (Tomlinson, 1994). Flowers are solitary with numerous stamens and vestigial (or no) petals. Fruits are fleshy and globule (Hogarth, 1999). *Sonneratia* species are mainly distributed in the tropical and subtropical areas, from East Africa through Indo-Malaya to tropical Australia, Micronesia and Melanesia, including the Hainan Island of Mainland China (Tomlinson, 1994).

Both *S. apetala* and *S. caseolaris* investigated in the present study belong to the Family Sonneratiaceae (海桑科) which consists of two genera, *Sonneratia* L. f. (海桑屬) and *Duabanga* (八寶樹屬) accounting for 12 species (Wang and Chen, 2002). The genus *Sonneratia* comprising six species and three varieties can be divided into two Sections: Section Sonneratia with capitate stigmas and Section Pseudosonneratia with peltate stigmas. The two *Sonneratia* species in Hong Kong belong to different sections as distinguished by the morphology of the leaf, flower and fruit (Table 2.1), with *S. apetala* belongs to Section Pseudosonneratia while *S. caseolaris* belongs to Section *Sonneratia*. Their morphological characteristics were comparable to those described by Tomlinson (1994).

The mangrove biogeography is widely recorded and summarized in published literature, the distribution of *S. apetala* and *S. caseolaris* are 7°N-22°N 72°-97°E and 18°S-20°N 24°-165°E, respectively (Spalding *et al.*, 1997). Clearly, Hong Kong which located on the South China coast 22°18'N, 114°10'E is out of the natural distribution of both *Sonneratia* species. This proved that the *Sonneratia* in Hong Kong was not naturally proliferated but accidentally transferred to Hong Kong by human.

The shortest distance between Mai Po and FMFNR is around 150 m. Seeds could be readily carried by the tide and established in the opposite bank. Undoubtedly, MPMNR was the first site colonized by *Sonneratia* due to the close proximity of FMFNR, Shenzhen where *Sonneratia* was used for

afforestation in mid 90's. This also explained why the total number of *Sonneratia* individuals in Mai Po mangrove stand accounted for more than half of the *Sonneratia* population in Hong Kong.

Sonneratia individuals appeared to favour mudflat and channels for establishment. Similar to the characteristics of most exotic plants which favour open areas with high light intensity and nutrient levels, as well as lower competition (Dudgeon & Corlett, 2004). According to baseline survey, it is worth to note that three (Hong Kong Island, Sai Kung area and Northeast New Territories) out of six areas were found free of *Sonneratia*, they were all situated on the eastern coast of Hong Kong, this may due to the high salinity in this areas which inhibits the germination process of *Sonneratia*. The effect of different physical factors on the germination of *Sonneratia* species would be further examined in Chapter 4.

The number of *Sonneratia* recorded in this survey represented the minimum number in Hong Kong, because the hotspots at the mouth of Sham Chun River were hard to access. The adult trees in the hotspot were closely packed, the outermost *Sonneratia* individuals could block the view and led to under-estimation of number. The aerial photo could count the numbers of mature *Sonneratia* in the patch but only large confined to tall individuals (approximately >5 m) that could be identified on the image. Additionally, only mature *Sonneratia* (>1.5 m) were counted in this survey and the

number of *Sonneratia* could be totally different in the coming year as young saplings were not counted and they are fast-growing (about 1 m per year). AFCD and Environmental Protection Department (EPD) removed approximately 1,553 individuals of *Sonneratia* in November 2004 from the foreshore mudflat areas in the Mai Po and Inner Deep Bay Ramsar Site in November 2004 which included 521 large trees (>2.5 m), 249 medium trees (1.5-2.5 m) and 783 seedlings (<1.5 m). AFCD further removed 750 individuals from Deep Bay in September 2006 which included 200 seedlings (<1 m), 250 small trees (1-1.5 m) and 100 large trees (>2.5 m). The World Wide Fund of Hong Kong (WWFHK) has also removed the *Sonneratia* seedlings on the mudflat out of the bird hide every year since 2003, and injected the herbicide glyphosate to more than 30 *Sonneratia* trees in 2004 and 2005 (personal communication with Mr. Bena Smith, WWFHK) which could contribute to the underestimation of current numbers in Hong Kong.

2.4.2 Reproductive biology of *Sonneratia* species

Seasons of fruiting and flowering of *Sonneratia* may change according to the climate and the availability of nutrients. In Hainan, *S. apetala* reported to have two flowering and fruiting seasons (Liao *et al.*, 1997a). The first flowering season was from early May to mid July and fruits were produced from late October to late November. The second flowering season started in

mid December and fruits could be found from April to May in the following year. *S. caseolaris* produced flowers throughout the year with two peak flowering and fruiting seasons. In the first peak season, *S. caseolaris* flowered from mid March to late May and fruits started to develop in mid May to late June, and became mature and abundant in mid June to late August. In the second peak season, the flower started to appear in September, fruits started to develop in mid October to mid November, and fruits were mature in January to mid February in the following year. The fruits collected from the first fruiting season generally had a higher germination success than the second one. In eastern Guangdong, *S. apetala* produced flowers and fruits in a similar pattern. Huang and Zhan (2003) reported that *S. apetala* produced flowers twice a year, the first flowering season started from early May and the peak season appeared from mid June to mid July, mature fruits found in late October to late November. The second flowering period started from mid December and mature fruits appeared from April to May in the following year.

This study showed that *S. apetala* in Hong Kong had a longer first peak fruiting period which fruits could be found in June as well; the second peak fruiting season was also longer than that of Hainan and eastern Guangdong, with mature fruits started to appear from September instead of late October. *S. caseolaris* in Hong Kong had a single prolonged period of fruiting instead of dividing into two peak fruiting periods as in the homeland, Hainan Island. Although both species had a longer fruiting period but the present data were

insufficient to draw any conclusion on the comparative productivities of *Sonneratia* in Hong Kong and mainland China.

Determining the peak fruiting seasons and evaluating the germination success in different seasons are essential for developing appropriate measures to control the spread of *Sonneratia*, and identifying the best season for removal. In the present study, results showed that *Sonneratia* produced more mature fruits and the fruits carried more seeds in autumn. Furthermore, the autumn seeds had a higher viability than those collected in spring. Based on these findings, the production of fruits and seeds in autumn should be avoided. The mature individuals should be cut and removed before the maturity of fruits in autumn. It is not recommended to remove *Sonneratia* once their fruits became mature as the removal process might help the dispersal of seeds.

Tam & Wong (2004) has conducted an experiment to determine the time needed for the germination of the eight native mangrove species and determined their fruiting seasons. Comparatively, *S. apetala* and *S. caseolaris* had a much longer period of fruiting, both produced fruits all year round, while the native mangrove species fruited for one to three months each year (Tam & Wong, 2004) (Table 2.12). For the time taken for germination, *Sonneratia* was far faster than the native species (Table 2.13). The fast germination rate and prolonged fruiting period of *Sonneratia* providing them a higher chance to survive and establish.

Table 2.12 The fruiting seasons of both native and exotic mangrove species in Hong Kong (data of eight native mangrove species were extracted from Tam, N.F.Y. & Wong, Y.S. (2004))

Species	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Sonneratia apetala				↔	↔	↔			↔	↔	↔	
Sonneratia caseolaris	↔	↔	↔			↔	↔	↔	↔	↔	↔	↔
Acanthus ilicifolius					↔	↔						
Aegiceras corniculatum							↔	↔				
Avicennia marina								↔				
Bruguiera gymnorrhiza				↔	↔							
Excoecaria agallocha			↔	↔								
Heritiera littoralis	↔	↔										
Kandelia obovata				↔	↔							
Lumnitzera racemosa	↔											

Table 2.13 Comparison of budding and first leaf unfurling times of *Sonneratia* and eight native mangrove species in Hong Kong (*Fruits were planted after 35 days' storage as this species requires a dormant period; ND: Not determined, data of eight native mangrove species were extracted from Tam, N.F.Y. & Wong, Y.S. (2004))

Species	Germination Time (Days)	
	Budding	First Pair of Leaf Unfurling
Sonneratia apetala	4	5
Sonneratia caseolaris	1	5
Acanthus ilicifolius	15	20
Aegiceras corniculatum	17	19
Avicennia marina	6	8
Bruguiera gymnorrhiza	15	25
Excoecaria agallocha	ND	11
Heritiera littoralis	36	56
Kandelia obovata	15	19
*Lumnitzera racemosa**	14	22

2.5 Conclusions

The *Sonneratia* occurred in Hong Kong were identified as *S. apetala* and *S. caseolaris*, both were out of their natural distribution range. The study gave the first account on the number of *Sonneratia* individuals in Hong Kong after ten years of the first introduction of *Sonneratia* in FMFNR. A total of 1,693 mature *Sonneratia* individuals distributed in 14 out of the 63 mangrove stands, and *S. caseolaris* (74.4%) was more abundant and more widely distributed than *S. apetala* (25.6%). Surveys showed that 99.4% of the *Sonneratia* individuals were distributed within Deep Bay area of Hong Kong, more than half distributed in Mai Po mangrove stand. Kam Tin River mangrove stand had the highest density (23.5 ind. per ha). Only *S. caseolaris* was dispersed to areas out of Deep Bay. The distribution maps showed that *Sonneratia* was mainly found in the forest edge and river or stream channels. The chance of the two *Sonneratia* species invaded into the mature mangrove forest in Mai Po and Tsim Bei Tsui was low. The present study also showed that both *S. apetala* and *S. caseolaris* produced higher numbers of fruits in autumn and each mature fruit had higher numbers of seeds with higher unfurling numbers than that in spring. This implied that the individuals should be removed prior to the fruit maturity in autumn. When comparing with other native mangrove species in Hong Kong, *Sonneratia* had a longer fruiting period and faster germination rate. The high reproductive ability of *Sonneratia* might pose threat to the native species in term of colonization of common niches.

CHAPTER 3

IMPACT ASSESSMENT: DISPERSAL ABILITY OF *SONNERATIA*

3.1 Introduction

While the current distribution clearly showed that *Sonneratia* has been naturalized in Hong Kong, there is yet no evaluation or prediction on their spread. To expand its territories, *Sonneratia* must be able to disperse, establish and propagate. Seed dispersal is an important stage during the life history of any plant. The dispersal influences the distribution (McGuinness, 1997) and the success of dispersal is determined by the availability of suitable habitat (Duke *et al.,* 1998).

Plants are sessile and rely on dispersal of seeds or spores to expand their territory. There are many methods of seed dispersal, including mechanical, wind, water and animal. All mangroves are dispersed by water, and their propagules, including fruits, seeds and seedlings have some initial ability to float for a particular period of time (Duke *et al.,* 1998; Tomlinson, 1994). It is a kind of adaptation for life in the estuarine, coastal and oceanic environments to replenish its own stand and expand its territory (Duke *et al.,* 1998). The Family Rhizophoracea, which the dominant *Kandelia obovata* Sheue, Liu & Young sp. nov. in Hong Kong belonged to, has developed highly specialized viviparous propagules to assist its dispersal (Tomlinson, 1994). In other mangrove species such as *Acanthus, Aegialitis, Conocarpus, Dolichandrone, Excoecaria* and *Xylocarphus*, the fruits are capsule-like and seeds are their units of dispersal (Tomlinson, 1994).

Like other mangroves, *Sonneratia* dispersed by current. They disperse in the form of fruits in the initial stage, the mature fruits fall from the tree and sink to the bottom. After few days, the calyx is separated and the seeds are exposed. The fruit wall is then further softened, and the floatable seeds are released and carried by water current (Tomlinson, 1994). During the dispersal phrase, both *Sonneratia* can germinate (budding and first pair of leaves unfurling). Rejmanek (1996) suggested that the invasiveness of a woody species is associated with its seed size, and a small dispersal unit can be easily and further transferred by current. Among the mangrove genera in Hong Kong, genus *Sonneratia* has the smallest seed (Table 3.1), suggesting the highest potential for it to spread, expand its territory and colonize other habitats.

Table 3.1 Type and size of propagules of true mangroves in Hong Kong based on Tomlinson (1994)

Genus	**Type**	**Size (Length in cm)**
Kandelia	Seedling	40-30
Bruguiera	Seedling	30-15
Aegiceras	One-seeded fruit	7-5
Avicennia	One-seeded fruit and seed	4-3
Lumnitzera	One-seeded fruit	2-1
Heritiera	One-seeded fruit	6-5
Excoecaria	Seed	0.3
Sonneratia	Seed	0.2-0.1

Dispersal can determine where the species grows and its abundance in a mangrove system (Rabinowitz, 1978a; Duke *et al.,* 1998). The presence of a species in a particular site depends firstly on the proximity to the source of its population. The dispersal to a distant site depends on the direction of the sea current, tides and the land barriers. The distance is also limited by the days that

the propagules remain buoyant and viable, the rate of surface currents and the availability of suitable habitats (Duke *et al.*, 1998). The buoyancy and viability vary from species to species. There are some discussion in literature about the ability of mangroves to disperse and their subsequently establishment (Rabinowitz, 1978a; Ball and Pidsley, 1988; McGuinness, 1997). Rabinowitz (1978b) conducted an experiment on the length of time the propagules of *Avicennia* could float in salt and fresh water, and found that this species always floated and must be stranded in place with little tidal disturbance for establishment. McGuinness (1997) conducted the capture and recapture experiment for *Ceriops tagal* (Perr.) C. B. Robinson propagules, and reported that most of the propagules were found within the parent plants. *Sonneratia* seeds are too small (<1 cm) for the capture and recapture experiment, the present study will use floating experiment to investigate their dispersal ability. Such information is useful for managers of the nature reserve to evaluate the threat of *Sonneratia* and set up appropriate control program.

If the seeds are in the dispersal stage and carried away from their parent plants by current, one of the biggest challenges to the seed is the changes of salinity (Duke *et al.*, 1998). Salinity in Hong Kong progressively increases from west to east. The inshore hydrography is affected by the freshwater input from two major sources. Firstly, the heavy rainfall in Hong Kong that on average is 217 cm/year, associated with the monsoons prevailing from May to September appreciably dilutes the coastal waters (Morton & Morton, 1983). Second, the input of freshwater from the Pearl River Delta reduces the salinity of seawater in the western coast of Hong Kong, especially during the summer month when

the rainfall is the highest. The salinity of Inner Deep Bay can fall below 10 part per thousands (ppt) in the wet season (June and July). The effect of the Pearl River progressively reduces towards the eastern coast of Hong Kong which is virtually unaffected by the freshwater discharge when compared with the western coast.

The water quality of 76 marine sampling stations distributed in 10 water control zones is monitored by the Environmental Protection Department (EPD), the Government of the Hong Kong Special Administrative Region (Fig. 3.1) (EPD, 2007). By averaging the hydrographical data from years 2000 to 2004, the characteristics of all stations are summarized in the following sections.

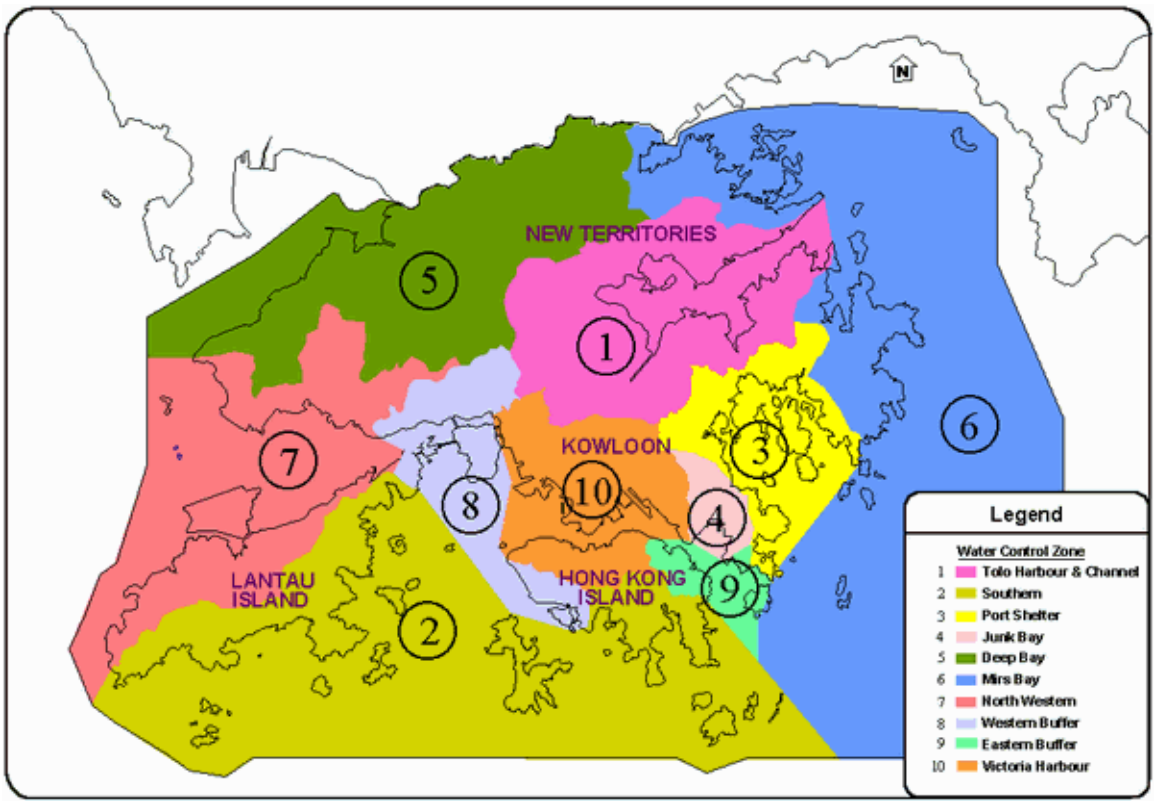


Fig. 3.1 Diagram shows the locations of the 10 Water Control Zones regularly monitored by EPD, the Government of the Hong Kong Special Administrative Region (EPD, 2007)

Deep Bay area (Fig. 3.2)

Inner Deep Bay (DM1-DM2): These stations are closest to the Mai Po Marshes Nature Reserve (MPMNR) and Futian Mangrove Forest Nature Reserve (FMFNR). They are highly sheltered and influenced by the freshwater input of Pearl River and Sham Chun River, the salinity is the lowest in Hong Kong. It can fall below 10 ppt during the rainy season (June-July) and the most saline period is the winter time (October to March) when the salinity can be as high as 25 ppt.

Outer Deep Bay (DM3-DM4): compare with the Inner Deep Bay, there is more circulation with the ocean current and less influenced by the inland freshwater input from Sham Chun River. The salinity is higher than the Inner Deep Bay, ranging from 10.7 ppt in July to 29.7 ppt in December.

Lantau North (Fig. 3.3)

North Western Water (NM1-3, 5, 6 & 8): Exposure with freshwater input from the Pearl River, the average salinities of western stations NM5, 6 and 8 are lower than the eastern stations NM1-3. Similar to Deep Bay area, the influx of freshwater during the rainy season dilutes the salinity of seawater, the lowest salinity of NM5, 6 & 8 is 14.8 ppt in June and the highest salinity is 32.1 ppt in December. Salinity of stations NM1-3 is slightly higher than the salinity of NM5, 6 & 8 in the winter time with a maximum of 5 ppt higher in the wet season.

Ma Wan area (Fig. 3.4)

Western Buffer (WM1-4): Salinity in Ma Wan area is generally higher than 25 ppt with the exception of June and July, when the average salinities were 24.1 ppt and 23.8 ppt, respectively.

Southern Lantau and Hong Kong Island area (Fig. 3.5)

Southern Water (SM1-20): With the land barrier of Lantau Island, water form this area is relatively undiluted by the freshwater discharge from the Pearl River. Salinity in this area is always higher than 25 ppt with the exception of June (23.7 ppt).

Mirs Bay, Tolo Harbour and Port Shelter areas (Figs. 3.6-3.8)

Salinities in the eastern Hong Kong including Mirs Bay, Tolo Harbour and Port Shelter areas are not affected by the discharge of Pearl River. Instead, they are more oceanic and the salinities are always higher than 30 ppt.

From the available information, seeds of *Sonneratia* are more likely to expose to salinities ranging from 10 to 35ppt during their dispersal period, with and progressively increase in salinities when they are carried by tides or currents to the southern or eastern part of Hong Kong. Can *Sonneratia* seed remain viable during the dispersal phrase?

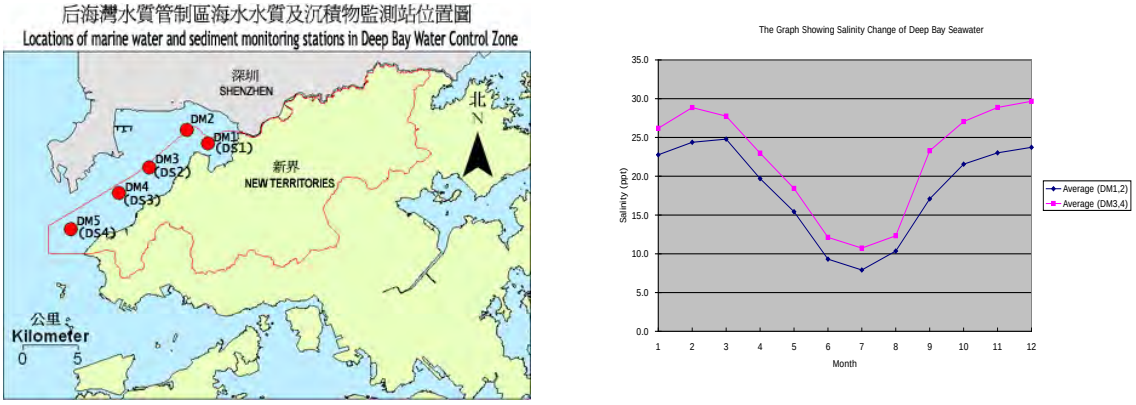


Fig. 3.2 Salinity change in Deep Bay area (average of 2000-2004) (EPD, 2007)

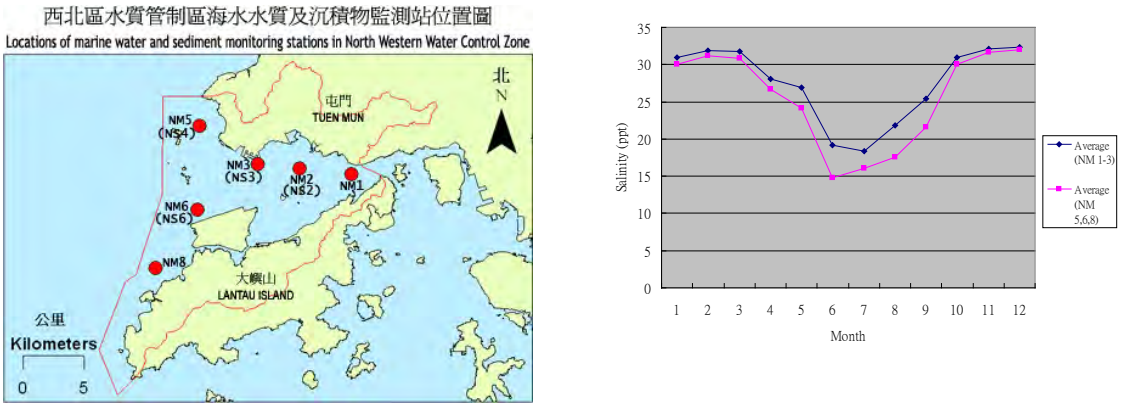


Fig. 3.3 Salinity change in Lantau North area (average of 2000-2004) (EPD, 2007)

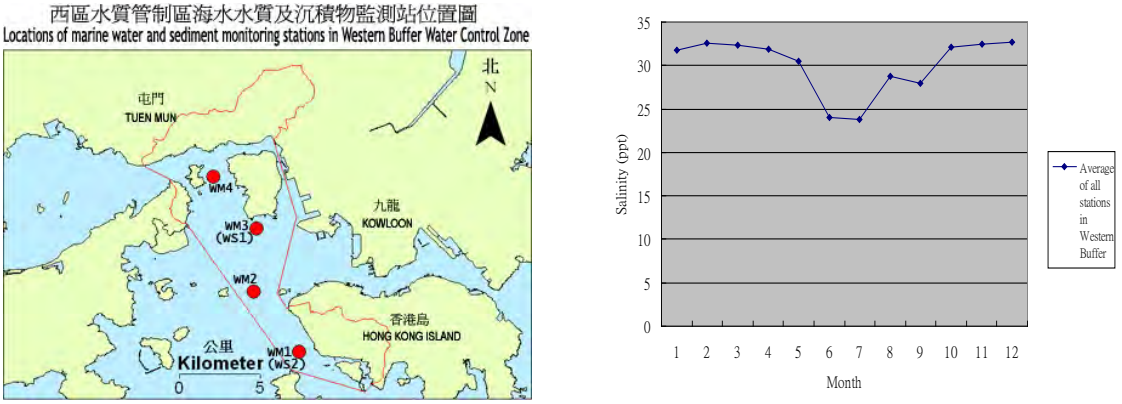


Fig. 3.4 Salinity change in Ma Wan area (average of 2000-2004) (EPD, 2007)

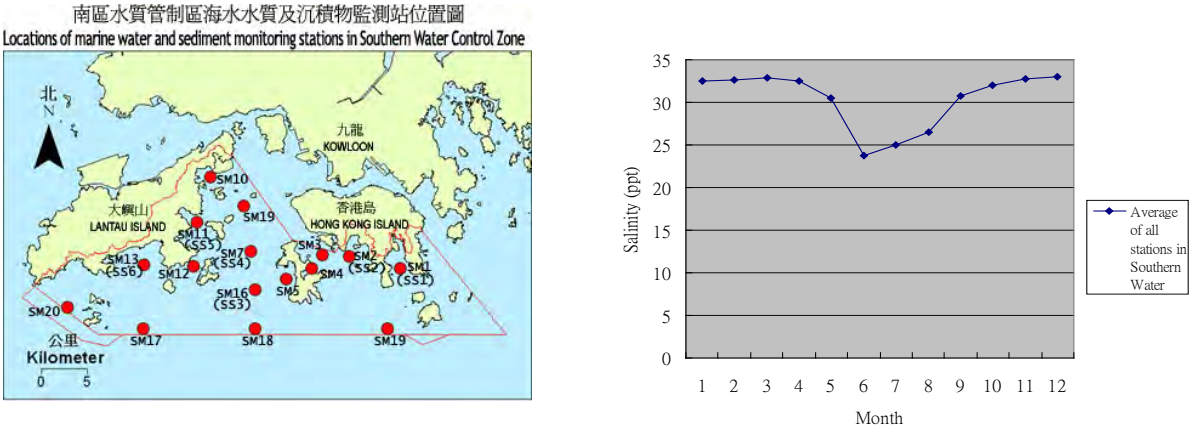


Fig. 3.5 Salinity change in Southern Lantau and Hong Kong Island area (average of 2000-2004) (EPD, 2007)

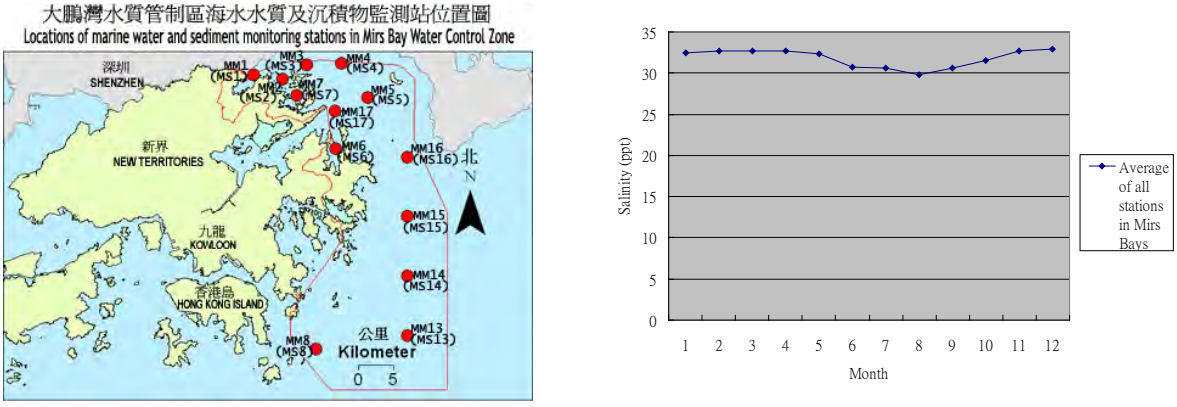


Fig. 3.6 Salinity change in Mirs Bay area (average of 2000-2004) (EPD, 2007)

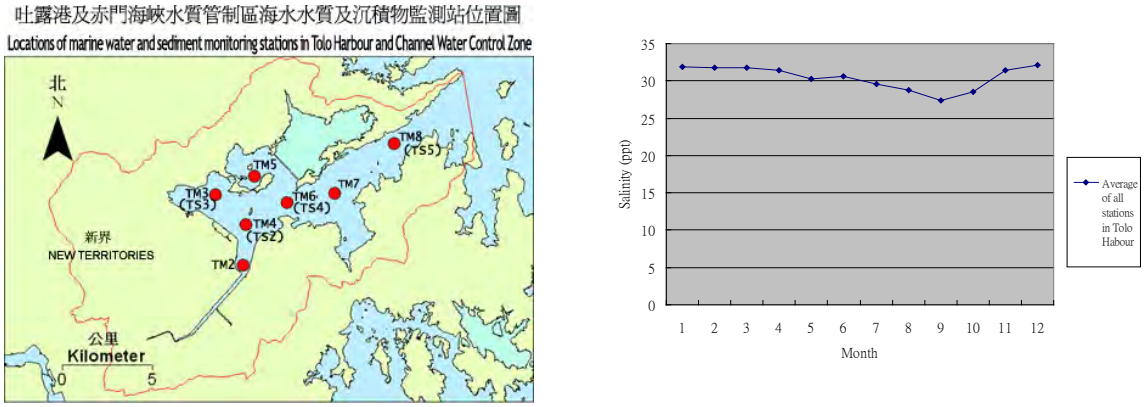


Fig. 3.7 Salinity change in Tolo Harbour area (average of 2000-2004) (EPD, 2007)

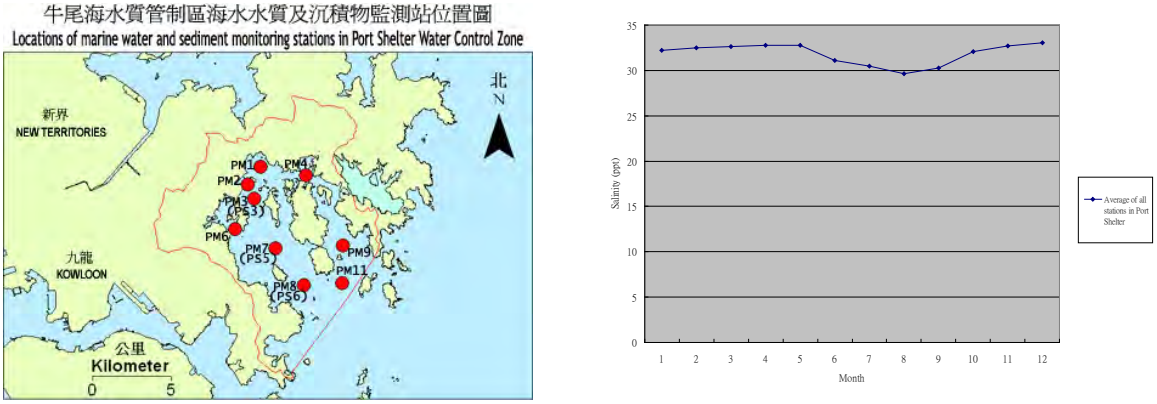


Fig. 3.8 Salinity change in Port Shelter area (average of 2000-2004) (EPD, 2007)

The objectives of this study were to (1) determine the dispersal rate and direction of *Sonneratia* seeds carried out from Deep Bay to other mangrove stands using desktop analysis, (2) identify the mangrove stands in Hong Kong that may be invaded by the two *Sonneratia* species, (3) examine the longevity and germination success of the *Sonneratia* species at salinities ranging from 0 to 35 ppt, and (4) assess the ability of *Sonneratia* seedlings to cope with the change in salinity. Before conducting the greenhouse experiment on the dispersal ability of *Sonneratia* seeds, a desktop data analysis was performed to predict the floating route and days required for *Sonneratia* fruits to travel from Inner Deep Bay to various mangrove stands in Hong Kong. This can predict the possible dispersal range of *Sonneratia* in Hong Kong and define the days required for the floating experiment to be carried out in greenhouse.

3.2 Materials and methods

3.2.1 Determination of dispersal direction and rate

A reference point situated at the outlet of Sham Chun River in the Inner Deep Bay (22°30’26’’N 114°1’56”E) representing the source of *Sonneratia* seeds. It

was used to measure the approximate distances (to the nearest hundredth) between Inner Deep Bay and different mangrove stands in Hong Kong by the ArcGIS Desktop 9.1 (ESRI, China (HK)) (Table 3.2). A software developed by the Hydrographic Office, Marine Department, the Government of the Hong Kong Special Administrative Region named as Hong Kong Digital Tidal Stream Atlas 2006 (Version 1.01 ®) was used to calculate the time required for dispersing *Sonneratia* from Inner Deep Bay to other mangrove stands in Hong Kong. This is a tidal stream and height prediction program. The predictions are based on tidal constituents and algorithm that calculated by mathematical models, and hydraulic modeling results assuming average monsoon conditions. However, it cannot compare ad-hoc phenomena such as typhoon. Another limitation is the tidal stream on western Hong Kong is strongly influenced by the discharge of Pearl River as Hong Kong is geographically located at its mouth. The meteorological dry and wet seasons of freshwater discharged from the river had a remarkable influence on tidal current strength within Hong Kong waters. The flow data of these dry and wet seasons used in predicting the tidal current strength are generated separately using the average seasonal Pearl River discharge rates over a long period of time. There are 7,700 reference points showing either the surface current or the average depth current in this program. In the present study, only the surface current was used for calculation as seeds of *Sonneratia* were floated on water surface. The land barrier and the flushing of Pearl River Delta change the surface tidal flow direction in certain point at both ebbing and flowing tides (Figs. 3.9 & 3.10). According to the tidal flow direction and speed, seven zones were defined (Fig. 3.11). Within each zone, the direction and speed of tides at any points were assumed to be the

same. A reference point laid on the center line of the zone with the median speed was selected from each zone. Some zone exhibit unsymmetrical background which may contribute to the difference in speed and direction. To compare the difference of speed and direction between the center of the zone and near the edge, another point laid close to the coastline was selected in Zone 1. As the direction and rate of flow changed from time to time, the determinant flow rate of the reference point were measured at every 15 minutes interval (Fig. 3.12).

Table 3.2 Distance between mangrove stands in Hong Kong and the reference point (22°30'26''N 114°1'56"E) in Inner Deep Bay

Area	**Mangrove stands**	**Distance from Inner Deep Bay (to the nearest hundredth meter)**
Deep Bay area	Lau Fau Shan	4,200
	Sha Kong Tsuen	8,600
	Sheung Pak Nai	9,700
	Pak Nai	11,800
	Ha Pak Nai	14,100
Out of Deep Bay area		19,100
Lantau Area		
Northern Lantau	San Tau	35,200
	Tung Chung	35,400
	Tai Ho Wan	36,500
	Yam O	37,500
	Ma Wan (Ma Wan Island)	39,000
Western Lantau	Sham Wat	34,800
	Tai O	39,600
	Yi O	40,900
Southern Lantau	Shui Hau	62,700
	Chi Ma Wan	62,200
	Pui O	72,500

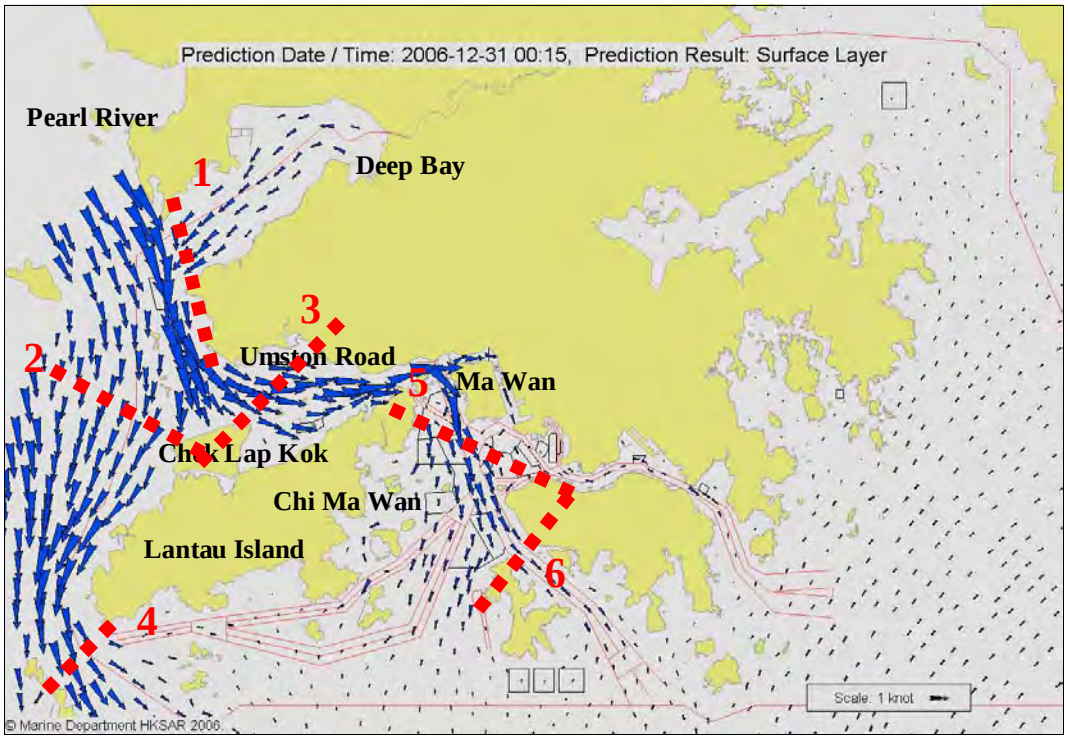


Fig. 3.9 Ebbing tide (red dot line indicates the change of tidal flow due to land barrier)

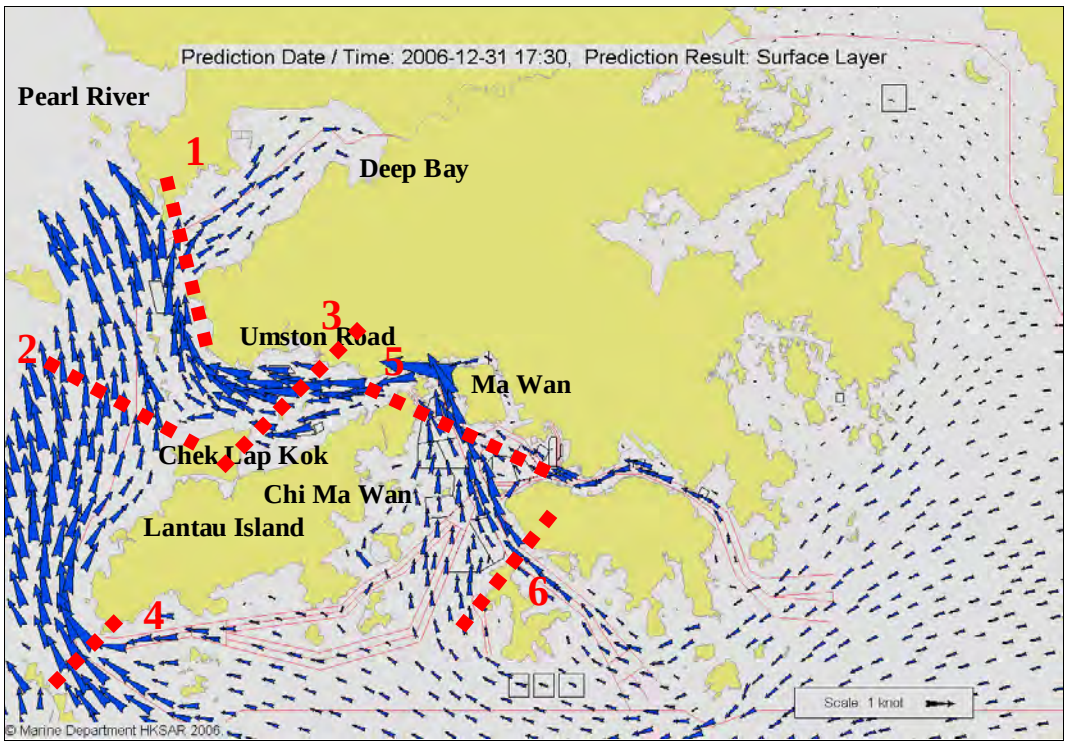


Fig. 3.10 Flowing tide (red dot line indicates the change of tidal flow due to land barrier

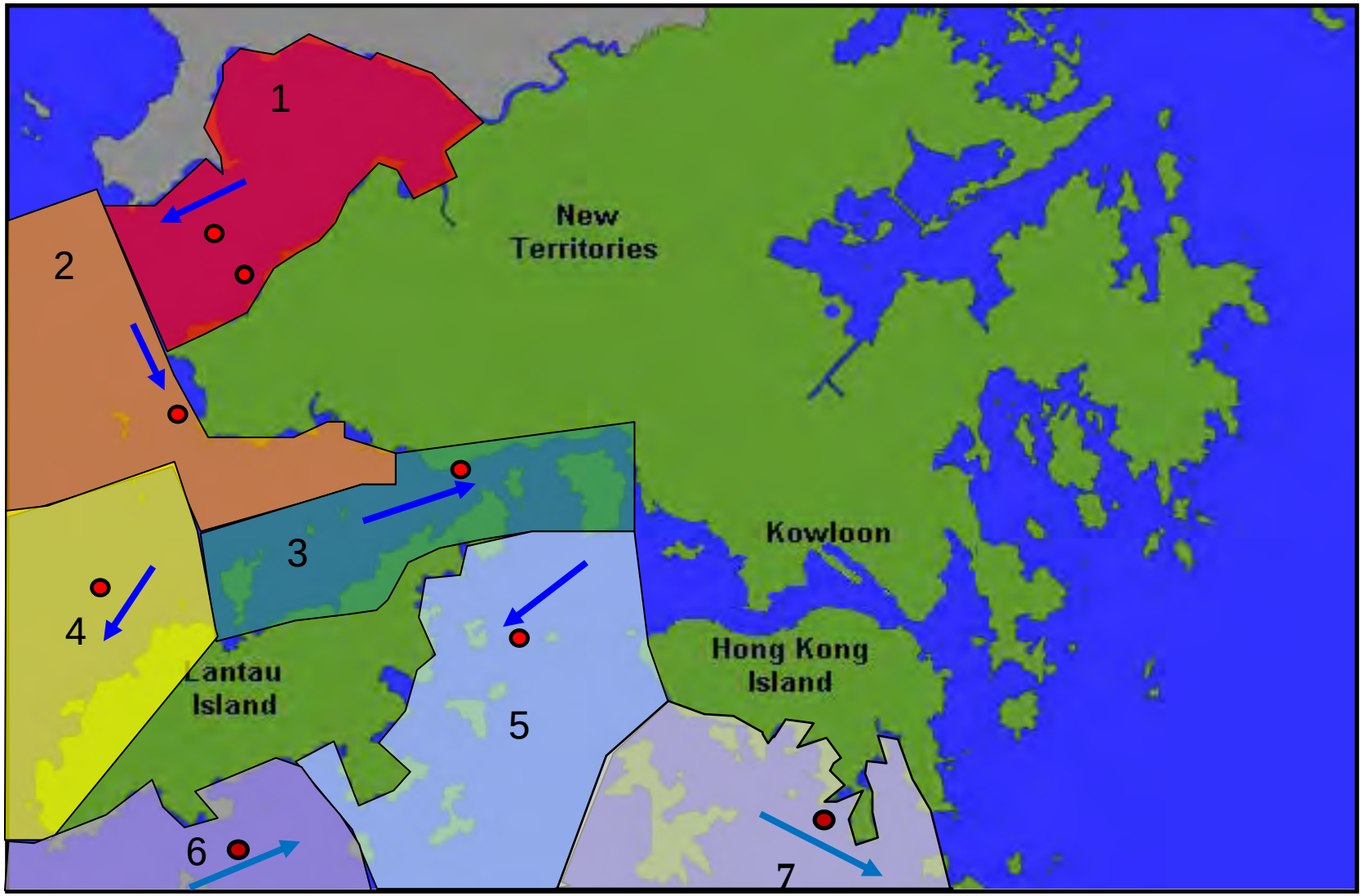


Fig. 3.11 Diagram indicating the seven defined zones (arrow indicates the tidal flow during the ebbing tide and red dot indicates the reference point(s) in each zone)

DTSA 2006

Title: ----------

Pre. Result: Surface Layer

Position: 22 - 27.692 N 113 - 55.845 E

Date/Time		deg	kts
2006/12/31	00:15	230	1.0
2006/12/31	00:30	230	1.0
2006/12/31	00:45	229	0.9
2006/12/31	01:00	229	0.8
2006/12/31	01:15	230	0.7
2006/12/31	01:30	230	0.6
2006/12/31	01:45	231	0.5
2006/12/31	02:00	233	0.4

Fig. 3.12 Data generated from the Digital Tidal Stream Atlas 2006 for the reference point in Deep Bay area on 31/12/2006 (00:15-02:00)

A boundary on the flow direction was drawn separating the tide flowing towards or away from the mangrove stand within the zone. For example, in zone 1, the major flow direction during the ebbing tide was 220° in compass bearing (Fig. 3.13). A line was drawn perpendicular to the flow direction. In the compass, half was regarded as “flow towards the mangrove stand” while another half was regarded as “flow away from the mangrove stand”. In this case, if the flow direction was between 130° and 310°, the tide was regarded as “flows towards the mangrove stand” and the distance traveled was assumed to be a positive value. On the other hand, if the flow direction was between 311° and 129°, the

tide was regarded as “flows away from the mangrove stand” and the distance traveled was considered as a negative value. The time required for the *Sonneratia* seeds to reach each mangrove stand was then estimated.

The movement of *Sonneratia* seed was repeatedly tested on the first day of every month. The days required for the seeds to travel to various mangrove stands were calculated based on the assumption that the seeds were not stranded or tangled along the way from the Inner Deep Bay to various mangrove stands. These stands included those in Deep Bay, namely Lau Fau Shan, Sha Kong Tsuen, Sheung Pak Nai, Pak Nai and Ha Pak Nai, were calculated. Other stands such as Mai Po, Tsim Bei Tsui, Kam Tin River, Yuen Long Industrial Area and Wetland Park were not calculated as they were situated in Inner Deep Bay, where the flow direction was unpredictable. If the cumulative movement at any time exceeded -50,000 m, it is assumed that the seed had stranded and could not get out of the Deep Bay area because the distances between the reference point and the furthest point of Mai Po mangrove stand in Sham Chun River was 5,000 m. Then the test was terminated.

In this prediction, only the mangrove stands on the northwestern and southern sides (Deep Bay, Lantau areas) were included but not the stands on eastern side of Hong Kong (Tolo, Sai Kung, Northeast New Territories areas). According to the Digital Tidal Stream Atlas, the seed was theoretically unable to reach those areas as there was a strong current from north-east to south-west direction drifting it to the Pacific Ocean once it reached the eastern side of Hong Kong Island during January to April and September to December. Thus, the eastern side of Hong Kong is naturally sheltered from the invasion of *Sonneratia*.

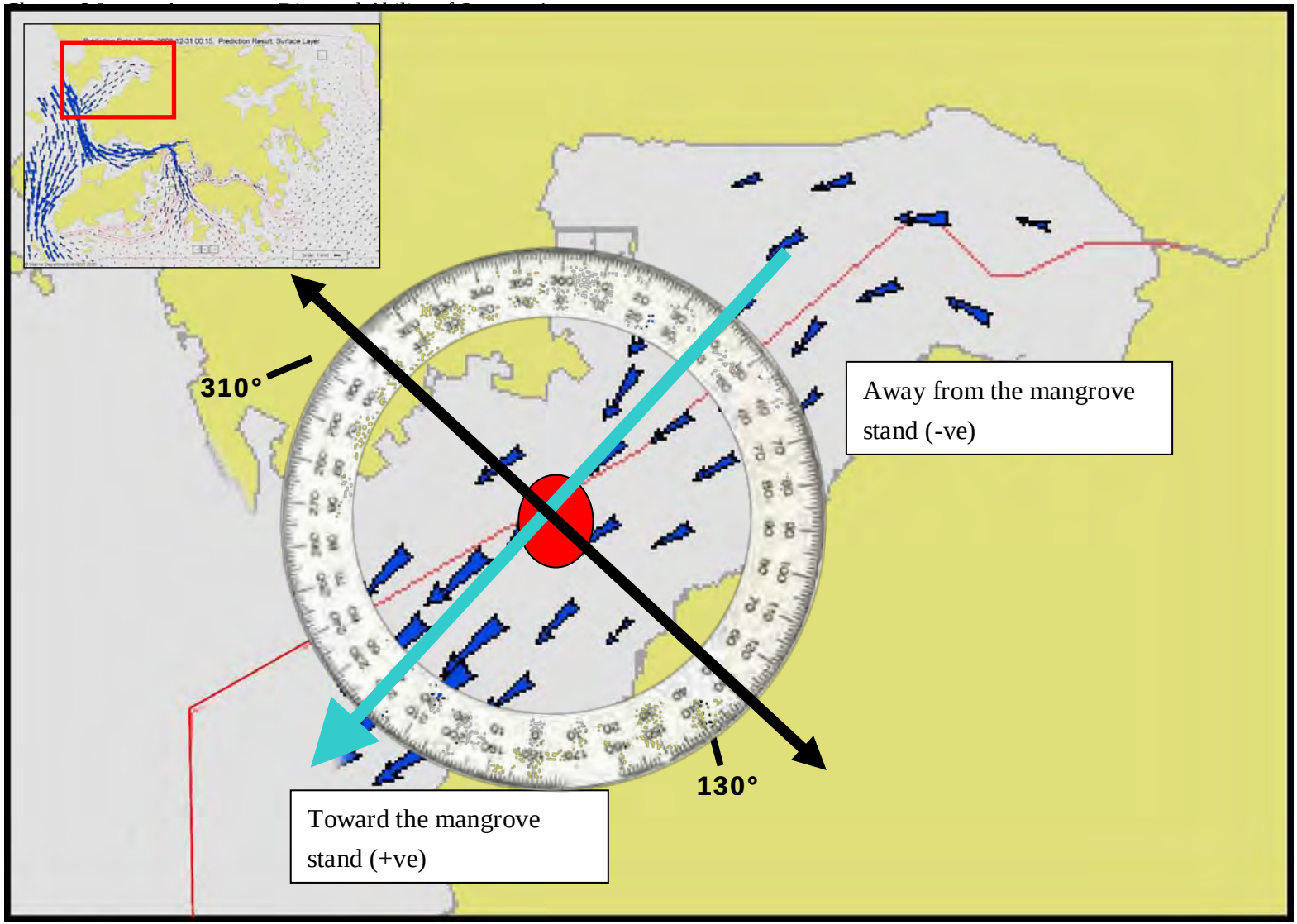


Fig. 3.13 Diagram showing the flow in Zone 1 during the ebbing tide and the assumptions for calculation (Red circle indicates the reference point, arrow in light blue indicates major flow direction while the black arrow is perpendicular to the light blue arrow)

3.2.2 Viability of *Sonneratia* seedlings during the dispersal phrase

3.2.2.1 Defining the day for salinity change

The seeds moved through the salinity gradient when they were carried away from Deep Bay area to other areas. A graph was plotted to illustrate how the seeds moved through the salinity gradient when they were carried by the tide over the year. Assumed the seeds were released and went into the water column on the first day of every month, days required for the seeds to move from one zone to another were calculated according to Section 3.2.1, and a graph was plotted by these data against the average salinities of different zones obtained from EPD (EPD, 2007). By studying the graph, the relationship between the salinity change and the time could be found. Days with most seeds moving from one salinity gradient to another and the change in salinity gradient could be defined as the standard and an experiment was designed to test how long the seeds were remain viable after the salinity change.

3.2.2.2 Experiment setup for testing the viability of *Sonneratia apetala* and *S. caseolaris* seedlings moving through the salinity gradient

Sonneratia seedlings have to cope with different salinities during the dispersal phrase, an experiment was decided to simulate the salinities change in the wild and find out their survival rates. Fruits of two *Sonneratia* species, *Sonneratia apetala* Buch. –Ham and *S. caseolaris* (L.) Engl., were collected from Tsim Bei Tsui ($22^{o}28'40"N$ $114^{o}01'22"E$) and Sheung Pak Nai ($22^{o}26'52"N$ $113^{o}57'15"E$) respectively, during the peak fruiting season, from July to October. The seeds were then obtained following the method described in Section 2.2.3.2. Seeds

were allowed to float and germinate freely in freshwater (0 ppt) for the period defined in Section 3.2.2.1. After that period, seedlings with similar radicle length were selected and transferred to seawater with four different salinity treatments, 0 ppt, 15ppt, 25 ppt and 35 ppt, simulating they moved through the salinity gradients during the dispersal phrase in the wild. The sea water with different salinities was prepared by dissolving different amounts of artificial sea salt (Instant Ocean, Aquarium Systems, Inc., Mentor. Ohio) in tap water. In each treatment, three replicates were prepared, with 30 seedlings in each replicate. The seeds were allowed to flow freely in plastic trays (32 cm x 23 cm x 11.5 cm) containing 8 L seawater. The salinity was monitored twice a week using a hand refractometer (ATAGO, S-10, Japan). The water level was maintained daily by adding tap water to compensate the water lost from evaporation. The water was replaced once a week. In total, 12 trays and 360 seedlings for each *Sonneratia* species were used in this experiment. The numbers of unviable seedlings were recorded daily for 90 days. A seedling was considered unviable if its radicle was entirely darkened.

3.2.2.3 Data treatment

Mean and standard deviation values of three replicates of each treatment were calculated. To test for the different unviable rate, one-way analysis of covariance (ANCOVA) was employed to compare the effects of salinity change on the unviable percentages of both *S. apetala* and *S. caseolaris* at the level of $p<0.05$. Time after transferring from 0 ppt was regarded as covariate, salinity as a cofactor and logarithmic transformed numbers of unviable seeds as a dependent variable. Tukey test was employed for multiple comparisons if ANCOVA result

was significant at the level of $p<0.05$. To test the cumulative numbers of unviable seeds at the end of the experiment, one-way analysis of variance (ANOVA) followed by the Tukey test were employed to compare the effects of different salinity changes on the numbers of unviable seeds at the level of $p<0.05$.

All the statistical tests were performed by the computer program called Statistical Package for Social Science (SPSS 13.0 for Windows, SPSS Inc, Illinois, USA).

Graphs were plotted with the time after transferring from 0 ppt against the cumulative unviable percentages calculated as follow:

$$\frac{\text{Cumulative number of seedlings with entirely darkened radicle at time t}}{\text{Total number of seedlings}} \times 100\%$$

3.3 Results

3.3.1 Dispersal direction and rate

3.3.1.1 Distance between reference point in inner Deep Bay and different mangrove stands in Hong Kong

The five mangrove stands located in outer Deep Bay, namely Lau Fau Shan, Sha Kong Tsuen, Sheung Pak Nai, Pak Lai and Ha Pak Nai, distributed from 4,200 m to 14,100 m away from the reference point in inner Deep Bay (Table 3.2). In addition, five mangroves stands located on the northern side of Lantau, namely San Tau, Tung Chung, Tai Ho Wan, Yam O and Ma Wan; three stands on the western side of Lantau, namely Sham Wat, Tai O and Yi O and another three stands on the southern side, Shui Hau, Chi Ma Wan and Pui O were measured.

All these mangrove stands in Lantau area were 34,800 m to 72,500 m away from the reference point.

3.3.1.2 Zonings in floating prediction

The surface tidal flow direction in certain point of the Atlas changed during both ebbing and flowing tides because of the land barrier and the flushing of Pearl River Delta (Figs. 3.9 & 3.10). According to the tidal flow direction and the floating rate, seven zones were defined (Fig. 3.11), they were (1) inner Deep Bay to outer Deep Bay where the tide flows from northeast to southwest during ebbing tide; (2) Pearl River to Chek Lap Kok where the tide flows from northwest to southeast during ebbing tide; (3) Chek Lap Kok to Ma Wan where the tide flows from west to east during ebbing tide; (4) Chek Lap Kok to western Lantau where the tide flows from northeast to southwest during ebbing tide; and (5) Ma Wan to Chi Ma Wan where the tide flows from northeast to southwest during ebbing tide; (6) western Lantau to southern Lantau where the tide flows from west to east during ebbing tide, and (7) northern Lamma Island to southern Hong Kong Island where the tide flows from northwest to southeast during ebbing tide. The coordinates of the selected points and the defined angles in all zones were summarized in Table 3.3.

Table 3.3 The reference points and defined angles in calculating the speed and direction of tides (location of each zone refers to Fig. 3.11)

Zone	Coordinates	Description	Away from the mangrove stands (-ve)	Towards the mangrove stands (+ve)
1	22°27'41.52"N 113°55'50.70"E 22°31'8.4"N 113°58'29.22"E	Between inner Deep Bay and outer Deep Bay	311° to 359° & 0° to 129°	130° to 310°
2	22°23'25.86"N 113°53'43.02"E	Between Pearl River and Chek Lap Kok	241° to 359° & 0° to 59°	60° to 240°
3	22°21'3.72"N 113°58"34.32"E	Between Chek Lap Kok and Ma Wan	181° to 359°	0° and 180°
4	22°17'38"N 113°51'19.62"E	Between Chek Lap Kok and western Lantau	311° to 359° & 0° to 129°	130° to 310°
5	22°18'1.92"N 114°4"3.66"E	Between Ma Wan and Chi Ma Wan	321° to 359° & 0° to 139°	140° to 320°
6	22°11'56.46"N 113°65"56.1"E	Between western Lantau to southern Lantau	181° to 359°	0° and 180°
7	22°12'35.4"N 114°10"17.52"E	Between northern Lamma Island to southern Hong Kong Island	241° to 359° & 0° to 59°	60° to 240°

3.3.1.3 Time required for *Sonneratia* to reach different mangrove stands

Two points were selected from the Deep Bay area to compare the time required for travelling to the mangroves in outer Deep Bay and Lantau Area. Point A lied on the center line of the zone which had a faster speed than Point B which lied close to the coastline. For the seeds dropped and floated on the first day of January to April and September to December, a net ebbing tide was calculated since the first day. This indicates that there was a high tendency for the seeds to escape from Deep Bay area and flow to the southern side of Hong Kong. If the seed floated along the coastline (speed and direction of point B), it could reach the mangrove stands in outer Deep Bay within 1 to 8 days and flowed out of Deep Bay area after 5 to 10 days (Tables 3.4 & 3.6). If the seed float took the faster route (speed and direction of point A), they could reach the mangrove stands in outer Deep Bay from 1 to 4 days and floated out of Deep Bay area from 2 to 5 days (Tables 3.4 & 3.6).

For the seeds released on the first day of May to August, calculations showed that there was no net ebbing tide in the first month. In the contrary, there was a flowing tide, all the seeds remained in Deep Bay area for at least a month, indicating that the seeds had higher chance to strand within inner Deep Bay or reached various stands in the outer Deep Bay (Table 3.5). There was an unusual observation in May and August, the seeds released on first day of May and August could reach some of the mangrove stands in the outer Deep Bay. For May, seeds could reach only four mangrove stands (Lau Fau Shan, Sha Kong Tsuen, Sheung Pak Nai and Pak Nai) while seeds could only reach one mangrove stand (Lau Fau Shan) in August. This is due to the small ebbing tide that carried

the seed to some stands in the outer Deep Bay but the ebbing tide was not long or strong enough to carry them out of the Deep Bay area. For the seeds released on the first day of June and July, there was no ebbing tide to carry them out of the inner Deep Bay and out of the Deep Bay area. In fact, there was a net flowing tide carrying the seed towards the mangrove stands in the inner Deep Bay. The cumulative distances in these month exceeded -50,000 m, and the test was then terminated.

For January to April and September to December, once the seeds left the Deep Bay area, they could quickly carry to the Lantau area by tides. The seeds could reach the western Lantau from 3 to 6 days after they released to the water column, which they took 4 to 16 days and 5 to 8 days to reach the mangrove stands in the northern and southern Lantau, respectively (Tables 3.7 & 3.8).

These findings revealed that the spread of *Sonneratia* would depend on when the fruits ripened and released the seeds as well as the tidal flow. Generally, fruits developed from January to April and from September to December had a greater chance to disperse to mangrove stands out of the Deep Bay area.

Table 3.4 The predicted time required for the seed to travel to different mangrove stands in outer Deep Bay and out of Deep Bay area if seeds were dropped from January to April (Point A: 22°27'41.52"N 113°55'50.70"E; Point B: 22°31'8.4"N 113°58'29.22"E)

Destinations	**When to reach the site**							
	Seed released from 1st Jan		**Seed released from 1st Feb.**		**Seed released from 1st Mar**		**Seed released from 1st April**	
	Point A	**Point B**	**Point A**	**Point B**	**Point A**	**Point B**	**Point A**	**Point B**
Outer Deep Bay								
Lau Fau Shan	1/1/06 (Day 1)	1/1/06 (Day 1)	1/2/06 (Day 1)	1/2/06 (Day 1)	1/3/06 (Day 1)	2/3/06 (Day 2)	1/4/06 (Day 1)	2/4/06 (Day 2)
Sha Kong Tsuen	1/1/06 (Day 1)	4/1/06 (Day 4)	1/2/06 (Day 1)	5/2/06 (Day 5)	1/3/06 (Day 1)	6/3/06 (Day 6)	1/4/06 (Day 1)	4/4/06 (Day 4)
Sheung Pak Nai	1/1/06 (Day 1)	4/1/06 (Day 4)	1/2/06 (Day 1)	5/2/06 (Day 5)	1/3/06 (Day 1)	6/3/06 (Day 6)	1/4/06 (Day 1)	4/4/06 (Day 4)
Pak Nai	1/1/06 (Day 1)	6/1/06 (Day 6)	1/2/06 (Day 1)	6/2/06 (Day 6)	1/3/06 (Day 1)	7/3/06 (Day 7)	2/4/06 (Day 2)	5/4/06 (Day 5)
Ha Pak Nai	1/1/06 (Day 1)	7/1/06 (Day 7)	1/2/06 (Day 1)	7/2/06 (Day 7)	1/3/06 (Day 1)	8/3/06 (Day 8)	2/4/06 (Day 2)	6/4/06 (Day 6)
Out of Deep Bay area	2/1/06 (Day 2)	9/1/06 (Day 9)	3/2/06 (Day 3)	9/2/06 (Day 9)	5/3/06 (Day 5)	10/3/06 (Day 10)	4/4/06 (Day 4)	7/4/06 (Day 7)

Table 3.5 The predicted time required for the seed to travel to different mangrove stands in outer Deep Bay and out of Deep Bay area if seeds were dropped from May to August (Point A: 22°27'41.52"N 113°55'50.70"E; Point B: 22°31'8.4"N 113°58'29.22"E; ---- seeds could not reach the mangrove stand)

Destinations	**When to reach the site**							
	Seed released from 1st May		**Seed released from 1st Jun**		**Seed released from 1st Jul**		**Seed released from 1st Aug**	
	Point A	**Point B**	**Point A**	**Point B**	**Point A**	**Point B**	**Point A**	**Point B**
Outer Deep Bay								
Lau Fau Shan	1/5/06 (Day 1)	----	----	----	----	----	3/8/06 (Day 3)	----
Sha Kong Tsuen	1/5/06 (Day 1)	----	----	----	----	----	----	----
Sheung Pak Nai	1/5/06 (Day 1)	----	----	----	----	----	----	----
Pak Nai	1/5/06 (Day 1)	----	----	----	----	----	----	----
Ha Pak Nai	----	----	----	----	----	----	----	----
Out of Deep Bay area	----	----	----	----	----	----	----	----

Table 3.6 The predicted time required for the seed to travel to different mangrove stands in outer Deep Bay and out of Deep Bay area if seeds were dropped from September to December (Point A: 22°27'41.52"N 113°55'50.70"E; Point B: 22°31'8.4"N 113°58'29.22"E)

Destinations	**When to reach the site**							
	Seed released from 1st Sept		**Seed released from 1st Oct**		**Seed released from 1st Nov**		**Seed released from 1st Dec**	
	Point A	**Point B**	**Point A**	**Point B**	**Point A**	**Point B**	**Point A**	**Point B**
Outer Deep Bay								
Lau Fau Shan	1/9/06 (Day 1)	1/9/06 (Day 1)	1/10/06 (Day 1)	1/10/06 (Day 1)	1/11/06 (Day 1)	2/11/06 (Day 2)	1/12/06 (Day 1)	3/12/06 (Day 3)
Sha Kong Tsuen	1/9/06 (Day 1)	2/9/06 (Day 2)	1/10/06 (Day 1)	3/10/06 (Day 3)	1/11/06 (Day 1)	4/11/06 (Day 4)	2/12/06 (Day 2)	5/12/06 (Day 5)
Sheung Pak Nai	1/9/06 (Day 1)	3/9/06 (Day 3)	1/10/06 (Day 1)	3/10/06 (Day 3)	1/11/06 (Day 1)	5/11/06 (Day 5)	3/12/06 (Day 3)	5/12/06 (Day 5)
Pak Nai	2/9/06 (Day 2)	3/9/06 (Day 3)	2/10/06 (Day 2)	3/10/06 (Day 3)	2/11/06 (Day 2)	6/11/06 (Day 6)	3/12/06 (Day 3)	6/12/06 (Day 6)
Ha Pak Nai	2/9/06 (Day 2)	4/9/06 (Day 4)	2/10/06 (Day 2)	4/10/06 (Day 4)	2/11/06 (Day 2)	7/11/06 (Day 7)	4/12/06 (Day 4)	7/12/06 (Day 7)
Out of Deep Bay area	3/9/06 (Day 3)	5/9/06 (Day 5)	2/10/06 (Day 2)	6/10/06 (Day 6)	3/11/06 (Day 3)	9/11/06 (Day 9)	5/12/06 (Day 5)	9/12/06 (Day 9)

Table 3.7 The predicted time required for the seed to travel to different mangrove stands in Lantau area if seeds were dropped from January to April

Destinations	When to reach the site			
	Seed released from 1st Jan	**Seed released from 1st Feb.**	**Seed released from 1st Mar.**	**Seed released from 1st Apr.**
Northern Lantau				
San Tau	5/1/06 (Day 5)	5/2/06 (Day 5)	7/3/06 (Day 7)	11/4/06 (Day 11)
Tung Chung	5/1/06 (Day 5)	5/2/06 (Day 5)	7/3/06 (Day 7)	11/4/06 (Day 11)
Tai Ho Wan	5/1/06 (Day 5)	5/2/06 (Day 5)	7/3/06 (Day 7)	11/4/06 (Day 11)
Yam O	5/1/06 (Day 5)	5/2/06 (Day 5)	7/3/06 (Day 7)	11/4/06 (Day 11)
Ma Wan	6/1/06 (Day 6)	5/2/06 (Day 5)	16/3/06 (Day 16)	11/4/06 (Day 11)
Western Lantau				
Sham Wat	4/1/06 (Day 4)	4/2/06 (Day 4)	6/3/06 (Day 6)	5/4/06 (Day 5)
Tai O	5/1/06 (Day 5)	4/2/06 (Day 4)	6/3/06 (Day 6)	5/4/06 (Day 5)
Yi O	5/1/06 (Day 5)	4/2/06 (Day 4)	6/3/06 (Day 6)	5/4/06 (Day 5)
Southern Lantau				
Shui Hau	5/1/06 (Day 5)	5/2/06 (Day 5)	7/3/06 (Day 7)	6/4/06 (Day 5)
Chi Ma Wan	16/1/06 (Day 6)	1/4/06 (Day 6)	31/3/06 (Day 8)	16/4/06 (Day 5)
Pui O	16/1/06 (Day 6)	1/4/06 (Day 6)	31/3/06 (Day 8)	16/4/06 (Day 5)

Table 3.8 The predicted time required for the seed to travel to different mangrove stands in Lantau area if seeds were dropped from September to December

Destinations	When to reach the site			
	Seed released from 1st Sep	**Seed released from 1st Oct**	**Seed released from 1st Nov**	**Seed released from 1st Dec**
Northern Lantau				
San Tau	4/9/06 (Day 4)	4/10/06 (Day 4)	4/11/06 (Day 4)	6/12/06 (Day 6)
Tung Chung	4/9/06 (Day 4)	4/10/06 (Day 4)	4/11/06 (Day 4)	6/12/06 (Day 6)
Tai Ho Wan	4/9/06 (Day 4)	4/10/06 (Day 4)	4/11/06 (Day 4)	6/12/06 (Day 6)
Yam O	4/9/06 (Day 4)	4/10/06 (Day 4)	4/11/06 (Day 4)	7/12/06 (Day 7)
Ma Wan	5/9/06 (Day 5)	4/10/06 (Day 5)	4/11/06 (Day 4)	7/12/06 (Day 7)
Western Lantau				
Sham Wat	3/9/06 (Day 3)	3/10/06 (Day 3)	4/11/06 (Day 4)	5/12/06 (Day 5)
Tai O	4/9/06 (Day 4)	3/10/06 (Day 3)	5/11/06 (Day 5)	5/12/06 (Day 5)
Yi O	4/9/06 (Day 4)	3/10/06 (Day 3)	5/11/06 (Day 5)	5/12/06 (Day 5)
Southern Lantau				
Shui Hau	5/9/06 (Day 5)	5/10/06 (Day 5)	6/11/06 (Day 6)	7/12/06 (Day 7)
Chi Ma Wan	8/9/06 (Day 6)	8/10/06 (Day 7)	9/11/06 (Day 7)	16/12/06 (Day 8)
Pui O	8/9/06 (Day 6)	8/10/06 (Day 7)	9/11/06 (Day 8)	16/12/06 (Day 8)

3.3.2 Viability of *Sonneratia* seedlings to salinity change

3.3.2.1 Time to change the salinity

According to the Digital Tidal Stream Atlas in the last section, seedlings had a higher chance to leave the Deep Bay area and moved to the Lantau area from January to April and September to December. While seedlings released from May to August had a higher tendency to stay within the Deep Bay area. According to the results obtained in Section 3.3.1 and the hydrographical data from EPD (Year 2000 to 2004) (EPD, 2007), a graph showing how the seedlings moved through the salinity gradient was drawn (Fig. 3.14). If the seeds were released to the water column in inner Deep Bay in Day 1, in most of the cases, they quickly moved through the salinity gradient within 8 days. To survive in the dispersal process, the seedlings should have the ability to adapt the changes in salinity when moved from one zone to another for their establishment in other areas out of their parent plants. An experiment was decided to test the viability of seedlings with treatment of moving up the salinity gradient at Day 7.

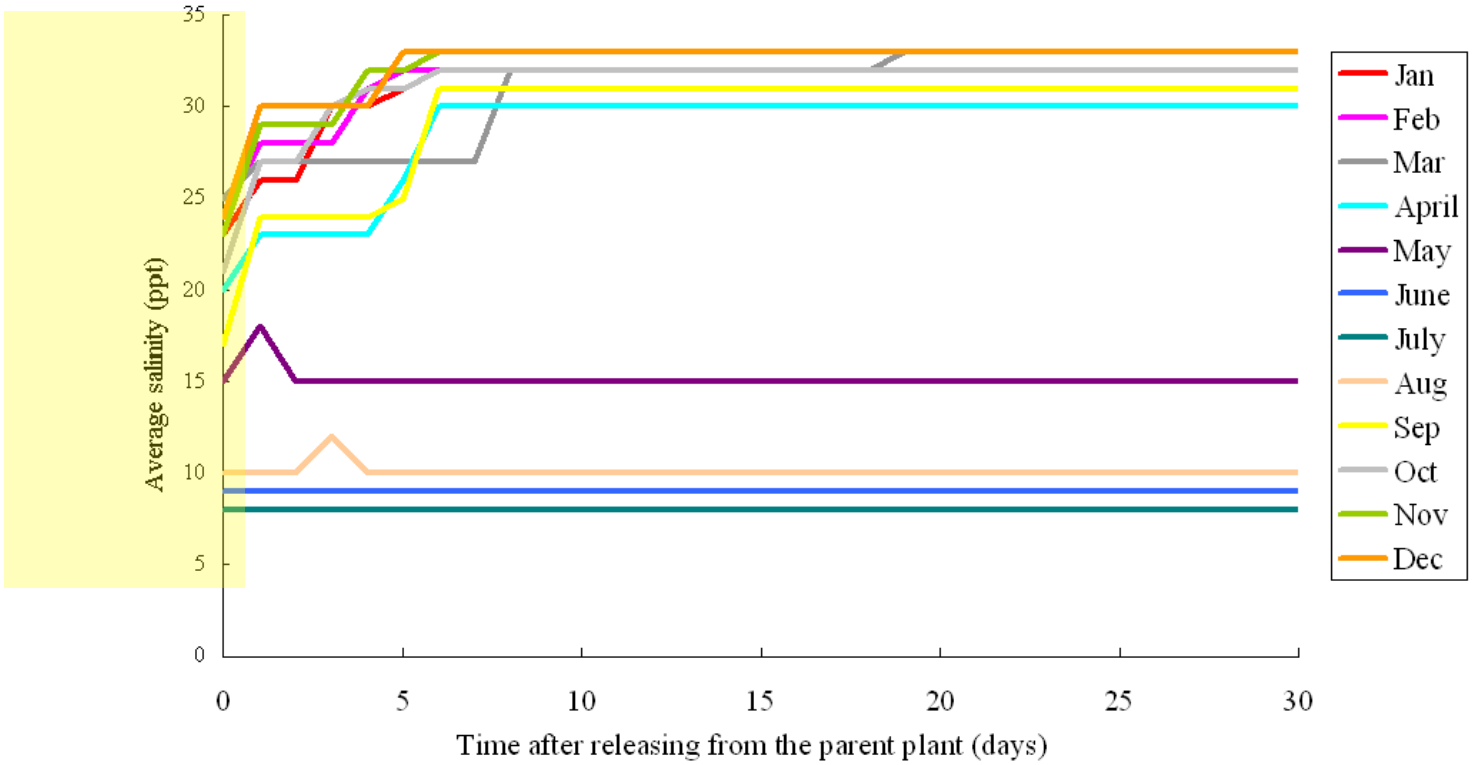


Fig. 3.14 The salinity change when the seedlings carried by tides (yellow box indicates the period when most seeds carried from one zone to another and suffered from salinity change, average salinity is the average salinities of ten water control zones from 2002 to 2004 (EPD, 2007))

3.3.2.2 Viability of *Sonneratia apetala* seedlings to salinity change

Sonneratia apetala seedlings had different extent of unviable under different salinities, with the highest percentages of 100% and 92.22% in 35 ppt and 25 ppt, respectively (Table 3.9 and Fig. 3.15). In 35 ppt, unviable percentages reached 75% within 53 days, the shortest among the four salinity gradients. Most of the seedlings remained viable in 0 ppt throughout the experimental period. Statistical analysis showed that the unviable number was significantly affected by salinity after controlling the effect of time (Table 3.10). At the end of the experiment, Day 90, salinity also significantly affected the number of unviable seedlings ($F(3,8)=525.19$, $p<0.05$). The unviable numbers of seedlings in different salinities were significantly different from each other (Fig. 3.16).

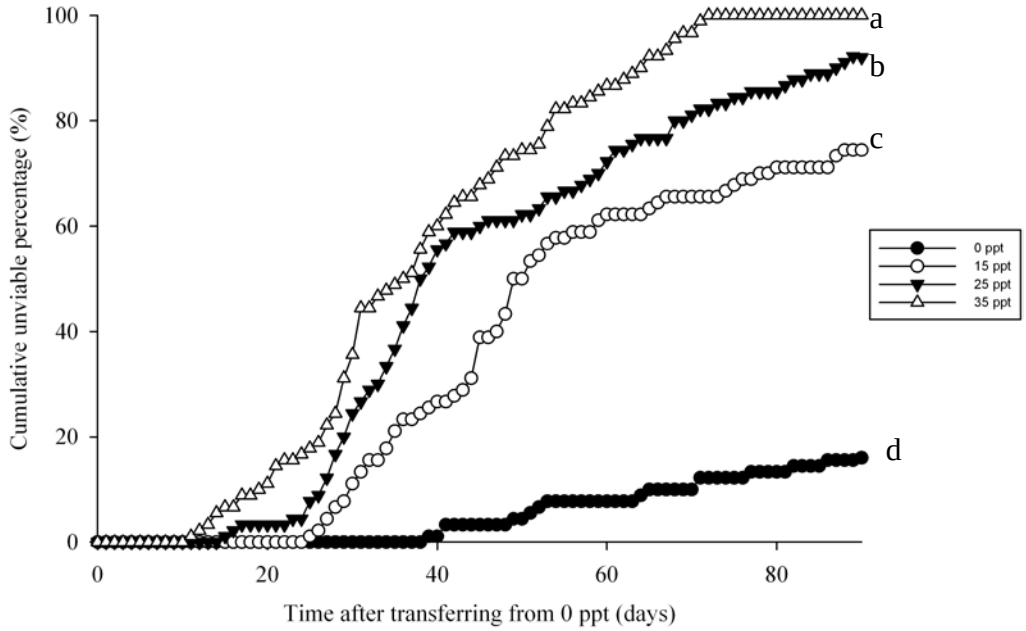
Table 3.9 Effect of salinity change on unviable percentages of *Sonneratia apetala* seedlings (NA: Not applicable)

Salinity	Cumulative Unviable Percentages			Highest Unviable Percentage
	25%	50%	75%	
0 ppt	NA	NA	NA	15.56%
15 ppt	40 days	50 days	NA	74.44%
25 ppt	32 days	39 days	64 days	92.22%
35 ppt	30 days	37 days	53 days	100%

Table 3.10 Summary of ANCOVAs for the unviable number of *Sonneratia apetala* seedlings in different salinities. (The variate is the salinity and the covariate is number of days after transferring from 0 ppt, * significantly difference at $p<0.05$ level)

Parameter	Unviable	
	F	p
Salinity	58.98	0.00*
Day	4847.03	0.00*
Salinity x Day	71.72	0.00*

Sonneratia apetala



Sonneratia caseolaris

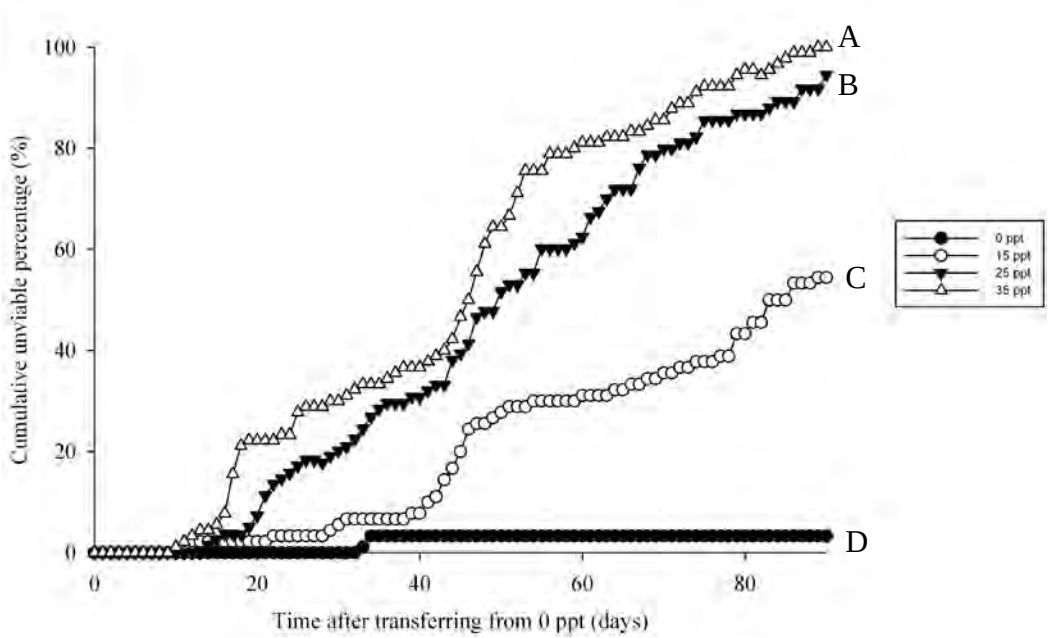


Fig. 3.15 Effect of salinity change on the unviable percentages of *Sonneratia apetala* and *S. caseolaris* seedlings after transferring from 0 ppt (different letters indicate significantly different at $p < 0.05$ according to ANCOVA test)

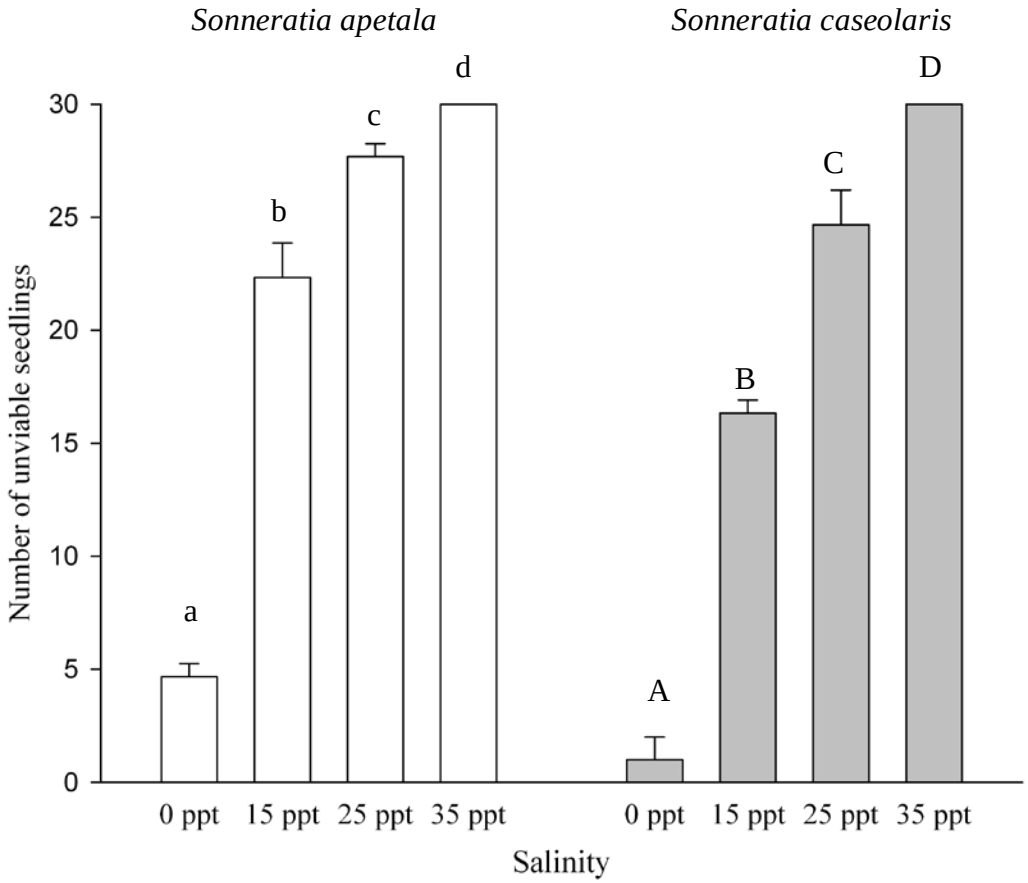


Fig. 3.16 Effect of salinity change on numbers of unviable *Sonneratia apetala* and *S. caseolaris* seedlings at Day 90 (The number under the bar are 0-35 ppt. Mean and standard deviation of the triplicate are shown. Mean of the same species with different letters are significantly difference at $p < 0.05$ level according to one-way ANOVA test)

3.3.2.3 Viability of *Sonneratia caseolaris* seedlings to salinity change

Sonneratia caseolaris seedlings had different extent of unviable under different salinities, with the highest percentages 100% and 94.5% in 35 ppt and 25 ppt, respectively (Table 3.11 and Fig. 3.15). In 35 ppt, unviable percentages reached 75% within 53 days, the shortest among the four salinity gradients. Most of the seeds remained viable in 0 ppt throughout the experimental period. Statistical analysis showed that the unviable number was significantly affected by salinity change after controlling the effect of time (Table 3.12). At the end of the experiment, Day 90, salinity change also significantly affected the number of unviable seedlings ($F(3,8)=523.88$, $p<0.05$). The unviable numbers of seedlings in different salinities were significantly different from each other (Fig. 3.16)

Table 3.11 Effect of salinity change on unviable percentages of *Sonneratia caseolaris* seedlings (NA: Not applicable)

Salinity	Cumulative Unviable Percentages			Highest Unviable Percentage
	25%	50%	75%	
0 ppt	NA	NA	NA	3.33%
15 ppt	47 days	83 days	NA	54.44%
25 ppt	33 days	50 days	67 days	94.5%
35 ppt	25 days	46 days	53 days	100%

Table 3.12 Summary of ANCOVAs for the unviable numbers of *Sonneratia caseolaris* seedlings in different salinities. (The variate is the salinity and the covariate is number of days after transferring from 0 ppt, *= significantly difference at $p<0.05$)

Parameter	Unviable	
	F	p
Salinity	170.61	0.00*
Day	4341.79	0.00*
Salinity x Day	242.74	0.00*

3.4 Discussion

There were many literatures illustrated how environmental conditions affected the early establishment of mangroves but ignoring the effects of tidal flooding. This is the first attempt to add tidal flow and the corresponding salinity change as a consideration on the survival rates of *S. apetala* and *S. caseolaris.*

In chapter two, it shows that over 99% *Sonneratia* distributed in the Deep Bay area, western part of Hong Kong, where the salinity was low and thus favorable to the growth of *Sonneratia.* Seeds of *Sonneratia apetala* and *S. caseolaris* seeds are exclusively dispersed by sea water due to their small-sized (0.1-0.2 cm) and their light weight. To predict the dispersal ability of *Sonneratia* to different areas in Hong Kong, we had to consider the environmental constraints while the seeds carried by current. One of the remarkable factor is the salinity change from west to east of Hong Kong due to the influx of freshwater from Pearl River Delta.

The Hong Kong Digital Tidal Stream Atlas 2006 was adopted to predict the time required for dispersing *Sonneratia* from inner Deep Bay Area to other mangrove stands. Although there were some assumptions; (1) the mathematical calculation based on tidal constituents and algorithm; (2) the seven zones defined by the tidal flow direction and speed of tides, and (3) the same tidal flow direction and speed within each zone, which may contribute to the errors in prediction. This tidal flow prediction provides the first insight on how tidal flow affected the dispersal of mangrove seeds in Hong Kong.

The computer model showed that the seeds developed from January to April and from September to December could disperse to mangrove stands out of the Deep Bay. It predicted the seeds would spend 2 to 10 days in Deep Bay area where the salinity was relatively low and provided sufficient time for them to bud and unfurl and then leave the Deep Bay area. Due to the influx of Pearl River and the sea water from the Pacific Ocean, *Sonneratia* seedlings would encounter a significant salinity change once they leave the Deep Bay area.

Most mangrove seedlings can tolerate a wide range of salinities when they are carrying by tide or sea current, the optimal range of physiological function and growth is approximately from 3 ppt to 27 ppt (Ball and Pidsley, 1995). Above or below this optimal range, growth was inhibited or reduced. In this study, it showed that both *S. apetala* and *S. caseolaris* would remain viable for more than 10 days notwithstanding the change of salinity (Figs. 3.15). This could explain why there were some *Sonneratia*. Seedlings could leave the Deep Bay area and being carried to the mangrove stands in Lantau area. If the seedlings could not strand on suitable ground in Lantau area, it will carry to the open ocean where salinity remains 30-35 ppt over the year, their chance of survival are then relatively low. The experiment showed that half of the *S. apetala* seedlings were unviable after 37 days while half of the *S. caseolaris* seedlings were unviable after 46 days. In this circumstance, the salinity change was a limiting factor to control the dispersal of *Sonneratia* from Deep Bay to Lantau areas.

By combining peak fruiting seasons of the *Sonneratia* species and days required to reach the mangrove stands in outer Deep Bay and Lantau areas (Table 3.13),

Table 3.13 Table showing the peak fruiting seasons of *Sonneratia apetala* and *S. caseolaris* and the time required for their seeds to reach different mangrove stands (NP: Not possible to reach)

Peak fruiting season of	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	***Dec***
S. apetala				←	—	→			←	—	→	
S. caseolaris	←	—	→			←	—	—	—	—	—	→
Time required to reach mangrove stands in (number of Days)												
Outer Deep Bay	1-7	1-7	1-8	1-6	1	NP	NP	3	1-4	1-4	1-7	1-7
Out of Deep Bay	2-9	3-9	5-10	4-7	NP	NP	NP	NP	3-5	2-6	3-9	5-9
Western Lantau	4-5	4	6	5	NP	NP	NP	NP	3-4	3	4-5	5
Northern Lantau	5-6	5	7-16	11	NP	NP	NP	NP	4-5	4-5	4	6-7
Southern Lantau	5-6	5-6	7-8	5	NP	NP	NP	NP	5-6	5-7	6-8	7-8

it showed that *S. apetala* seeds released in April and from September to November, and *S. caseolaris* fruits released from January to Mar and from September to December could leave Deep Bay area and colonize the mangrove stands in southern part of Hong Kong.

3.5 Conclusions

By using the Digital Tidal Stream Atlas, an analysis was conducted to estimate the spread and the dispersal rate of *Sonneratia* seeds and to predict the potential affected mangrove stands. Results showed that the seeds released from January to April and from September to December had a high tendency to escape from Deep Bay and flow to the southern side of Hong Kong. For the seeds released from May to August, they would remain in Deep Bay for at least one month as there was no net ebbing tide in the first month. This indicates the seeds would have a higher chance to strand within inner Deep Bay or just reached the mangrove stands in outer Deep Bay. These findings revealed that the spread of *Sonneratia* would depend on when the fruits ripened and the seeds were released, as well as the tidal flow. The greenhouse germination experiment further proved that half of the seeds remained viable for more than a month notwithstanding the salinity change. The result explained why *Sonneratia* spread to the southern part of Hong Kong. With considering their peak fruiting seasons, manager should pay attention to the *S. apetala* fruits released in April and from September to November, and *S. caseolaris* fruits released from January to Mar and from September to December that can leave Deep Bay area and further colonize the mangrove stands in southern part of Hong Kong.

CHAPTER 4

IMPACT ASSESSMENT: ESTABLISHMENT OF *SONNERATIA*

4.1 Introduction

If the seedling remains viable in the dispersal stage (Chapter 3), establishment of a seedling is another critical stage in the life cycle for all mangroves plants. The unstable and variable substrates as well as the tidal flushing would hinder their establishment (McKee, 1995). The habitat conditions, the biotic and physio-chemical factors would affect the distribution and abundance of a plant (Delgado *et al.*, 2001).

Studies of the germination conditions can demonstrate the factors that may influence the abundance and distribution of a species (Ball & Pidsley, 1995; McGuinness, 1997), and hence assess and predict the potential impact in the future. Rabinowitz (1978b) proposed that all of the mangrove species had its unique distribution zone within a mangrove stand as each species had a narrow range of tolerance to environmental factors, and these factors could exclude the intruders or the invaded species. Rabinowitz (1978b) also demonstrated that seedlings did not always grow better in a habitat where the conspecific adults were abundant. The environmental conditions that could affect the germination and establishment of mangroves, such as *Sonneratia* species, include salinity, substrate type, shade tolerance, temperature, light intensity, submerging tolerance and cold tolerance would also determine their invasive potential.

4.1.1 Salinity

Salinity is one of the outstanding environmental features for mangrove plants. Previous studies showed that dispersal, germination, establishment, growth and propageules sizes were significantly affected by salinity (Allen *et al.*, 2003; Ball and Pidsley, 1995; Ball, 1998; Smith & Snedaker, 1995). Salinity refers to the number of grams of dissolved salts (mostly sodium chloride) in 1000 g of sea water, measured by the concentration of chloride (Tomlinson, 1994). Values usually express in part per thousand (ppt) or with the notation 0/00. Seawater does not have the same salinity throughout the world, freshwater runoff from the continent can dilute the water. The salinity in the open ocean can be ranged from 33 ppt to 38 ppt (Morton & Morton, 1983) while the salinity of freshwater is 0 ppt. Generally, high salt concentration can inhibit the growth of most plants as it can increase the water potential of the substrate to levels beyond which the plant can absorb water through the roots and salt are toxic to the plants (Lily, 2001; Tomlinson, 1994). Plants grown on saline substrate accumulate salts (Na^+ and Cl^- ions) during the process of water uptake and the salts accumulated on the transpiring surfaces of plants can inhibit their growth (Medina *et al.*, 1990). Salinity can affect the growth of roots and leaves, leaf area, tree height, internode length, primary productivity and propagules size (Medina *et al.*, 1990; Smith & Snedaker, 1995).

Mangrove is a member of the halophytes and develops tolerance to salinity by maintaining high cellular water potential or excluding salts (Tomlinson, 1994), thus mangrove plants can grow in the estuaries. Salinity tolerance varies from species to species. Generally, greater the salt tolerance of a mangrove species,

the slower in its growth rate under optimal salinity conditions (Duke *et al.*, 1998). Seeds in the establishment phase need to cope with a wide range of salinity as they are brought to different places by sea current. Li *et al.* (1997) and Zan *et al.* (2003) showed that *Sonneratia* favored low salinity with the highest germination percentage under 2.5 ppt and the germination percentage of *Sonneratia* decreased once exceeded 10 ppt.

4.1.2 Substrate type

Ye *et al*. (2005) suggested that the most significant factor for the establishment of mangrove plants in Hong Kong was the substrate type. Substrate type or soil texture refers to the relative coarseness or fineness of soil mineral particles, and expressed in terms of proportions of sand, silt and clay (Lily, 2001). The mangrove substrates in Hong Kong were reported to vary from very sandy (>95% sand) to clayey (>30% clay) (Tam & Wong, 1997). With the influx of freshwater from the Pearl River and Sham Chun River, fine sediments are brought from the inland and settle onto the mudflat. This explains why the substrate type in western side is more clayey than the eastern side of Hong Kong. The clayey substrate is made up of fine-textured particles and has a larger surface area to volume ratio. In turn, fine clay can retain more water and minerals with less aeration than the coarse sand. Plants grown in different substrate type behave differently, for example, leaves of the *Kandelia obovata* seedlings grown in sandy substrate were significantly thicker than those in loamy-sandy and silty substrates (Ye *et al.*, 2005). According to the distribution data summarized in Chapter 2, the two *Sonneratia* species were mainly developed in the channels or stream outlets of Deep Bay area where the substrate was clayey. The experiment

aimed at testing whether *Sonneratia* could establish in both fine and coarse substrates.

4.1.3 Shade tolerance

The survival and growth of most plant species were reduced under canopy as low light intensity would impose a low level of photosynthesis that the seedlings could barely make a positive carbon gain (Turner, 2001). McGuinness (1997) reported that the growth of mangroves was related to the availability of light. McKee (1995) showed that mangroves had a greater investment in root biomass at low light levels. Allen *et al*. (2003) found that the growth of mangrove species *Xylocarpus granatum* decreased dramatically under 80% shade-cloth. Ye *et al.* (2005) also demonstrated that *K. obovata* was a shade intolerance species and seedlings under canopy shade died eventually. However, not every species is affected by light intensity. Smith (1987) found that the growth of *Bruguiera gymnorrhiza* was not significantly different between forest gap and under canopy, indicating this species is more shade tolerant. Similarly, Fraver *et al*. (1998) reported that there was no significant difference in the survival of *Protium panamense* and *Desmopsis panamensis* between gap and under canopy in Panamanian rain forest over the four-year monitoring period.

For *Sonneratia,* Liao *et al.* (1997a) and Zan *et al*. (2003) showed that germination of *S. caseolaris* seeds required light for germination, shortage of illumination could reduce germination percentages and seedling growth. In the field, *Sonneratia* individuals tended to grow in open gaps at the seaward edge of the mangrove stand with high light intensity but absent in closed canopy of

mature mangrove forest. These suggested that the *Sonneratia* species were shade intolerant.

4.1.4 Tidal level: submerging time

The mangrove plants show marked zonation from landward to seaward due to the sea level (Rabinowitz, 1978b; Tomlinson, 1994). Different tidal levels provide different submerging time and water depths to plants growing in coastal area and thus affect the germination rate. Ellison & Farnsworth (1997) showed that the change in water depth could affect physiology, growth, morphology and reproduction of *Rhizophora mangle*. Huang (2000) stated that low tidal level (prolonged submerging) could lead to the deficiency of nutrients, for example, nitrogen, phosphorus and potassium in some plants.

As discussed in Chapter 3, tide acts as a sorting factor for the dispersal of mangrove plants which contributes to their different geographical ranges. Tide also affects the duration of submerging in different tidal levels (Delgado *et al.*, 2001). Tide alters substrate properties, such as reducing oxygen diffusion rate or availability, and in turn affects the photosynthesis and respiration rates, the energy budget and hence inhibits plant growth (Cronk & Fennessy, 2001; Ernst, 1990; McKee, 1996; Wilkinson, 2000). Seedlings withstand the submergence or flooding by oxidizing the rhizosphere and developing anatomical and morphological adaptations so that roots could maintain aerobic metabolism and conserve oxygen for longer periods during submergence (Youssef & Saenger, 1996).

Most of the mangrove stands in Hong Kong do not show any obvious zonation as they only cover a narrow fringe or belt from land to sea, except in some large mangrove stands such as Mai Po (Young, 1993). The general zonation pattern in Hong Kong is *Avicennia marina* locate at the foreshore, follows by *K. obovata* and *Aegiceras corniculatum, B. gymnorrhiza* occupy the mid shore, while *Lumnitzera racemosa*, *Excoecaria agallocha* and *Heritiera littoralis* dominate the landward zone with short submerging time (Tam & Wong, 1997). Ye *et al.* (2003) found that *K. obovata* could grow under longer submerging time than *B. gymnorrhiza*, and the former species was distributed in a lower tidal level in the field. Liao *et al.* (2004) suggested that the reduced oxygen diffusion rate and availability had significant effect on germination of *S. caseolaris* seeds.

According to field observation summarized in Chapter 2, both *S. apetala* and *S. caseolaris* tended to develop in the low intertidal zone, the area with long submerging time. This study aimed at investigating whether *Sonneratia* could establish in mid and high tidal levels.

4.1.5 Cold tolerance

Most of the mangrove plants are distributed in the tropical latitudes, and some outliers in the subtropical latitudes such as Victoria and southern Japan are the consequence of warm ocean currents (Tomlinson, 1994). Duke *et al.* (1998) described that the distribution of mangroves in the world is chiefly determined by their tolerance to low temperature. Mangrove generally occurs in areas with mean air temperature higher than 20°C, even in the coldest months. Their limits are often marked by the incidence of ground frost, even temperature around 5°C

are inimical to the growth of most mangrove plants (Tomlinson, 1994). In China, mangrove plants are mainly distributed along the southeastern coast, mangrove in Fujian province (27°20'N) marked the northern limit (Yang & Lin, 1997). Unlike homoeothermic animals, plants cannot regulate the temperatures in cells and tissues to the optimum level for metabolism, growth and development. Cooling leads to a decrease in the metabolic processes, notably respiration, and disrupts the uptake activities. In some case, the "chilling injury" could kill the plant within few hours or days (Fitter & Hay, 2002). Tropical and subtropical plants are mostly sensitive to chilling (0-10°C) (Rajashekar, 2000; Taiz & Zeiger, 2006).

Hong Kong's climate is subtropical (Hong Kong Observatory, 2007; Morton & Morton, 1983). It has a monsoon climate with seasonal alternation of wind direction that is the warm, rain-bearing south-easterly wind in summer and the cool dry north-easterly wind in winter. The summer monsoon is dominant from early May to the late September, while the winter monsoon is from November to February. Therefore, Hong Kong's summer is hot and humid, interspersed with showers, thunderstorms and typhoons while winter is cool and dry, affected by cold fronts from northerly winds in January and February. The average annual temperature (average of 30 years from 1961 to 1990) is 22.8℃ (Dudgeon & Corlett, 2004). The lowest temperature recorded by the Hong Kong Observatory is 0°C, in fact, sub-zero temperatures and frost occur in the New Territories and higher ground from time to time in winter. Compare with Sundarbun of Bangladesh and Dongzhaigang in Hanian, the lowest and mean temperatures in January recorded in Hong Kong are lower (Table 4.1) (Chen, 1999). The occurrence of cold surges, sudden arrivals of cold fronts from inland that cause a

sudden drop in temperature, can severely damage the seedlings and possibility affect the germination of *Sonneratia* in Hong Kong.

Prior to the present study, field observations suggested that *S. caseolaris* appeared to have low tolerance to cold weather. The leaves of numerous *S. caseolaris* trees were found shedding in Tsim Bei Tsui and Sham Chun River in March 2005. It may be due to the cold night from 31st December, 2004 to 1st January, 2005 when the temperature dropped to 6.4 ℃ in the urban area. Such phenomenon was also seen in the December of 2006. Leaf buds reappeared around April and May in both years when weather became warmer. *S. apetala* showed better adaptation to cold weather as their leaves did not shed. This suggests that the *S. caseolaris* and *S. apetala* had different cold tolerance.

Table 4.1 Table showing the temperatures of different mangrove stands (*S.a.*= *Sonneratia apetala* and *S.c. = Sonneratia caseolaris*)

Site	Species	Climate	Latitudes	Mean annual temp. (°C)	Mean temp. in January (°C)	Lowest temp.(°C)
Sundarban, Bangladesh	*S. a.*	Monsoon tropical moist	22°30’	29.4	13.8	7.7
Dongzhaigang, Hainan Island, China	*S. c.*	Tropical monsoon marine	20°00’	23.5	17.1	2.8
Mai Po, Hong Kong, China	*S. c.* *S. a.*	Subtropical monsoon	22°29’	22.8	15.8	0

Apart from Hong Kong, Zan *et al.* (2003) also found that the seedlings of *S. caseolaris* with heights of 15-55 cm collected in Dongzhaigang, Hainan Island, China could not withstand the cold weather in Futian Mangrove Forest Nature

Reserve (FMFNR) from January and February in 1994. Similarly, around 20-87% leaves of *S. caseolaris* in Shantou shed during winter while only few leaves of *S. apetala* were affected in winter (Xiao, *et al.,* 2004). These observations in mainland China also indicated that *S. apetala* had high cold tolerance than *S. caseolaris.* Nevertheless, there was no record of these plants to be deciduous.

Although chilling was proved to be a challenge to the growth of *Sonneratia* individuals, Taiz & Zeiger (2006) proposed that continuous exposure to cool and non injurious temperatures could improve the chilling resistance step by step. Since the first introduction of *Sonneratia* to FMFNR in 1993, *Sonneratia* had established themselves in Deep Bay for 15 years. Researches focused on their cold tolerance was insufficient, there was no record for the frigid harm to the seeds. As *Sonneratia* were found fruiting even in the coldest month in Hong Kong, there is a need to know the viability of the overwintering seeds. This can help deciding the best month for the removal of *Sonneratia*.

4.1.6 Aims and objectives

Greenhouse experiments were conducted to investigate the germination requirements of *Sonneratia apetala* and *S. caseolaris*. The study aimed to (1) find out the effect of salinity on germination of two *Sonneratia* species; (2) compare *Sonneratia* developed in the fine substrate collected from Tsim Bei Tsui in Deep Bay area and coarse substrate collected from To Kwa Ping in Sai Kung area; (3) investigate the capability of *Sonneratia* to germinate under closed canopy; (4) determine the submerging tolerance of *Sonneratia*; and (5) compare

the cold tolerances of the two *Sonneratia* species. The results were then compared with the germination study conducted by Tam & Wong (2004) and evaluated whether the exotic *Sonneratia* shared the common niches with native mangroves.

4.2 Materials and methods

4.2.1 Collection of seeds

Seeds of two *Sonneratia* species were obtained from mature fruits collected from Tsim Bei Tsui (22°28'40"N 114°01'22"E) and Sheung Pak Nai (22°26'52"N 113°57'15"E) during the peak fruiting season, from July to October. The seeds were obtained following the method described in Section 2.2.3.2 in Chapter 2.

4.2.2 Collection of substrate

Two mangrove stands in Hong Kong were selected for collection of substrate, namely Tsim Bei Tsui (22°28'40"N 114°01'22"E) and To Kwa Ping (22°25'40"N 114°20'04"E) in Deep Bay and Sai Kung areas, respectively. Surface 10 cm substrate from the low tidal zone was collected in August 2005 and stored in room temperature prior to experimental use. To remove the salt which could affect the result of the salinity experiment, the substrate samples were rinsed with tap water thoroughly before the experiment started. Both physical and chemical characteristics of the substrates were determined as follow.

4.2.3 Substrate analysis

The physical and chemical properties of the substrate affecting germination were determined. These included pH, redox potential, particle size and texture, the amount of organic matter and nutrients {nitrogen (N), phosphorus (P) and potassium (K)}. The physical and chemical properties of Tsim Bei Tsui and To Kwa Ping were compared by student t-test at the level of $p<0.05$. About 100 g of substrate samples from each site were air-dried. Three replicates were done for each determination.

4.2.3.1 pH and redox potential

10 ml deionized water was added to 10 g of air-dried substrate, the solution was stirred vigorously until a thin paste was formed. The sample was allowed to stand for an hour and pH in the supernatant was measured using a calibrated pH meter (Orion 9103, Allometrics, Inc., USA).

4.2.3.2 Particle size and texture of substrate

Particle size distribution was determined by the standard pipette method (Sheldrick & Wang, 1993). The following procedure was adopted.

Fifty grams of air-dried substrate (Mo) were placed in a 300 ml medical flat bottle. 100 ml deionized water and 25 ml dispersing agent, sodium hexametaphosphate (10% w/v) were added into the flat bottle. The bottle was sealed with paraffin and shaken on a horizontal shaker for 24 hours. The entire

suspension from the medical flat bottle was sieved through a 63 μm sieve. The solution was collected in a beaker and then transferred into a 1 L measuring cylinder. The used beaker was rinsed with water and all remaining particles were poured into the cylinder. The cylinder was then made up to 1 L by deionized water. The substrate particles on the 63 μm sieve representing particles of size > 63 μm were transferred to a pre-weighted crucible (Msv) which was preheated at 105℃ oven overnight. The sample was dried in 105℃ oven overnight and oven-dried weight was measured (Ms). The cylinder was allowed to reach ambient temperature and temperature of suspension was recorded. The suspension in the measuring cylinder was mixed thoroughly by inversion. An aliquot of 20 ml of suspension at a depth about 15-20 cm representing particles of size <63 μm was pipetted immediately and transferred into a pre-weighted crucible. The used pipette was rinsed with water and all remaining was poured into the crucible. The sample was evaporated in 105°C oven and the oven-dried weight (Mz) was recorded. After standing for 4 hours, another aliquot of 20 ml suspension at 5 cm depth representing particles in the size of <2 μm was pipetted into a pre-weighted crucible. The sample was dried in 105℃ oven and the oven-dried weight (Mc) was recorded. An aliquot of 5 ml of sodium hexametaphosphate solution was evaporated in 105℃ oven to determine the dried weight of the residue (Mr). The particle size was then determined by the following equations. The texture was classified based on the standard substrate triangle (Sheldrick and Wang, 1993).

Sand (>63μm) =Ms-Msv/Mo x 100

Silt (2-63μm) =(Mz-Mc) x 50/ Mo x 100

Clay (<2μm) =[Mc-(Mr/50)]x50/Mo x 100

4.2.3.3 Total organic matter content

For each sample, 10 g of air-dried substrate was placed in a pre-weighted crucible and weighted. The wet air-dry weight (place in 25℃ for 48 hours), oven-dried weight (place in 105℃ oven for 24 hours) and furnace-dried weight (550℃ ignition for 8 hours) were measured. The total organic matter of oven dried weight (TOM) content was calculated according to this equation:

$$TOM = \frac{(\text{oven-dried weight} - \text{furnace-dried weight})}{\text{oven-dried weight}} \times 100\ \%$$

4.2.3.4 Total nitrogen and phosphorus

Each substrate sample was digested using Kjeldahl acid digestion method (Page *et al*., 1982). The total Kjeldahl nitrogen (TKN) in the digest was measured using FIA (Flow Injection Analyzer) colorimetry (Lachat QuickChem Method 8000, USA). The procedure was as follows:

0.5 g air-dried substrate was placed into a 50 ml digestion tube with 5 ml concentrated sulphuric acid and a copper Kjeldahl catalyst tablet (consisted of 1.5 g K_2SO_4 and 0.125 g $CuSO_4 \cdot 5H_2O$). Few anti-bumping granules were added to the tube. With the catalyst, the organic nitrogen in the sample was converted to ammonium ion. Potassium sulfate was added to raise the boiling temperature of the digestion in order to speed up the conversion. A small funnel with a small marble was placed onto the top of the tube to minimize loss of acid fumes. The tubes were heated in a Block Digestor (Lachat Part No. 1800-000, USA) at

160℃ to get rid of water vapor for an hour. The temperature was then raised to 390℃ for 3 hours, until the sample became clear. After cooling, the digested sample was filtered through Whatman No. 42 filter paper and diluted to 50 ml in a volumetric flask with double distilled and deionized (3D) water. The digests were stored in 4℃ before FIA measurement. About 0.06 ml of the digested sample was injected into the chemistry manifold where its pH was raised to 8.5 with a concentrated buffer. Ammonium ion was converted to ammonia by this in-line neutralization. The ammonia produced was heated with salicylate and hypochlorite to produce blue colour, and the color intensity was proportional to the ammonia concentration. Total nitrogen was obtained from adding nitrate and nitrite ion concentration with TKN and expressed in term of oven-dried weight.

Total phosphorus was also measured using the same Kjeldahl acid digest as described above and measured by FIA colorimetry (Lachat QuickChem Method 8000, USA).

4.2.3.5 Total inorganic phosphorus and inorganic nitrogen

For inorganic phosphorus, 2 g of air-dried sample was added in a 50 ml flat bottle, 20 ml of 0.5 M sodium bicarbonate $NaHCO_3$ was added. The bottle was allowed to shake for an hour. It was then filtered with Whatman No. 42 filter paper. The filtrate was placed in 4℃ refrigerator before measurement. The amount of inorganic phosphorus was measured by FIA colorimetry (Lachat QuickChem Method 8000, USA).

For inorganic nitrogen, the procedures were same as above except that 5 g of air-dried sample 50 ml 2M KCL was used.

4.2.3.6 Exchangeable K, Na, Ca and Mg

10 g of air-dried sample was weighted and poured into a 500 ml container. 250 ml of 0.5 M ammonium acetate NH_4OAc was added and the container was shaken for an hour on a rotary shaker. The solution was then filtered by Whatman No. 44 filter paper into a polyethene bottle and the first 20-30 ml was rejected. The filtrate was kept at 4℃ refrigerator before measurement. The concentrations of various cations in the filtrate were measured using the atomic absorption spectrophotometer (SHIMADZU.AA-6501S). A blank and a series of standard solutions were used to calibrate the equipment.

4.2.4 Experimental setup for seed germination

The experimental setup was the same as described in Section 2.2.3.2 but the seeds were grown in the greenhouse at an average temperature of 25 ± 5°C with natural sunlight instead of environmental chambers. Parameters as described by Tam & Wong (2004) were used to determine the germination time, these include the time required for budding and unfurling, cumulative budding and unfurling percentage. The germination was recorded every day until the numbers of seeds germinated and leaf unfurling became steady.

4.2.4.1 Salinity

The tanks were filled with artificial seawater at different salinity treatments, that is, 0 ppt, 5 ppt, 10 ppt, 15 ppt, 25 ppt and 35 ppt. The sea water with different salinities was prepared by dissolving different amounts of artificial sea salt (Instant Ocean, Aquarium Systems, Inc., Mentor. Ohio) in tap water. The salinity was monitored twice a week suing a hand refractometer (ATAGO, S-10, Japan). The water level was maintained daily by adding tap water to compensate the water lost from evaporation. Each treatment was triplicated. In total, 21 tanks and 630 seeds for each species were used in the experiment.

4.2.4.2 Substrate type

Seeds were sowed on two different types of substrates, collected from Tsim Bei Tsui in Deep Bay area (fine substrate type) and To Kwa Ping in Sai Kung area (coarse substrate type). Every treatment was triplicated and 30 seeds were used in each replicate. In total, six tank and 180 seeds were used in this experiment.

4.2.4.3 Shade tolerance

To find out the difference in light intensities between open gap and closed canopy, the light intensities in the open mudflat, open canopy and closed canopy of Mai Po Marshes Nature Reserve (MPMNR) were measured using a photometer LI-COR Lightmeter Quantum/ Radiometer/ Photometer L1-189 (LI-COR, Lincoln,. Nebraska, USA). Five replicates were taken for each canopy type. In this study, open area was regarded as full light intensity (0% shading),

open canopy was defined as the gap at the foreshore which is dominated by *Acanthus ilicifous* (average height of 1.5 m) while closed canopy was defined as the mature forest at the backshore dominated by *K. obovata* (average height of 8 m). Baseline data were obtained from MPMNR at noon on 21st September, 2005.

The shading percentage was calculated by

$$= \left(1 - \frac{\text{light intensity (canopy type: open / closed canopy)}}{\text{light intensity (open area)}}\right) \times 100\%$$

The shading percentage of each canopy type was then obtained (Table 4.15 in Section 4.3.6). To evaluate the shade tolerance of the two *Sonneratia* species, four treatments with different shading percentages, each in triplicate, were prepared. They were (1) 0% shading (i.e. no shading), (2) 56% shading, (2) 90% shading and (4) 100% shading (i.e. total darkness). Green nylon mesh was used as the shade-cloth to mimic the environment (shading effect) of open area, open canopy and closed canopy. The percentages of shading by the shade-cloth were measured using the same photometer. The tanks were placed underneath the shade-cloth. In total, nine tanks and 270 seeds for each species were used.

4.2.4.4 Tidal level: submerging time

Thirty seeds for each *Sonneratia* species were cultivated in perforate trays and placed inside a tank of 54.5 cm x 31.5 cm x 14 cm and filled with 15 cm depth of tap water (0 ppt) during the high tide period. During the drained period, the water was drained from the tank and the plants were exposed to air. Effect of the submerging time were examined under three different treatments: (1) High tidal level: 4 hours submerged and 20 hours drained per day, (2) Mid tidal level: 10

hours submerged and 14 hours drained per day, and (3) Low tidal level: 16 hours submerged and 8 hours drained per day. Three replicates were done for each treatment. In this experiment, nine tanks and 270 seeds for each species were used.

4.2.4.5 Cold tolerance

This part examined the effect of cold front on seeds that may cause frigid harm. To mimic the arrival of cold front at different duration, fresh seeds were placed in a refrigerator at 4℃ for 0, 24 hours (1 day) and 48 hours (2 days), and then germinated in the greenhouse using the same setup described above. In total, nine tanks and 270 seeds for each *Sonneratia* species were used.

4.2.5 Data treatment

The same method as described in Chapter 2.2.3.3. was used to analyze data in this chapter.

4.3 Results

4.3.1 Characteristics of substrate

The substrate analysis showed that the two sites had different substrate texture, that is, fine in Tsim Bei Tsui and coarse in To Kwa Ping (Table 4.2). All the nutrients, physical and chemical properties were significantly difference except the amount of nitrate NO_3^- - N.

Table 4.2 Texture, nutrient and other chemical properties of the substrates from two mangrove stands, Tsim Bei Tsui and To Kwa Ping. Mean and standard deviation of three replicates and the results of the t-test on the properties of substrates are shown.

Particle Size Distribution			
Properties	Tsim Bei Tsui	To Kwa Ping	Result of t-test
Sand (%)	42.84 ± 1.31	65.15 ± 1.39	$t(4)=20.23$, $p=0.00<0.05$
Silt (%)	15.69 ± 5.35	9.61 ± 1.87	$t(4)=1.86$, $p=0.14>0.05$
Clay (%)	25.16 ± 3.34	18.11 ± 0.13	$t(4)=3.65$, $p=0.02<0.05$
Substrate Texture	Fine	Coarse	NA
Substrate Type	Sandy clay loam	Loamy-sandy	NA
Organic Matter Concentration (% dwt)	4.95 ± 0.31	2.91 ± 0.11	$t(4)=10.70$, $p=0.00<0.05$
pH	5.66 ± 0.03	8.57 ± 0.18	$t(4)=27.62$, $p=0.00<0.05$
Conductivity (mV)	70.7 ± 2.17	95.5 ± 9.96	$t(4)=4.21$, $p=0.01<0.05$
TKN (μg g^{-1} dwt)	58.58 ± 5.81	21.35 ± 1.92	$t(4)=10.54$, $p=0.00<0.05$
NH_3 (μg g^{-1} dwt)	26.35 ± 8.74	5.25 ± 0.21	$t(4)=4.18$, $p=0.01<0.05$
NO_3^- - N (μg g^{-1})	20.42 ± 6.07	29.75 ± 2.95	$t(4)=2.40$, $p=0.08>0.05$
PO_4^{3-} - P (μg g^{-1})	18.15 ± 1.50	5.82 ± 0.80	$t(4)=12.56$, $p=0.00<0.05$
K^+ (μg g^{-1})	185.71 ± 9.79	229.57 ± 24.14	$t(4)=2.92$, $p=0.04<0.05$
Na^+ (μg g^{-1})	1470 ± 48	2466 ± 72	$t(4)=20.02$, $p=0.00<0.05$
Ca^{2+} (μg g^{-1})	1416 ± 124	388 ± 30	$t(4)=14.01$, $p=0.00<0.05$
Mg^{2+} (μg g^{-1})	937.00 ± 13.08	605.84 ± 21.38	$t(4)=22.86$, $p=0.00<0.05$

4.3.2 Effect of salinity on germination of *Sonneratia apetala*

Seeds of *S. apetala* were able to bud in all salinity gradients with the highest budding percentages 77% and 80% in 0 ppt and 5 ppt, respectively (Table 4.3 and Fig. 4.1). In 5 ppt, budding percentages reached 75% within 8 days, the shortest time among six salinity gradients. In 10 ppt and 15 ppt, around 50%

budding percentages were achieved in 9 and 8 days, respectively. The budding numbers in 0 and 5 ppt were significantly higher than those in 10 ppt, 25 ppt and 35 ppt (Fig. 4.1). At the end of the experiment, 40% of seeds were able to germinate in 25 ppt while only 3.33 % of the seeds were germinated in 35 ppt (Table 4.3). Statistical analysis showed that the budding number was significantly affected by salinity after controlling the effect of time (Table 4.4).

Another parameter used to evaluate the germination percentage of *S. apetala* was the cumulative percentage of the seeds with first pair of leaf unfurling. The budded seeds were able to unfurl their first pair of leaves after budding in salinity gradients from 0 to 25 ppt (Fig. 4.1). The germination percentage at Day 30 was the highest in 5 ppt (95.83%), followed by 10 ppt with the highest percentage of 88.89% (Table 4.5). However, less than 20% budded seeds had their leaf unfurled in 25 ppt. For 35 ppt, none of them had leaf unfurled. These results indicated that *S. apetala* was unable to germinate in high saline area. Statistical analysis showed that the unfurling number was significantly affected by salinity after controlling the effect of time (Table 4.4).

At the end of the experiment, Day 30, salinity also significantly affected the numbers of budded seeds ($F(5, 12)=15.64$, $p=0.000<0.05$) and unfurled seeds ($F(5, 12)=18.80$ $p=0.000<0.05$). Seeds at 0 ppt to 15 ppt had similar budding numbers at Day 30 (Fig. 4.2). At 35 ppt, the budding number showed a very distinct result, with extremely low number of budded seeds. The first four low salinities (0 ppt, 5 ppt, 10 ppt and 15 ppt) also had similar leaf unfurling numbers at Day 30, which were significantly higher than those in 25 ppt and 35 ppt (Fig. 4.2).

Table 4.3 Effect of salinity on budding percentages of *Sonneratia apetala* seeds (NA: Not applicable)

Salinity	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
0 ppt	5 days	6 days	11days	77%
5 ppt	5 days	5 days	8 days	80%
10 ppt	6 days	9 days	NA	60%
15 ppt	6 days	8 days	NA	70%
25 ppt	10 days	NA	NA	40%
35 ppt	NA	NA	NA	3.33%

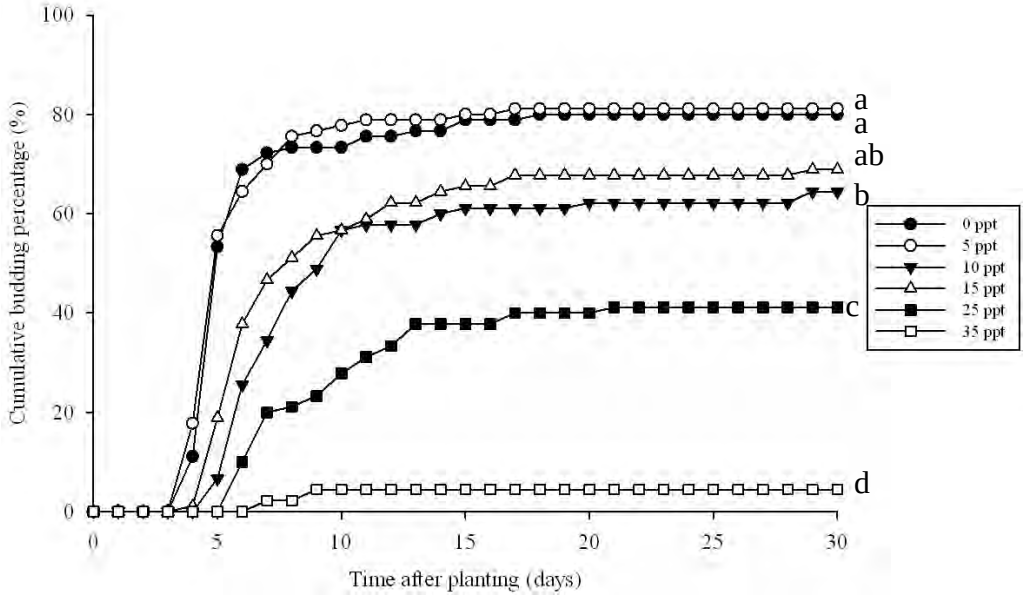
Table 4.4 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia apetala* seeds in different salinities. The variate is the salinity and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Salinity	112.26	0.000*	156.04	0.000*
Day	413.38	0.000*	486.76	0.000*
Salinity x Day	203.72	0.000*	16.48	0.000*

Table 4.5 Effect of salinity on unfurling percentages of *Sonneratia apetala* seeds (NA: Not applicable)

Salinity	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
0 ppt	7 days	9 days	23days	77%
5 ppt	8 days	9 days	14 days	95.83%
10 ppt	10 days	13 days	18 days	88.89%
15 ppt	10 days	13 days	18 days	90.48%
25 ppt	NA	NA	NA	16.67%
35 ppt	NA	NA	NA	0%

Budding



Unfurling

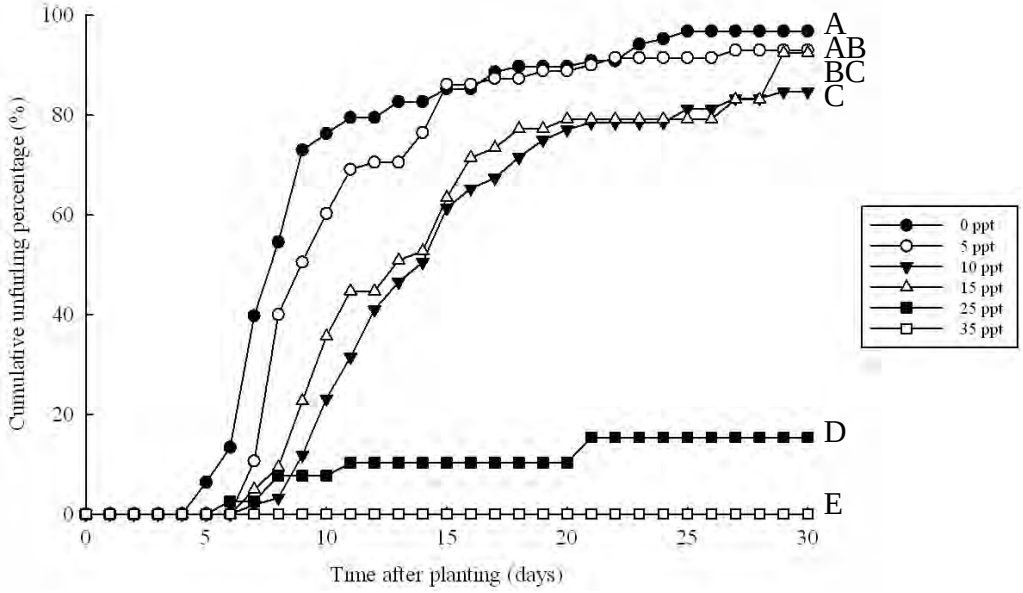


Fig. 4.1 Effect of salinity on budding and unfurling percentages of *Sonneratia apetala* seeds (different letters indicate significant difference at $p < 0.05$ level according to ANCOVA test)

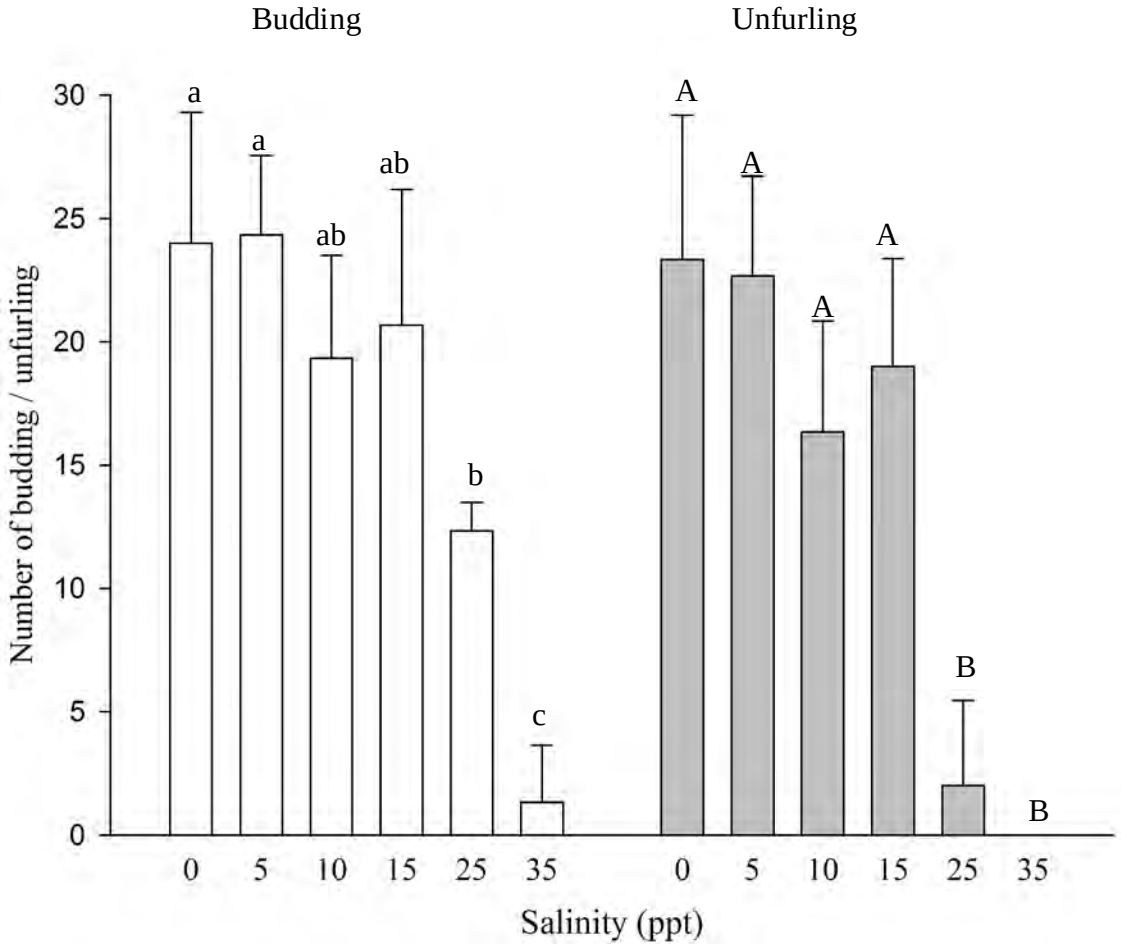


Fig. 4.2 Effect of salinity on numbers of *Sonneratia apetala* seeds with budding and unfurling at Day 30 (Mean and standard deviation of triplicate are shown. Mean of the same species with different letters are significantly difference at $p<0.05$ level according to one-way ANOVA test)

4.3.3 Effect of salinity on germination of *Sonneratia caseolaris*

Seeds of *S. caseolaris* were able to bud in all salinities with the highest budding percentages of 61.11% and 68.33% in 0 ppt and 5 ppt, respectively (Table 4.6 and Fig. 4.3). In 0 ppt and 5 ppt, 25% budding percentages were both achieved within 5 days and it took 11 days to achieve the same percentage in 10 ppt. The germination percentages dropped dramatically if the salinity exceeded 10 ppt, the budding percentages in 15 ppt and 25 ppt were 24.44% and 6.67%, respectively at Day 30, while the value was 1.11% for 35 ppt. Statistical analysis showed that the budding number was significantly affected by salinity after controlling the effect of time (Table 4.7).

In term of unfurling, the budded seeds of *S. caseolaris* were able to produce their first pair of leaves in salinity gradients from 0 ppt to 15 ppt (Fig. 4.3). The unfurling percentage at Day 30 was the highest in 5 ppt (87.86%), followed by that in 0 ppt, with the highest percentage of 86.40% (Table 4.8). For 25 ppt and 35 ppt, none of them had any leaf unfurled. This suggested that *S. caseolaris* preferred low saline area. Statistical analysis showed that the unfurling number was significantly affected by salinity after controlling the effect of time (Table 4.7).

At the end of the experiment, Day 30, salinity also significantly affected the numbers of budded ($F(5,12)=18.33$, $p=0.003<0.05$) and unfurled seeds ($F(5,12)=18.72$ $p=0.005<0.05$). Low salinities (0 ppt and 5 ppt) had a significant higher numbers of budding than high salinities (25 ppt and 25 ppt) (Fig. 4.4). For the unfurling number at Day 30, unfurling number in 0 ppt was significant higher than 25 ppt and 35 ppt.

Table 4.6 Effect of salinity on budding percentages of *Sonneratia caseolaris* seeds (NA: Not applicable)

Salinity	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
0 ppt	5 days	7 days	NA	61.11%
5 ppt	5 days	6 days	NA	68.33%
10 ppt	11 days	NA	NA	40%
15 ppt	NA	NA	NA	24.44%
25 ppt	NA	NA	NA	6.67%
35 ppt	NA	NA	NA	1.11%

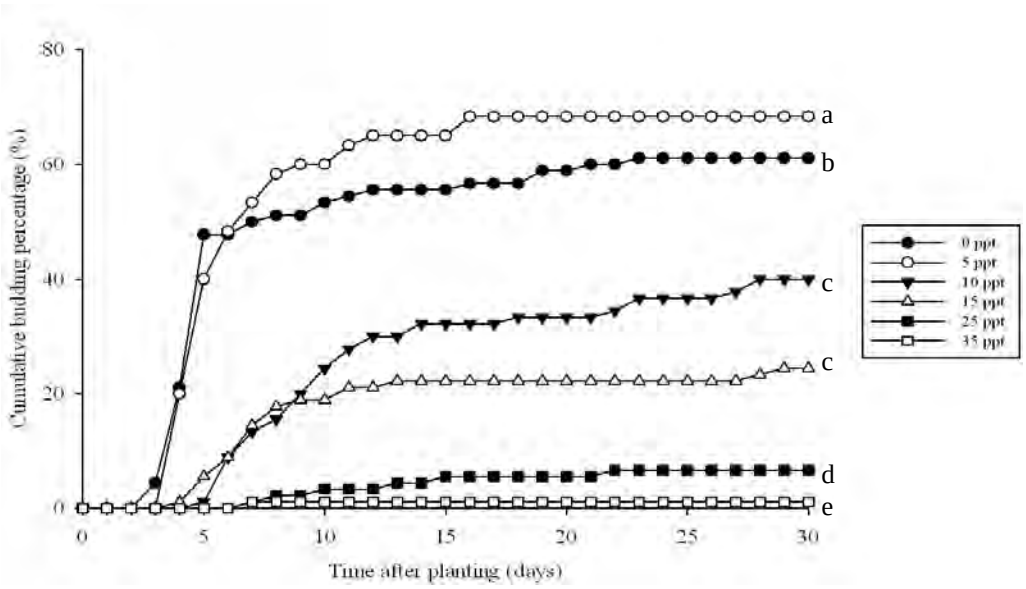
Table 4.7 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia caseolaris* seeds in different salinities. The variate is the salinity and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Salinity	22.06	0.000*	4.95	0.000*
Day	403.23	0.000*	640.83	0.000*
Salinity x Day	16.06	0.000*	67.16	0.000*

Table 4.8 Effect of salinity on unfurling percentages of *Sonneratia caseolaris* seeds (NA: Not applicable)

Salinity	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
0 ppt	8 days	10 days	19days	86.40%
5 ppt	9 days	12 days	17 days	87.86%
10 ppt	15 days	21 days	NA	63.61%
15 ppt	14 days	24 days	29 days	78.89%
25 ppt	NA	NA	NA	0%
35 ppt	NA	NA	NA	0%

Budding



Unfurling

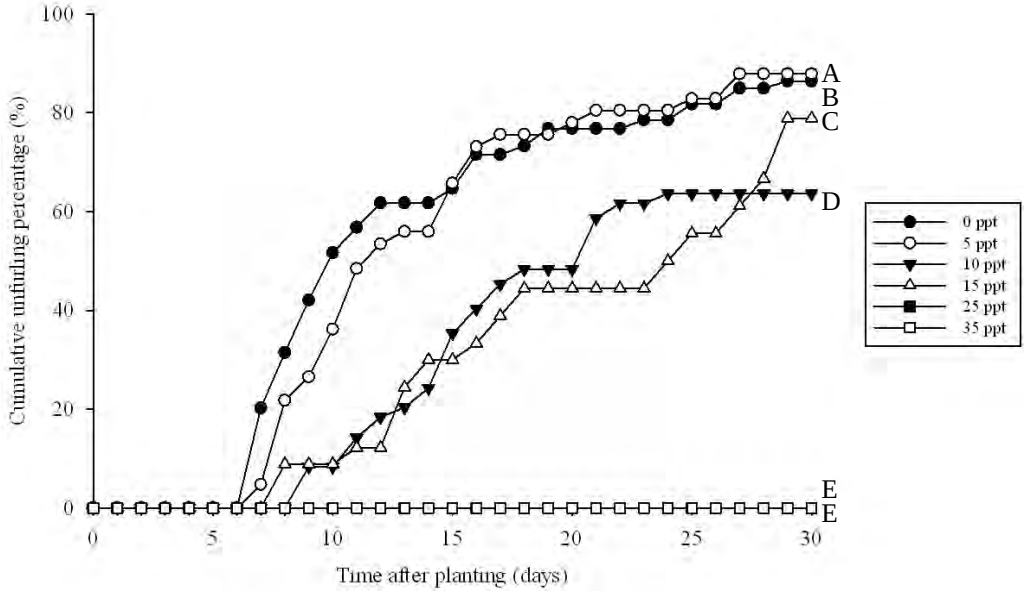


Fig. 4.3 Effect of salinity on budding and unfurling percentages of *Sonneratia caseolaris* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

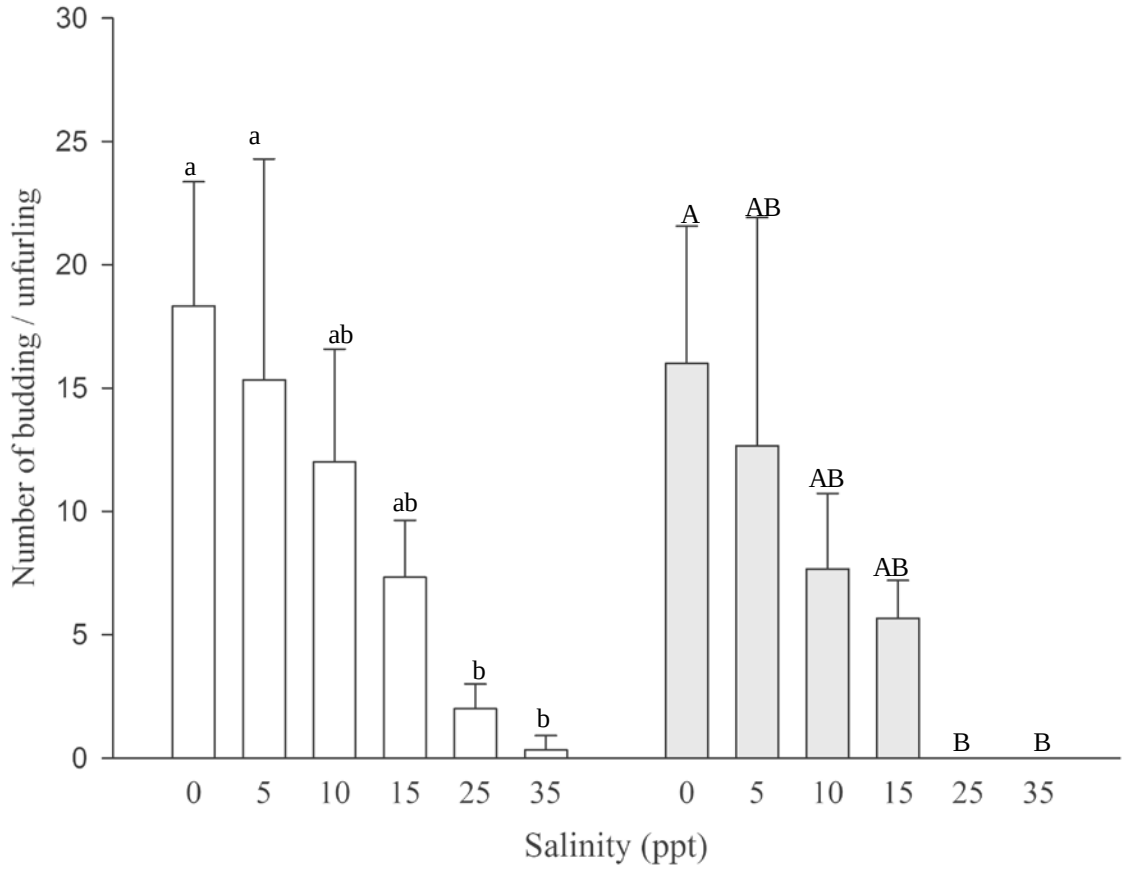


Fig. 4.4 Effect of salinity on numbers of *Sonneratia caseolaris* seeds with budding and unfurling at Day 30 (Mean and standard deviation of triplicate are shown. Mean of the same species with different letters are significantly different at $p < 0.05$ level according to one-way ANOVA test)

4.3.4 Effect of substrate type on germination of *Sonneratia apetala*

Seeds of *S. apetala* were able to bud in both types of substrate (Table 4.9 and Fig. 4.5). Seeds started to bud at Day 3 in both types of substrate, and achieved 93.33% and 96.67% for substrates of Tsim Bei Tsui (TBT) and To Kwa Ping (TKP) at Day 30, respectively. Seeds germinated at similar rates, which reached 25% after 3 and 4 days for TBT and TKP, respectively, and both reached 75% within 6 days. Statistical analysis showed that the budding number was not significantly affected by substrate type after controlling the effect of time (Table 4.10).

S. apetala seeds showed similar response in different substrate type in terms of the first pair of leaf unfurling. Seeds started to have the leaf unfurled from Day 5 onwards and around 96% was achieved at Day 30 for both types of substrates (Table 4.11 and Fig. 4.5). Seeds in TBT had a faster unfurling rate initially, achieved 25% in 7 days while the seeds in TKP achieved the same percentage in 8 days. Afterwards, the unfurling rate of TKP exceeded that of TBT and both had comparable percentages from Day 20 onwards. Statistical analysis showed that the unfurling number was not significantly affected by substrate type after controlling the effect of time (Table 4.10).

At the end of the experiment, Day 30, substrate type also did not have any significant effect on the numbers of budded ($F(4)=0.76$, $p=0.609>0.05$) and unfurled seeds ($F(4)=2.12$ $p=0.566>0.05$) (Fig. 4.6). Seeds in different substrate had similar numbers of budded and unfurled seeds.

Table 4.9 Effect of substrate type on budding percentages of *S. apetala* seeds

Substrate	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
Tsim Bei Tsui (TBT)	3 days	4 days	6 days	93.33%
To Kwa Ping (TKP)	4 days	5 days	6 days	96.67%

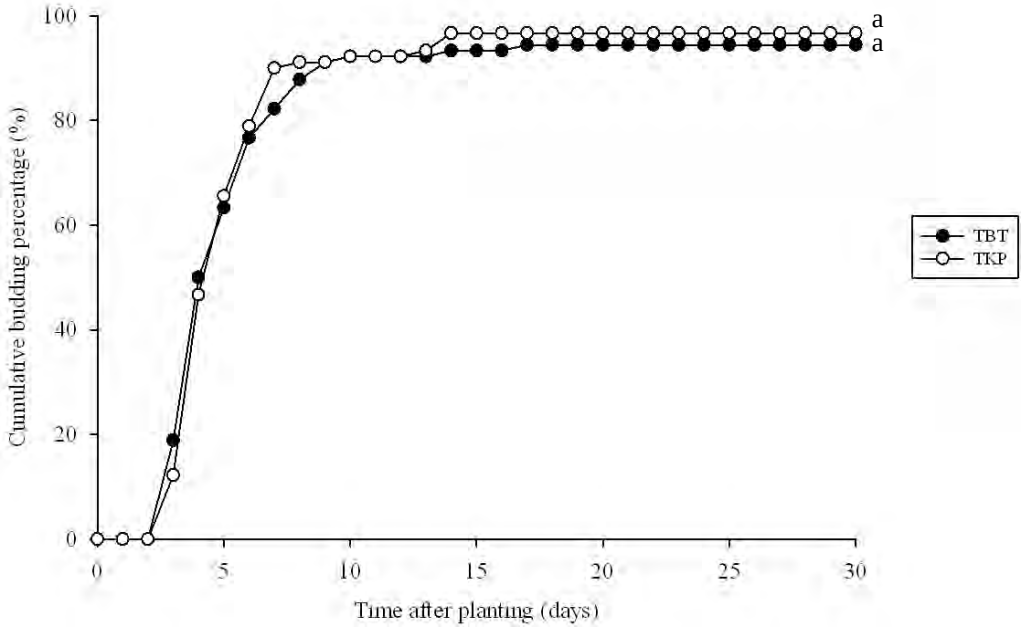
Table 4.10 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia apetala* seeds in different substrate types. The variate is the substrate type and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Substrate Type	0.04	0.844	0.13	0.722
Day	118.92	0.000*	459.10	0.000*
Substrate Type x Day	0.06	0.809	0.01	0.943

Table 4.11 Effect of substrate type on unfurling percentages of *Sonneratia. apetala* seeds

Substrate	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
Tsim Bei Tsui (TBT)	7 days	11 days	17 days	96.43%
To Kwa Ping (TKP)	8 days	10 days	15 days	96.55%

Budding



Unfurling

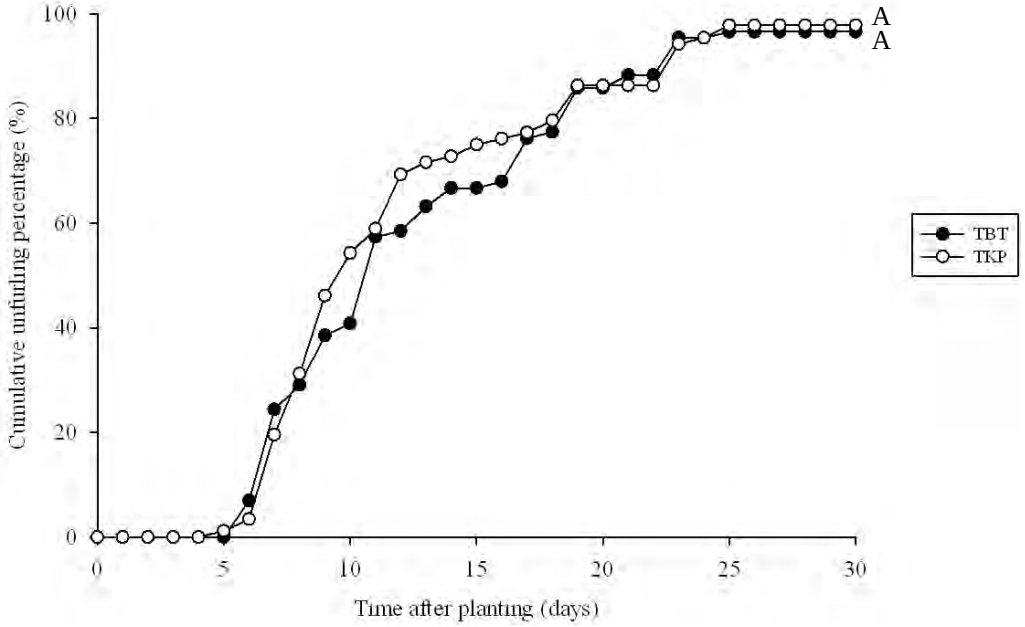


Fig. 4.5 Effect of substrate type on budding and unfurling percentages of *Sonneratia apetala* seeds (TBT: substrate from Tsim Bei Tsui; TKP: substrate from To Kwa Ping, same letter indicates no significant difference at $p < 0.05$ level according to ANCOVA test)

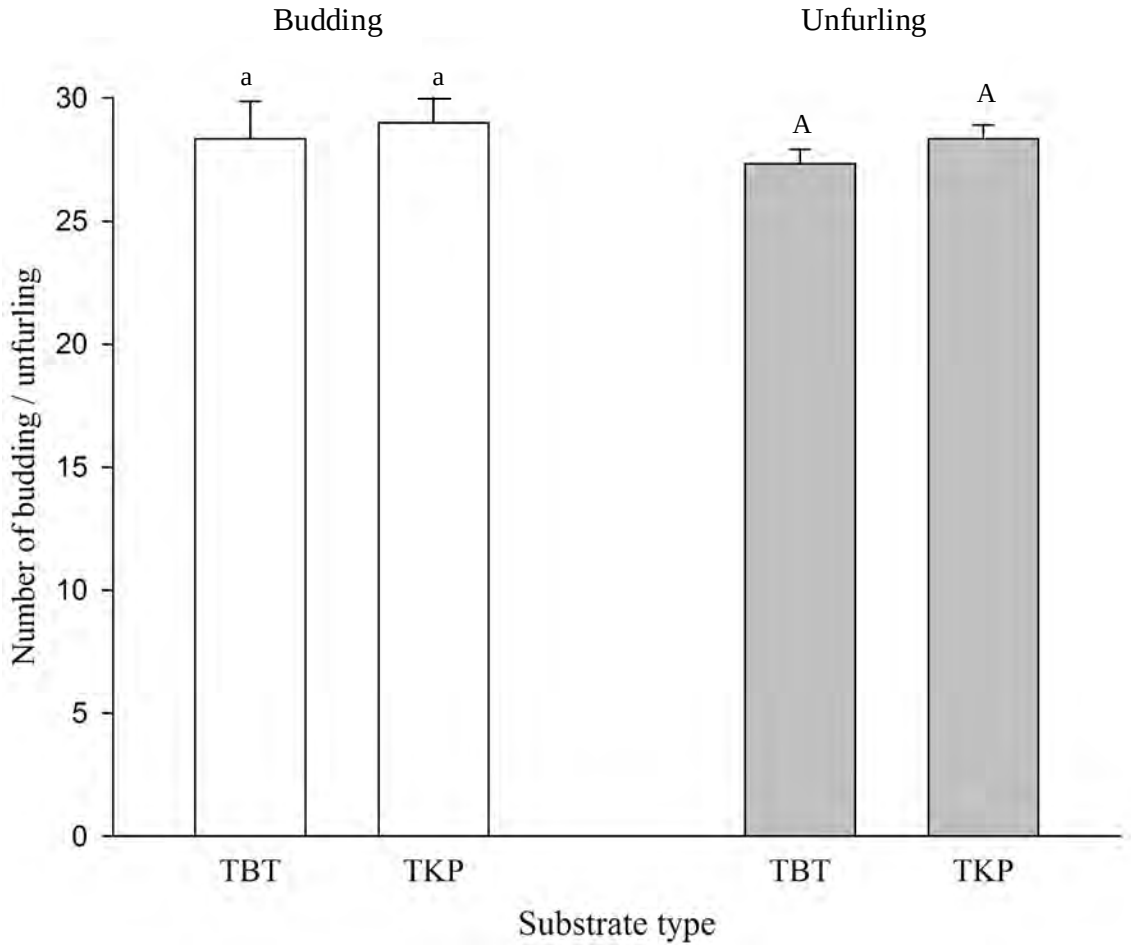


Fig. 4.6 Effect of substrate type on numbers of *Sonneratia apetala* seeds with budding and unfurling at Day 30 (TBT- substrate from Tsim Bei Tsui, TKP- substrate from To Kwa Ping. Mean and standard deviation of triplicate are shown. Mean of the same species with same letters are not significantly different at $p < 0.05$ level according to t-test)

4.3.5 Effect of substrate type on germination of *Sonneratia caseolaris*

S. caseolaris was able to bud in both types of substrate (Table 4.12 and Fig. 4.7). Seeds started to bud at Day 2 in both types of substrate, achieved 76.67% and 86.67% for Tsim Bei Tsui (TBT) and To Kwa Ping (TKP) substrate at Day 30, respectively. Seeds budded at similar rates initially which reached 25% within 2 days for both types of substrates. Afterwards, seeds in TKP had a faster rate than TBT and took 14 and 28 days to reach 75%, respectively. Statistical analysis showed that the budding number was not significantly affected by substrate type after controlling the effect of time (Table 4.13).

Seeds started to unfurl from Day 5 onwards and around 90% unfurling was achieved at Day 30 for both substrate (Table 4.14 and Fig. 4.7). In general, seeds in TBT had faster unfurling rate than TKP and had a higher unfurling percentage at Day 30 (95.65%). Statistical analysis showed that the unfurling number was not significantly affected by substrate type after controlling the effect of time (Table 4.13).

At the end of the experiment, Day 30, substrate type also did not significantly affect the numbers of budded ($F(4)=1.37$, $p=0.587>0.05$) and unfurled seeds ($F(4)=0.63$ $p=0.823>0.05$) (Fig. 4.8). Seeds in different substrates had similar numbers of budded and unfurled seeds.

Table 4.12 Effect of substrate type on budding percentages of *Sonneratia caseolaris* seeds

Substrate	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
Tsim Bei Tsui (TBT)	2 days	4 days	28 days	76.67%
To Kwa Ping (TKP)	2 days	5 days	14 days	86.67%

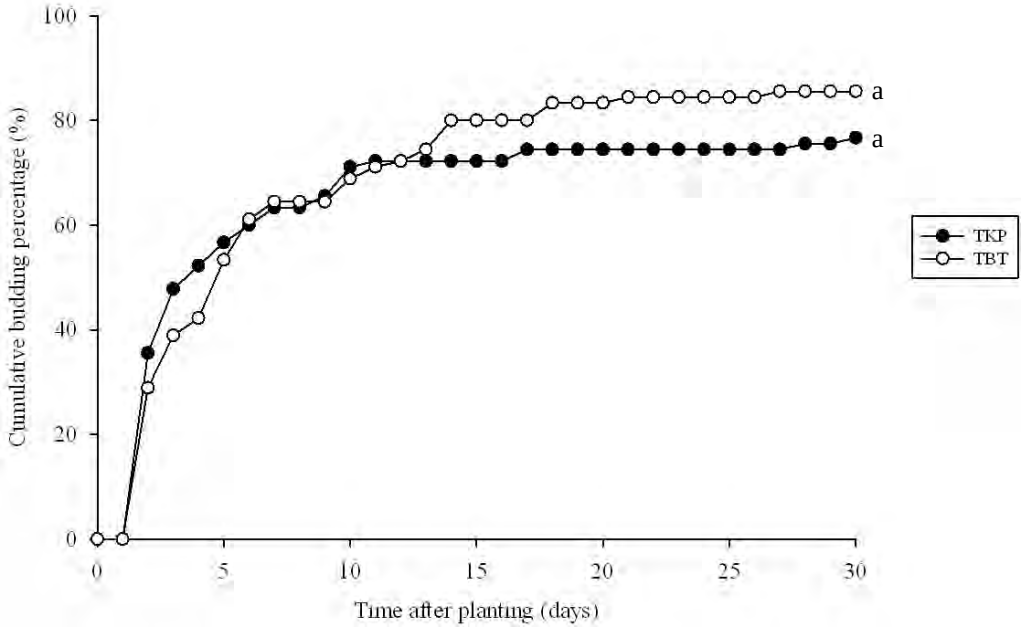
Table 4.13 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia caseolaris* seeds in different substrate types. The variate is the substrate type and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Substrate Type	0.19	0.661	1.83	0.178
Day	96.70	0.000*	454.17	0.000*
Substrate Type x Day	0.64	0.425	0.94	0.334

Table 4.14 Effect of substrate type on unfurling percentages of *Sonneratia caseolaris* seeds

Substrate	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
Tsim Bei Tsui (TBT)	6 days	10 days	21 days	95.65%
To Kwa Ping (TKP)	8 days	13 days	23 days	88.46%

Budding



Unfurling

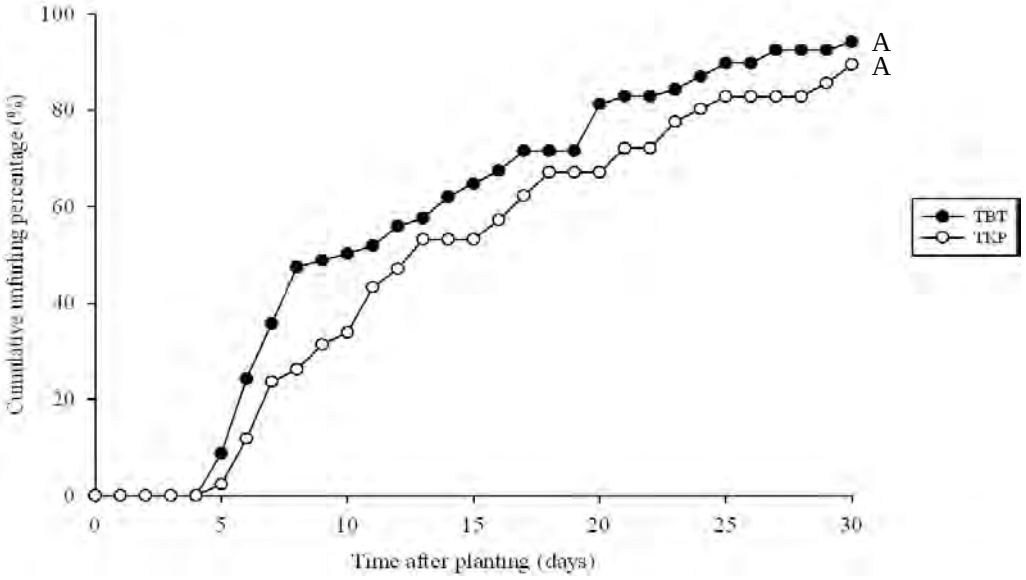


Fig. 4.7 Effect of substrate type on budding and unfurling percentages of *Sonneratia caseolaris* seeds (TBT: substrate from Tsim Bei Tsui; TKP: substrate from To Kwa Ping, same letter indicates no significant difference at $p < 0.05$ level according to ANCOVA test)

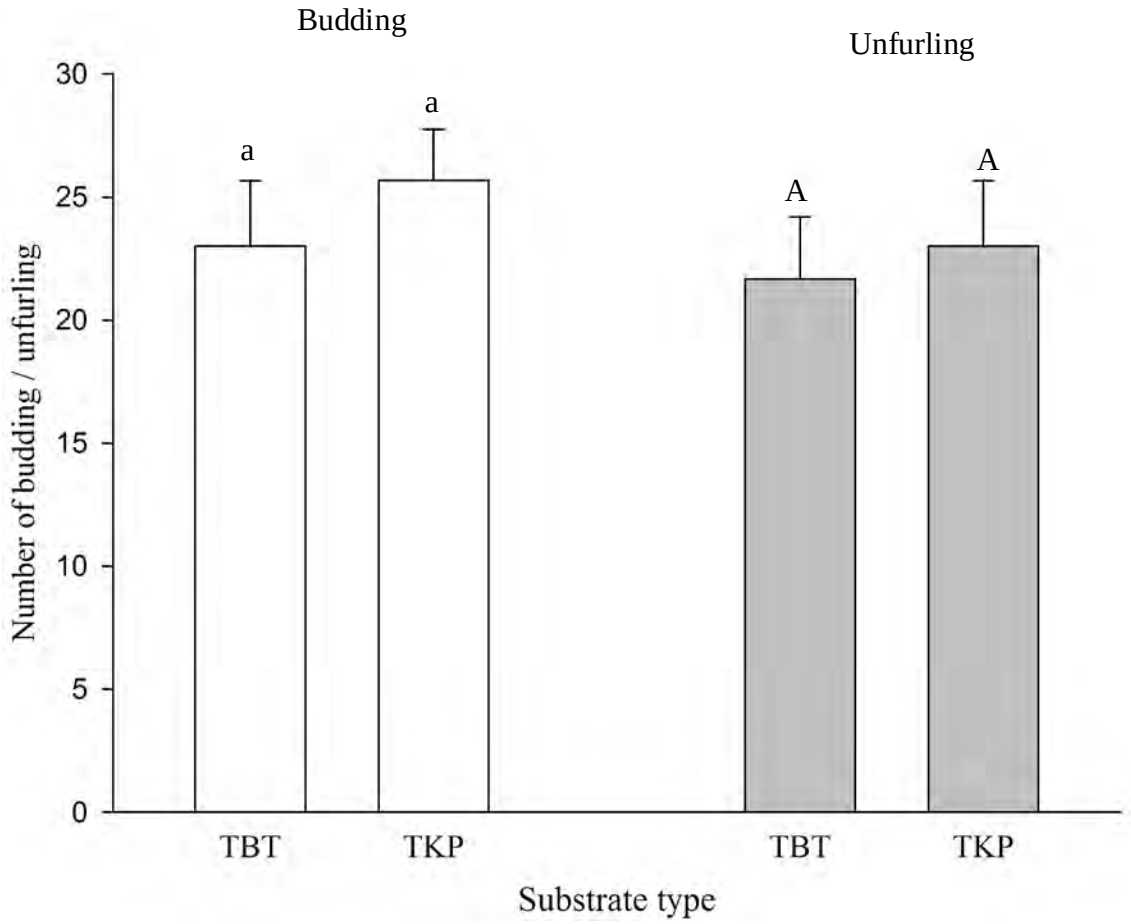


Fig. 4.8 Effect of substrate type on numbers of *Sonneratia caseolaris* seeds with budding and unfurling at Day 30 (TBT- substrate from Tsim Bei Tsui, TKP- substrate from To Kwa Ping. Mean and standard deviation of triplicate are shown. Mean of the same species with same letters are not significantly different at $p < 0.05$ level according to t-test)

4.3.6 Shading percentages of different canopy types

The light intensities showed a progressive increase from the closed canopy, open gap to the open area. Five samples were taken and averaged. With the light intensities in the open area representing 0% shading, the light intensities in open and closed canopies were 56% and 90%, respectively (Table 4.15).

Table 4.15 Table showing the shading percentages of different canopy types

Canopy Type	Sample (μ mol s^{-1} m^{-2})					Average	Shading Percentage
	S1	S2	S3	S4	S5		
Open Area	3550	3150	3492	2757	3506	3291	0%
Open Canopy	1300	1451	1531	1420	1521	1444.6	56%
Closed Canopy	307	267	343	354	374	329	90%

4.3.7 Shade tolerance on germination of *Sonneratia apetala*

Seeds of *S. apetala* were able to germinate in 0%, 56% and 90% shadings, they started to bud at Day 3 but seeds in 100% shading could hardly germinate, with the highest budding percentages of 2.22% (Table 4.16 and Fig. 4.9). Seeds in 0% shading reached 25% budding percentages in 6 days while seeds in 56% and 90% shadings required 7 days. At the end of the experiment, seeds in 0% shading had the highest germination percentages (42.22%). Statistical analysis showed that the budding number was significantly affected by shading after controlling the effect of time (Table 4.17).

Another parameter used to evaluate the germination percentages of *S. apetala* was the cumulative percentage of the first pair of leaf unfurling. The budded seeds were able to produce their first pair of leaves after budding in shading percentages of 0%, 56% and 90% shadings (Fig. 4.9). For the 100% shading, none of the seed had unfurling leaf. Only seeds in 0% and 56% shadings could attain 75% unfurling while those in 90% shading only had 50% unfurling throughout the experiment (Table 4.18). Seeds in 0% shading had the fastest unfurling rates, reached 75% in 15 days while seeds in 56% shading took 25 days to achieve the same percentage of unfurling. Statistical analysis showed that the unfurling number was not signifcantly affected by shading after controlling the effect of time (Table 4.17).

At the end of the experiment, Day 30, shading also significantly affected the number of budded seeds ($F(3,8)=7.45$, $p=0.011<0.05$) and unfurled seeds ($F(3,8)=6.30$, $p=0.017<0.05$). Seeds in 0%, 56% and 90% shadings had similar budding numbers at Day 30 (Fig. 4.10). At 100% shading, the budding number showed a very distinctive result, with extremely low number of budded seeds. For the first pair of leaf unfurling, similar result was attained. Seeds in 0%, 56% and 90% shadings had similar unfurling numbers at Day 30, which was significantly higher than 100% shading.

Table 4.16 Effect of shading on budding percentages of *Sonneratia apetala* seeds (NA: Not applicable)

Shading Percentage	Cumulative Budding Percentage			Highest Budding Percentage
	25%	50%	75%	
0%	6 days	NA	NA	42.22%
56%	7 days	NA	NA	35.56%
90%	7 days	NA	NA	33.33%
100%	NA	NA	NA	2.22%

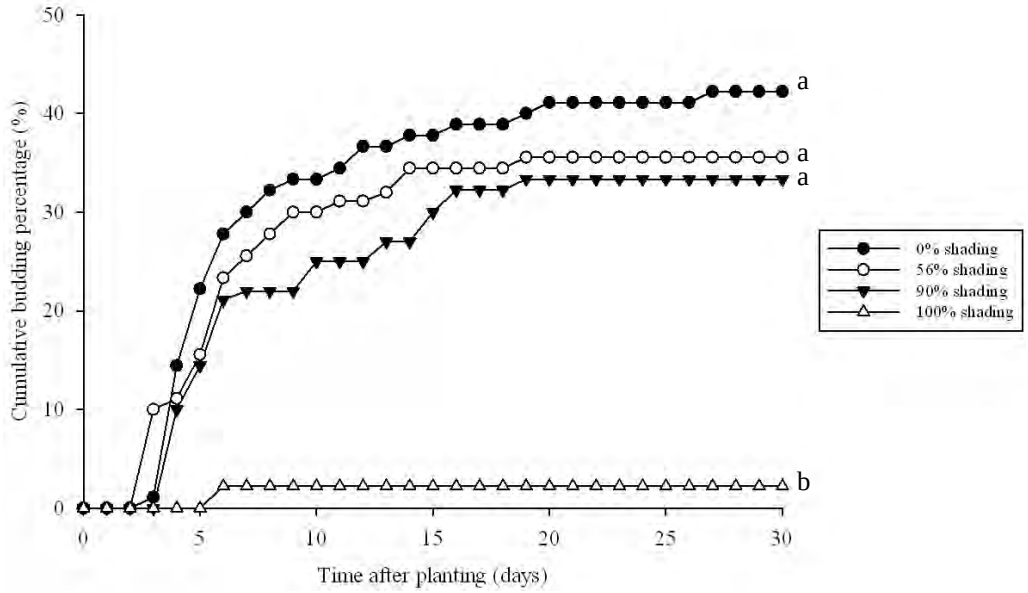
Table 4.17 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia apetala* seeds in different shading percentage. The variate is the shading and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Shading Percentage	14.53	0.000*	2.12	0.098
Day	224.24	0.000*	497.62	0.000*
Shading Percentage x Day	13.31	0.000*	56.146	0.000*

Table 4.18 Effect of shading on unfurling percentages of *Sonneratia apetala* seeds (NA: Not applicable)

Shading Percentage	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
0%	8 days	11 days	15 days	95.83%
56%	11 days	13 days	25 days	80.80%
90%	13 days	22 days	NA	69.52%
100%	NA	NA	NA	0%

Budding



Unfurling

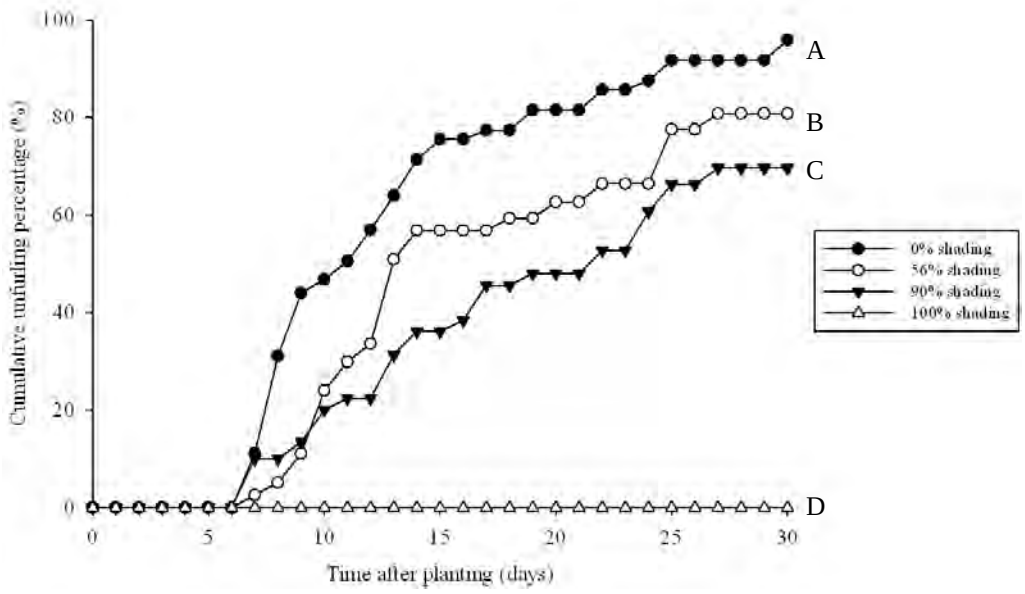


Fig. 4.9 Effect of shading on budding and unfurling percentages of *Sonneratia apetala* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

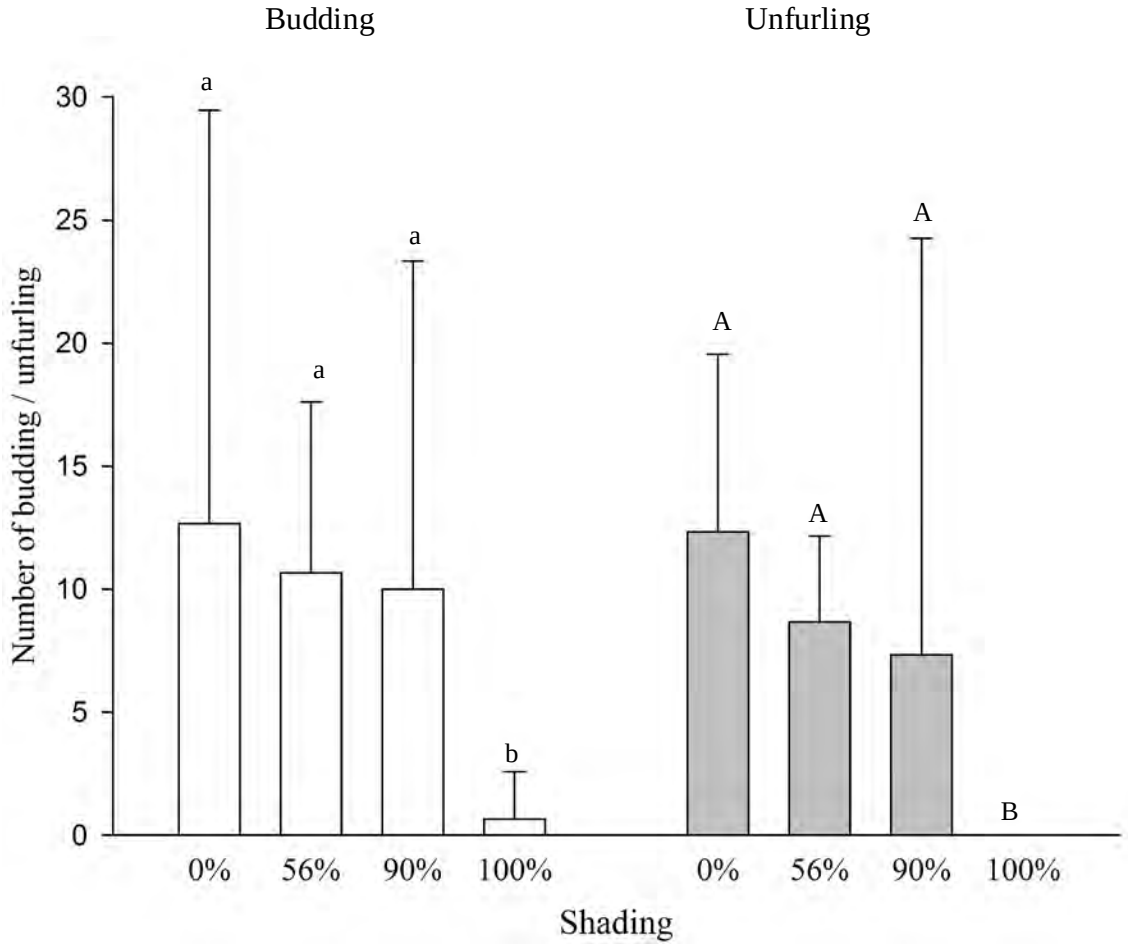


Fig. 4.10 Effect of shading on numbers of *Sonneratia apetala* seeds with budding and unfurling at Day 30 (Mean and standard deviation of triplicate are shown. Mean of the same species with different letters are significantly different at $p < 0.05$ level according to one-way ANOVA test)

4.3.8 Shade tolerance on germination of *Sonneratia caseolaris*

S. caseolaris was able to bud in all treatments (Table 4.19 and Fig. 4.11). Seeds started to bud at Day 3, seeds in 0% shading achived 25% budding in 7 days, while those in 56% and 90% shadings achived the same percentage in 14 days and 10 days, respectively. For the seeds under 100% shading, only 4.44% cumulative budding percentage was achieved at Day 30. At the end of the experiment, 30%, 28.89% and 36.67% were attained in 0%, 56% and 90% shadings, respectively. Statistical analysis showed that the budding number was signifcantly affected by shading after controlling the effect of time (Table 4.20).

Another parameter used to evaluate the germination of *S. caseolaris* was the cumulative percentage of the first pair of leaf unfurling. Fig. 4.11 showed that seeds were able to produce their first pair of leaves after budding in all shading percentages. Only seeds in 0% and 56% shadings attained 75% unfurling while those in 100% shading had lowest unfurling percentage at the end of the experiment at the end of the experiment (Table 4.21). Seeds in 0% shading had the fastest unfurling rate, 75% unfurling in 13 days while seeds in 56% shading took 23 days to reach the same level of unfurling. Statistical analysis showed that the unfurling number was signifcantly affected by shading after controlling the effect of time (Table 4.20).

At the end of the experiment, Day 30, shading did not significantly affect the number of budded ($F(3,8)=3.3$, $p=0.079>0.05$) and unfurled seeds ($F(3,8)=3.45$, $p=0.071>0.05$) among the four treatments, 0%, 56%, 90% and 100% shadings (Fig. 4.12).

Table 4.19 Effect of shading on budding percentages of *Sonneratia caseolaris* seeds (NA: Not applicable)

Shading Percentage	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
0%	7 days	NA	NA	30.00%
56%	14 days	NA	NA	28.89%
90%	10 days	NA	NA	36.67%
100%	NA	NA	NA	4.44%

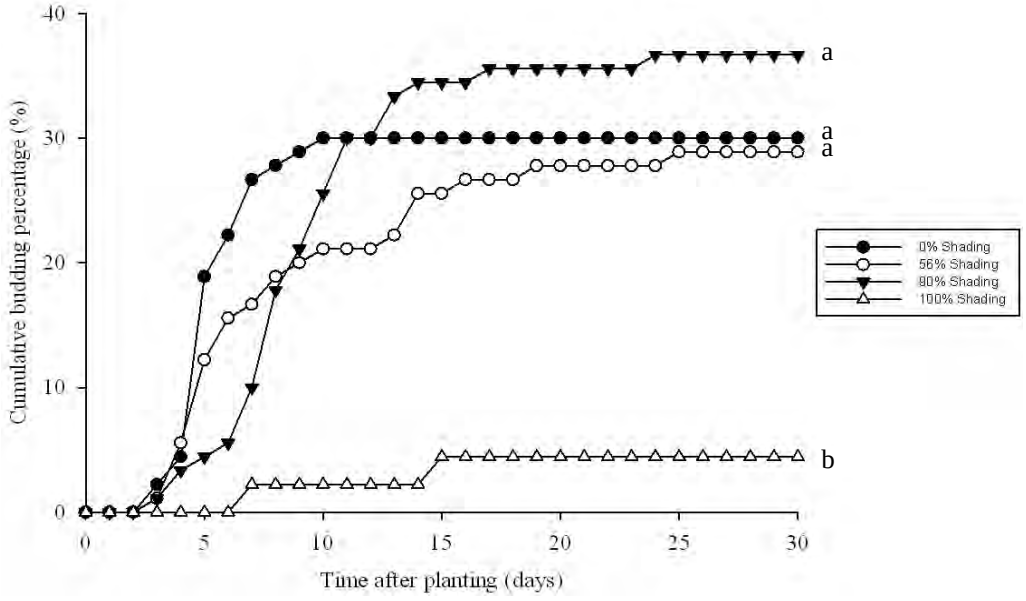
Table 4.20 Summary of ANCOVAs for the budding and unfurling percentages of *Sonneratia caseolaris* seeds in different shading percentages. The variate is the shading and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Shading Percentage	10.86	0.000*	3.57	0.014*
Day	260.41	0.000*	624.10	0.000*
Shading Percentage x Day	10.03	0.000*	32.41	0.000*

Table 4.21 Effect of shading on unfurling percentages of *Sonneratia caseolaris* seeds (NA: Not applicable)

Shading Percentage	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
0%	8 days	10 days	13 days	100.00%
56%	8 days	12 days	23 days	91.11%
90%	10 days	16 days	NA	74.29%
100%	16 days	32 days	NA	66.67%

Budding



Unfurling

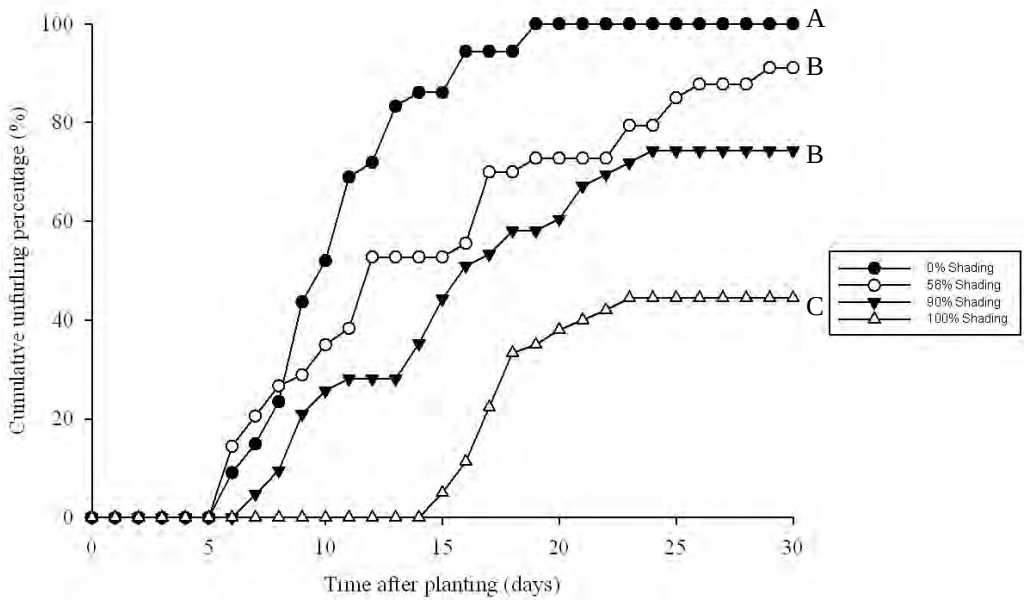


Fig. 4.11 Effect of shading on budding and unfurling percentages of *Sonneratia caseolaris* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

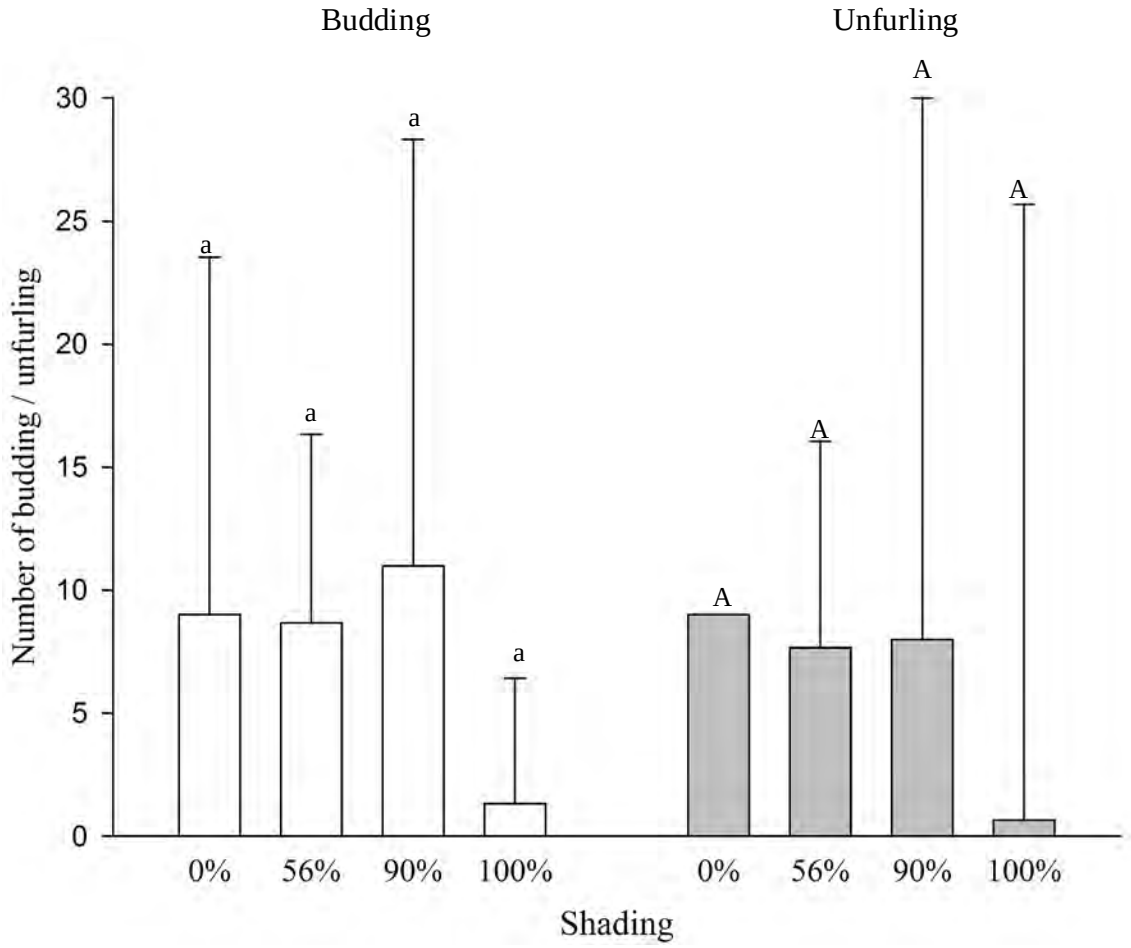


Fig. 4.12 Effect of shading on numbers of *Sonneratia caseolaris* seeds with budding and unfurling at Day 30 (Mean and standard deviation of triplicate are shown. Mean of the same species with same letters are not significantly different at $p < 0.05$ level according to one-way ANOVA test)

4.3.9 Effect of submerging time (tidal level) on germination of *Sonneratia apetala*

Seeds of *S. apetala* were able to bud in all submerging time (tidal level) (Table 4.22 and Fig. 4.13). Seeds started to bud at Day 4, seeds in high tidal level had the highest budding percentages (50%) and reached 25% budding in 13 days, which took 16 and 36 days in mid and low tidal levels to achieve the same percentage, respectively (Table 4.22). For seeds in low tidal level, the maximum budding percentage was 33.33%. Statistical analysis showed that the budding number was significantly affected by tidal level after controlling the effect of time (Table 4.23).

The effect of submerging time (tidal level) on the first leaf unfurling was similar to that on budding (Fig. 4.13). The order was high tidal level > mid tidal level > low tidal level. Seeds in high tidal level had the highest unfurling percentages (86.67%) and reached 25% unfurling in 16 days, 50% unfurling in 21 days and 75% unfurling in 32 days (Table 4.24). While the seeds in low tidal level took the longest time to unfurl, reaching 25% unfurling in 26 days, 50% unfurling in 39 days and 75% unfurling in 49 days. All tidal levels had more than 80% leaf unfurled at the end of the experiment, Day 50. Statistical analysis showed that the unfurling number was significantly affected by tidal level after controlling the effect of time (Table 4.23).

At the end of the experiment, Day 50, tidal level did not significantly affected the number of budded ($F(2,6)=1.16$, $p=0.376>0.05$) and unfurled seeds ($F(2,6)=1.22$, $p=0.361>0.05$) (Fig. 4.14). Seeds in different tidal levels had similar numbers of budded and unfurled seeds.

Table 4.22 Effect of tidal level on budding percentages of *Sonneratia apetala* seeds (NA: Not applicable)

Tidal Level	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
Low	36 days	NA	NA	33.33 %
Mid	16 days	NA	NA	46.67 %
High	13 days	33 days	NA	50 %

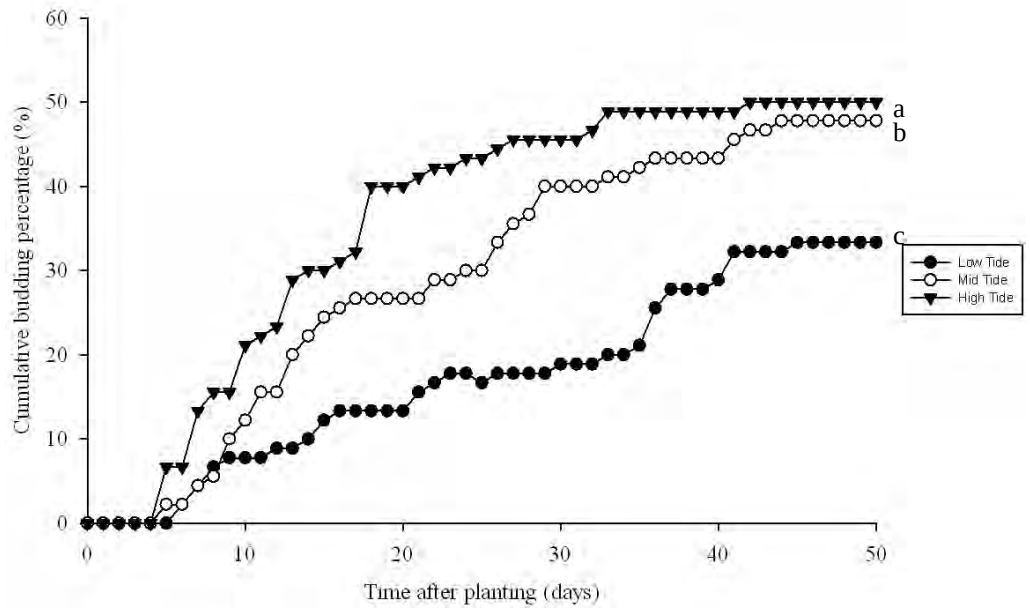
Table 4.23 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia apetala* seeds in different tidal levels. The variate is the tidal level and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Tidal Level	7.94	0.000*	3.86	0.022*
Day	817.75	0.000*	1694.66	0.000*
Tidal Level x Day	0.68	0.051	12.08	0.000*

Table 4.24 Effect of tidal level on unfurling percentages of *Sonneratia apetala* seeds

Tidal Level	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
Low	26 days	39 days	49 days	80 %
Mid	22 days	29 days	38 days	85.71 %
High	16 days	21 days	32 days	86.67 %

Budding



Unfurling

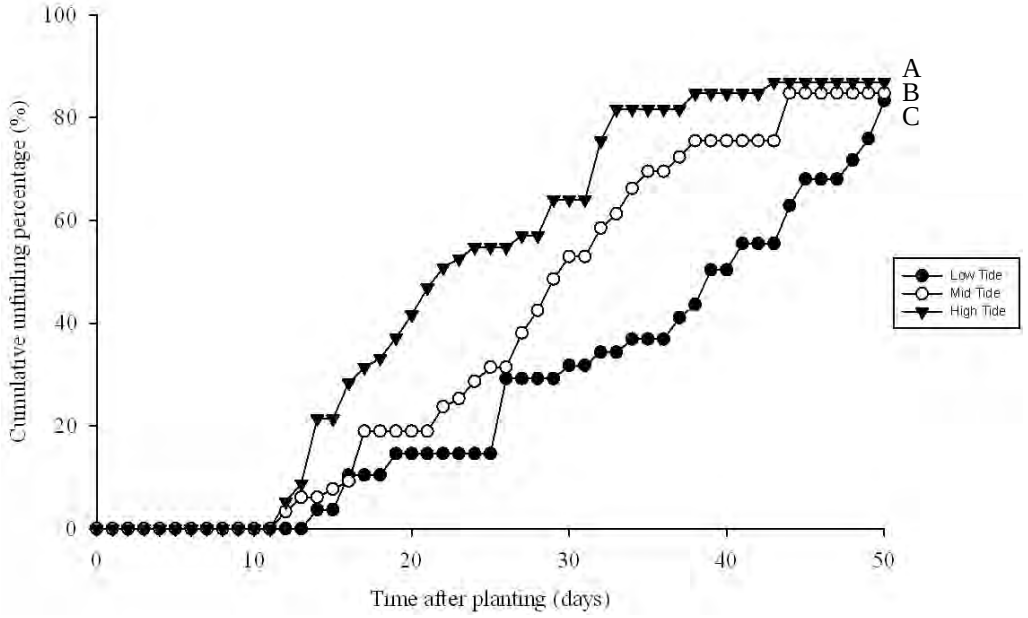


Fig. 4.13 Effect of tidal level on budding and unfurling percentages of *Sonneratia apetala* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

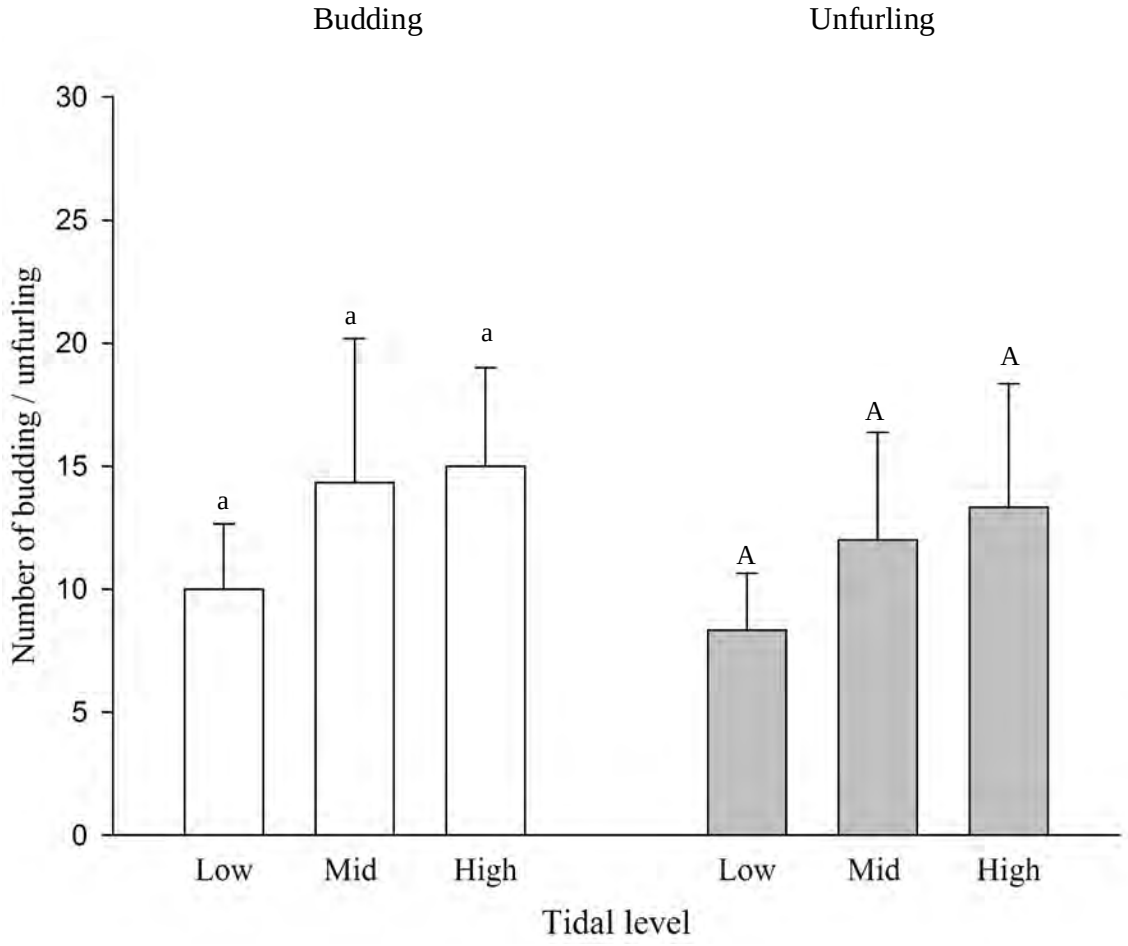


Fig. 4.14 Effect of tidal level on numbers of *Sonneratia apetala* seeds with budding and unfurling at Day 50 (Low- low tidal level, Mid- mid tidal level, High- high tidal level. Mean and standard deviation of triplicate are shown. Mean of the same species with same letters are not significantly different at $p < 0.05$ level according to one-way ANOVA test)

4.3.10 Effect of submerging time (tidal level) on germination of *Sonneratia caseolaris*

Seeds of *S. caseolaris* budded in all tidal levels and had the highest budding percentage in high tidal level, followed by mid and low tidal levels (Table 4.25 and Fig. 4.15). Seeds in the high tidal level attained 40% budding at Day 50, and the respective rates were 31.11% and 22.22% in the mid and low tidal levels. Statistical analysis showed that the budding number was significantly affected by tidal level after controlling the effect of time (Table 4.26).

The trend of leaf unfurling percentages among three tidal levels was similar to that of budding in the first 38 days, in the order of high tidal level > mid tidal level > low tidal level (Fig. 4.15). However, the unfurling percentages of mid tidal level became the highest at the end of the experiment (Day 50) which was 92.86%, followed by the low and high tidal levels which had 90% and 86.11% unfurling, respectively (Table 4.27). Despite the cumulative unfurling percentage in high tidal level at Day 50 was not the highest, seed required the minimum days to achieve 25%, 50% and 75% unfurling. Statistical analysis showed that the unfurling number was significantly affected by tidal level after controlling the effect of time (Table 4.26).

At the end of the experiment, Day 50, tidal level has significantly affected the number of budded seeds ($F(2,6)=5,49$, $p=0.044<0.05$) but not significantly affected the unfurled seeds ($F(2,6)=3.67$, $p=0.090>0.05$). At Day 50, the number of budded seeds in low tidal level was similar to that in mid tidal level but significantly lower than that in high tidal level (Fig. 4.16).

Table 4.25 Effect of tidal level on budding percentages of *Sonneratia caseolaris* seeds (NA: Not applicable)

Tidal Level	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
Low	NA	NA	NA	22.22 %
Mid	26 days	NA	NA	31.11 %
High	14 days	NA	NA	40 %

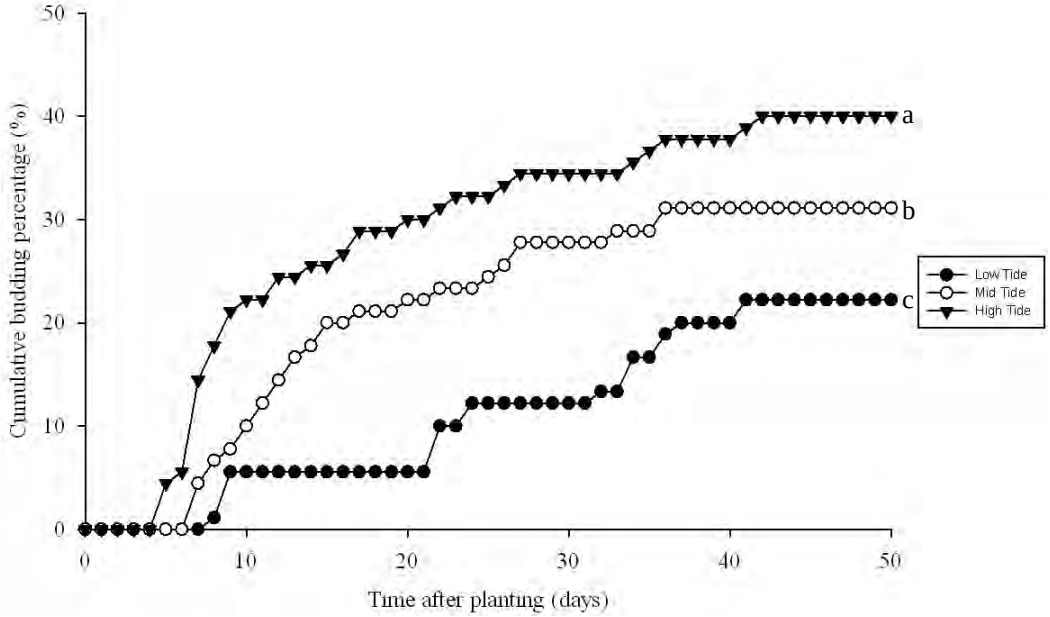
Table 4.26 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia caseolaris* seeds in different tidal levels. The variate is the tidal level and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Tidal Level	32.35	0.000*	39.64	0.000*
Day	764.80	0.000*	1094.11	0.000*
Tidal Level x Day	1.31	0.263	1.56	0.211

Table 4.27 Effect of tidal level on unfurling percentages of *Sonneratia caseolaris* seeds

Tidal Level	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
Low	30 days	34 days	41 days	90 %
Mid	13 days	22 days	34 days	92.86 %
High	11 days	15 days	30 days	86.11 %

Budding



Unfurling

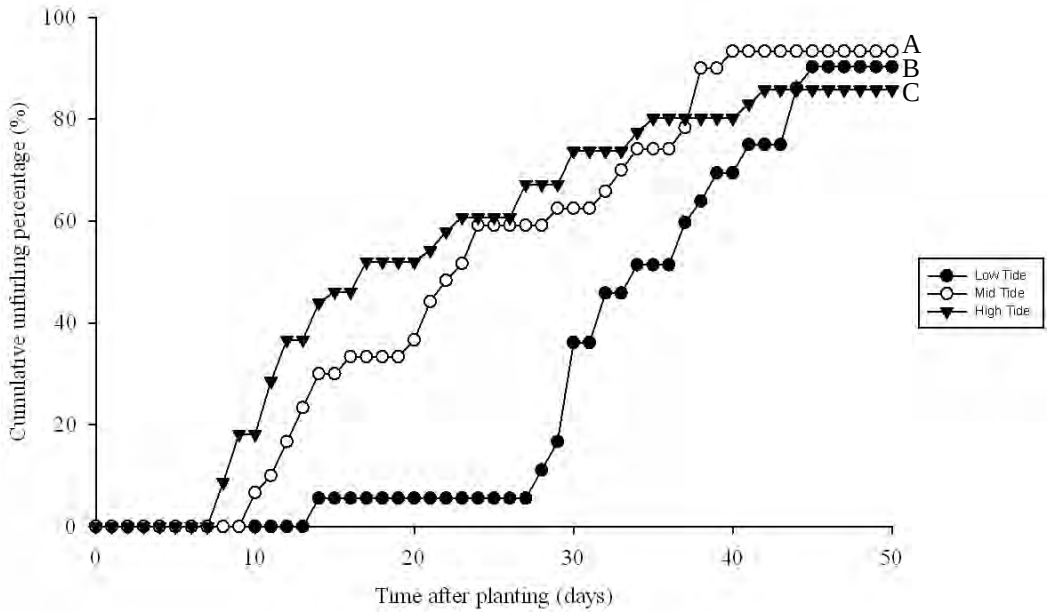


Fig. 4.15 Effect of tidal level on budding and unfurling percentages of *Sonneratia caseolaris* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

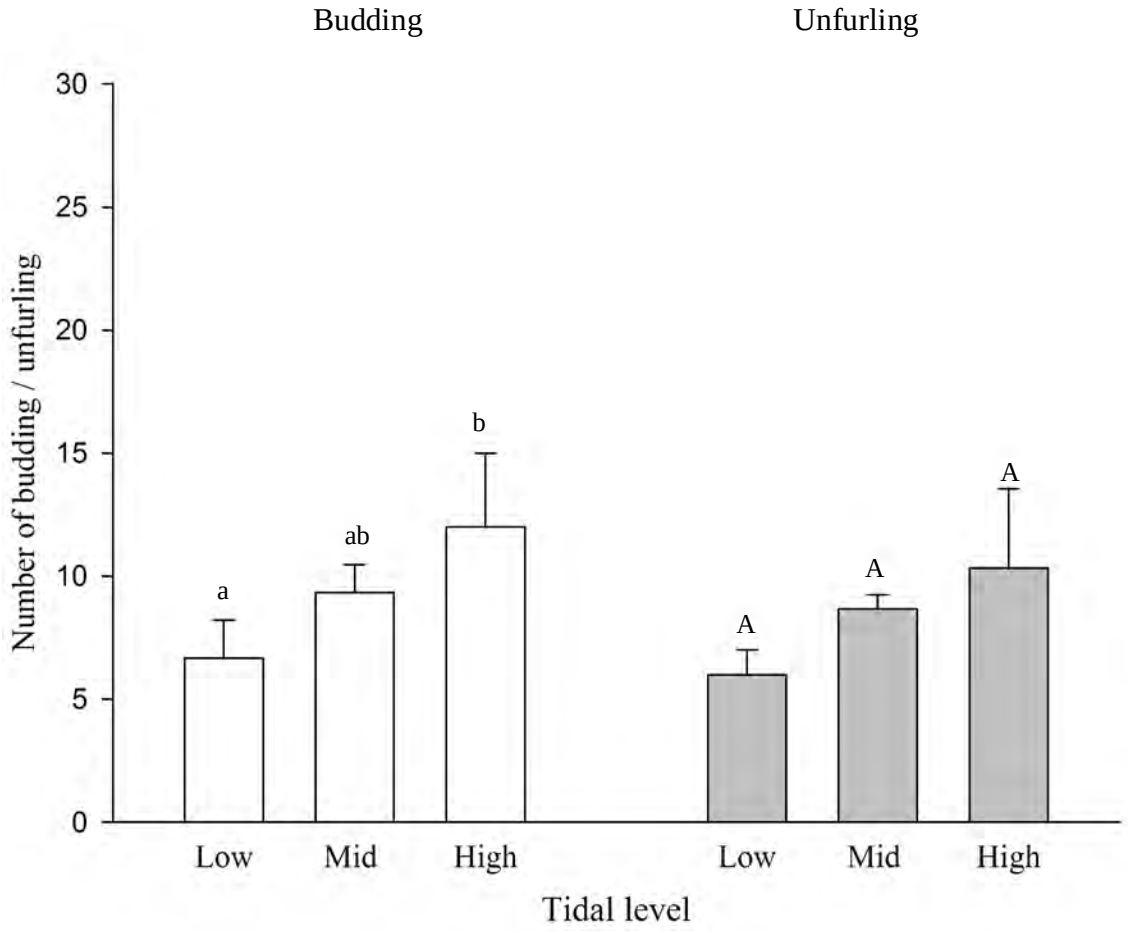


Fig. 4.16 Effect of tidal level on numbers of *Sonneratia caseolaris* seeds with budding and unfurling at Day 50 (Low- low tidal level, Mid- mid tidal level, High- high tidal level. Mean and standard deviation of triplicate are shown. Mean of the same species with different letters are significantly different at $p < 0.05$ level according to one-way ANOVA test)

4.3.11 Effect of cold period on germination of *Sonneratia apetala*

Seeds of *S. apetala* without any cold treatment (0 hour cold period) started to bud at Day 2 while seeds with 24 and 48 cold periods (stored in 4℃ refrigerator) both started to bud at Day 5 (Fig. 4.17). The highest budding percentages of the three treatments were similar; they all achieved around 40% at Day 30 (Table 4.28). They attained 25% budding around 8 to 10 days. Statistical analysis showed that the budding number was significantly affected by cold period after controlling the effect of time (Table 4.29).

For the unfurling, seeds without any cold treatment (0 hour cold period) started to unfurl at Day 8 while seeds with 24 and 48 cold periods started to unfurl at Day 10 (Fig. 4.17). Seed without cold treatment attained 100% unfurling at Day 30 (Table 4.30), it also required a shorter period of time to attain 25%, 50% and 75% unfurlings when compared with 24 and 48 hours cold periods. Statistical analysis showed that the unfurling number was not significantly affected by cold period after controlling the effect of time (Table 4.29).

At the end of the experiment, Day 30, cold period did not significantly affect the number of budded ($F(2,6)=0.01$, $p=0.994>0.05$) and unfurled seeds ($F(2,6)=0.11$, $p=0.901>0.05$). The numbers of seeds with budding and unfurling at Day 30 were similar among all treatments (Fig. 4.18).

Table 4.28 Effect of cold period on budding percentages of *Sonneratia apetala* seeds (NA: Not applicable)

Cold Period	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
0 hour	8 days	NA	NA	40 %
24 hours	10 days	NA	NA	38.89 %
48 hours	8 days	NA	NA	38.89 %

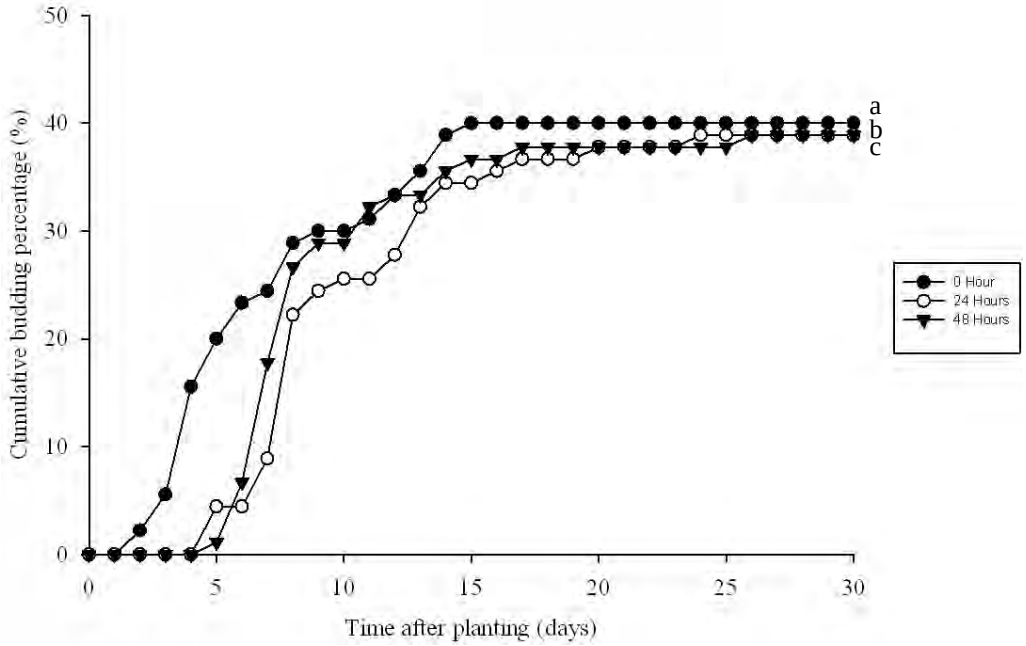
Table 4.29 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia apetala* seeds in different cold periods. The variate is the cold period and the covariate is number of days after planting, * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Cold Period	8.31	0.000*	1.79	0.170
Day	359.72	0.000*	660.80	0.000*
Cold Period x Day	4.23	0.016*	0.09	0.912

Table 4.30 Effect of cold period on unfurling percentages of *Sonneratia apetala* seeds

Cold Period	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
0 hour	8 days	10 days	11 days	100 %
24 hours	11 days	12 days	18 days	91.43 %
48 hours	11 days	12 days	15 days	88.57 %

Budding



Unfurling

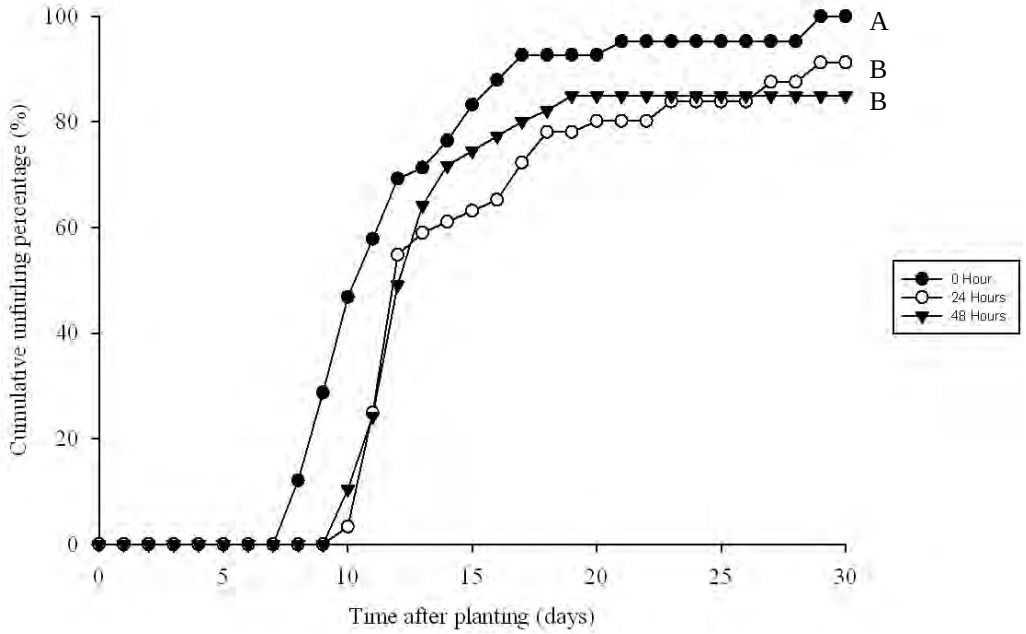


Fig. 4.17 Effect of cold period on budding and unfurling percentages of *Sonneratia apetala* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

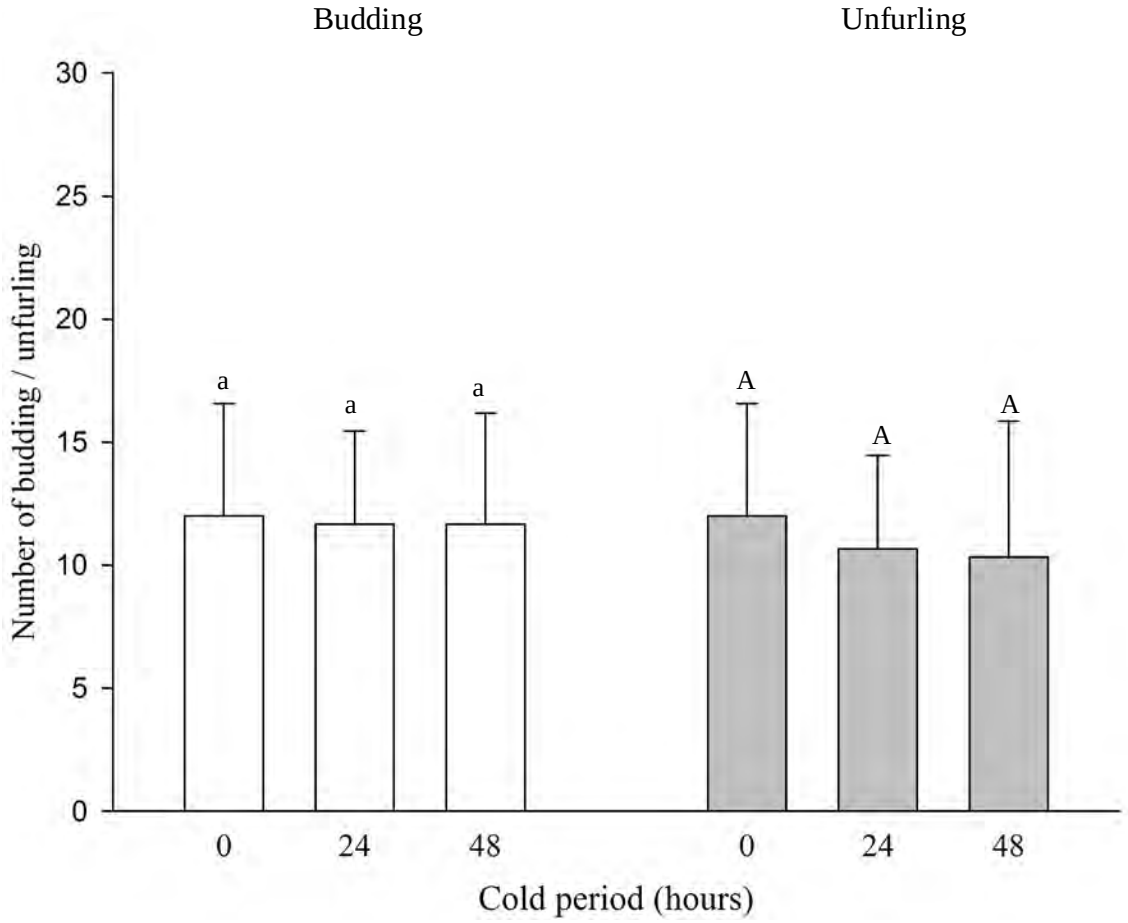


Fig. 4.18 Effect of cold period on numbers of *Sonneratia apetala* seeds with budding and unfurling at Day 30 (0, 24 and 48 represent 0, 24, 48 hours cold period in 4℃refrigerator. Mean and standard deviation of triplicate are shown. Mean of the same species with same letters are not significantly different at $p < 0.05$ level according to one-way ANOVA test)

4.3.12 Effect of cold period on germination of *Sonneratia caseolaris*

Seeds of *S. caseolaris* started to bud at Day 2, the budding percentages followed the order of 0 > 24 > 48 hours cold periods (Fig. 4.19). Seeds without cold treatment (0 hour cold period) had 80% budding at Day 30, while seeds with 24 and 48 hours cold periods had 61.11% and 42.22%, respectively (Table 4.31). Statistical analysis showed that the budding number was significantly affected by cold period after controlling the effect of time (Table 4.32).

Seeds of all treatments had similar unfurling percentages at Day 30 (Fig. 4.19). Both 0 hour and 48 hour cold periods attained 100% unfurling while that of 24 hours cold period was 96.36% (Table 4.33). Seeds without cold treatment (0 hour) required a shorter time to attain 25% and 75% unfurlings when compared with 24 and 48 hours cold periods. Statistical analysis showed that the unfurling number was significantly affected by cold period after controlling the effect of time (Table 4.32).

At the end of the experiment, Day 30, cold period did not significantly affect the number of budded seeds ($F(2,6)=4.93$, $p=0.054>0.05$) but significantly affected the number of unfurled seeds ($F(2,6)=5.31$, $p=0.047<0.05$). Seeds treated with 0 and 24 hours cold period had similar budding number at Day 30 while seeds treated with 24 and 48 hours cold period had similar budding numbers. In term of unfurling number at Day 30, the numbers of unfurled seeds treated with 0 and 24 hours cold period were similar while those treated with 24 and 48 hours cold period were similar (Fig. 4.20).

Table 4.31 Effect of cold period on budding percentages of *Sonneratia caseolaris* seeds (NA: Not applicable)

Cold Period	Cumulative Budding Percentages			Highest Budding Percentage
	25%	50%	75%	
0 hour	2 days	4 days	15 days	80 %
24 hours	4 days	11 days	NA	61.11 %
48 hours	7 days	NA	NA	42.22 %

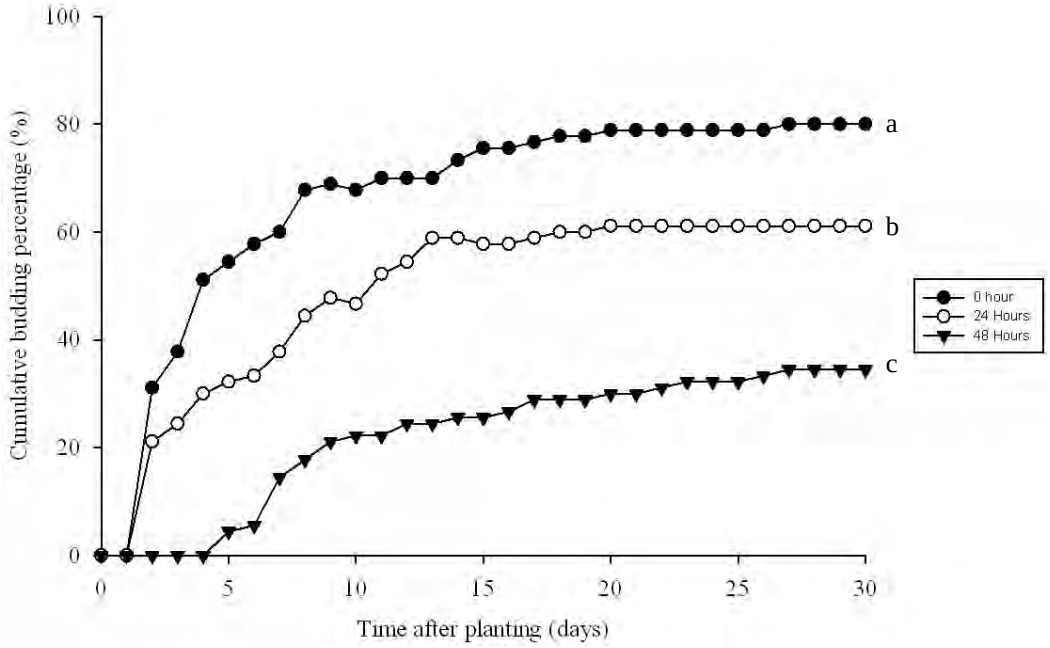
Table 4.32 Summary of ANCOVAs for the budding and unfurling numbers of *Sonneratia caseolaris* seeds in different cold periods. The variate is the cold period and the covariate is number of days after planting * = significant difference at $p<0.05$ level

Parameter	Budding		Unfurling	
	F	p	*F*	p
Cold Period	10.14	0.000*	4.03	0.019*
Day	188.10	0.000*	771.62	0.000*
Cold Period x Day	0.31	0.735	1.08	0.342

Table 4.33 Effect of cold period on unfurling percentages of *Sonneratia caseolaris* seeds

Cold Period	Cumulative Unfurling Percentages			Highest Unfurling Percentage
	25%	50%	75%	
0 hour	9 days	12 days	13 days	100 %
24 hours	11 days	12 days	14 days	96.36%
48 hours	10 days	12 days	14 days	100 %

Budding



Unfurling

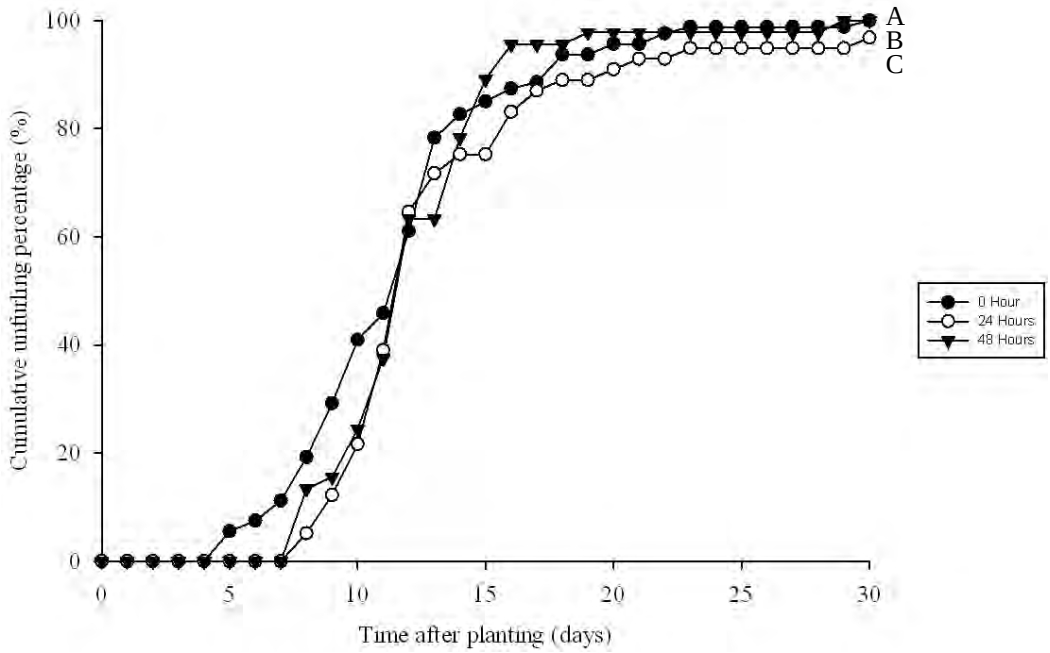


Fig. 4.19 Effect of cold period on budding and unfurling percentages of *Sonneratia caseolaris* seeds (different letters indicate significant difference at $p<0.05$ level according to ANCOVA test)

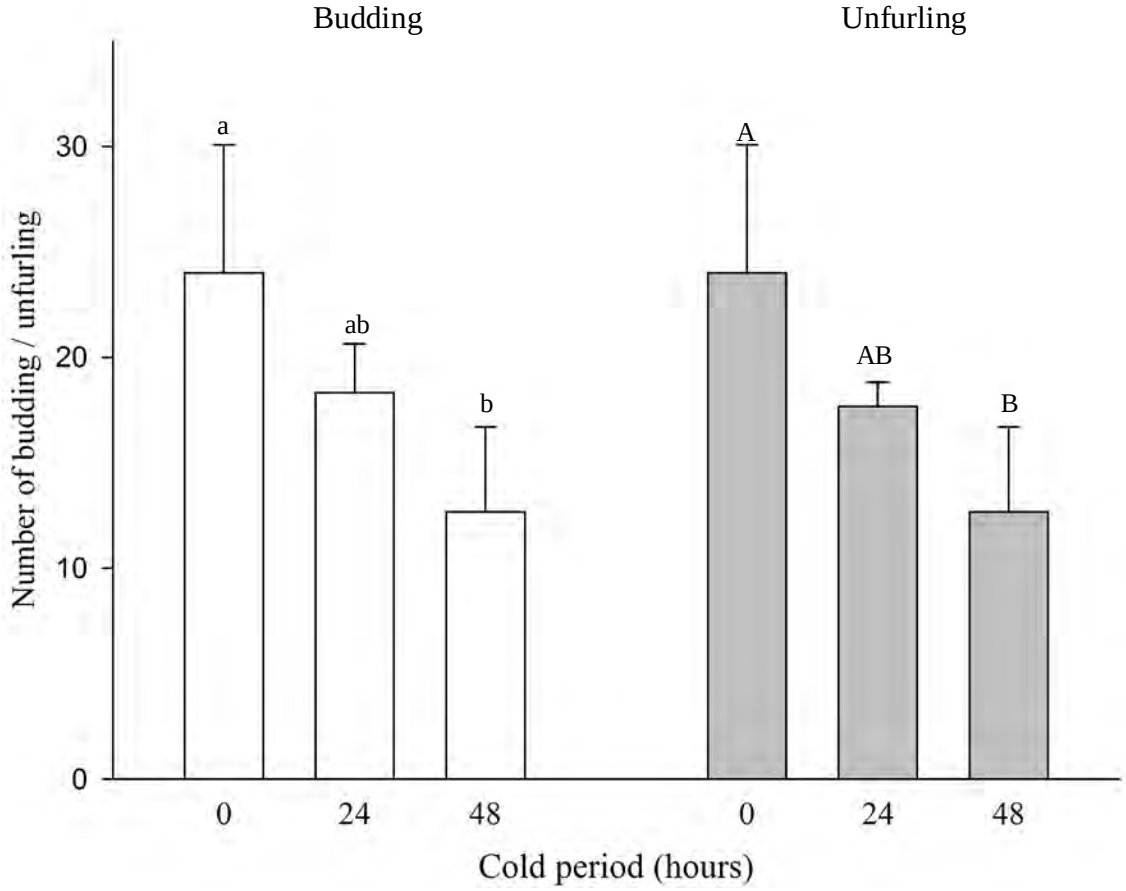


Fig. 4.20 Effect of cold period on numbers of *Sonneratia caseolaris* seeds with budding and unfurling at Day 30 (0, 24 and 48 represent 0, 24 and 48 hours cold period in 4℃ refrigerator. Mean and standard deviation of triplicate are shown. Mean of the same species with different letters are significantly difference at $p < 0.05$ level according to one-way ANOVA test)

4.4 Discussion

The dispersal abilities of *Sonneratia apetala* and *S. caseolaris* were evaluated in Chapter 3 which defined the areas where may potentially colonized. Once the viable seeds or propagules land on a substrate, environmental conditions are the more critical selective pressure on their establishment.

4.4.1 Effect of salinity on germination of *Sonneratia apetala* and *S. caseolaris*

There were some literatures stating that *Sonneratia* preferred low salinity. *S. caseolaris* was reported to prefer tidal creek and inner mangroves in Southern Asia (Tomlinson, 1994). In the nursery farm of Futian and Shantou of Mainland China, *S. caseolaris* was germinated in salinity lower than 10 ppt (Liao *et al.*, 1997a) while *S. apetala* was able to germinate in salinity lower than 5 ppt (Chen, *et al.*, 2000; Li, *et al.*, 1997; Huang & Zhan, 2003; Wu, *et al.*, 2000; Zhong *et al.*, 2003). Lau (1995) suggested that the low salinity in FMFNR encouraged *Sonneratia* to flourish.

In Hong Kong, most of the *Sonneratia* individuals (99.4%) were distributed in Deep Bay area (Chapter 2) where the salinity are the lowest compared to other areas throughout the year. The results of the germination experiment were consistent with the field observation and the works previously done by other scientists. Results showed that seeds of *S. apetala* had significant higher germination numbers (in terms of budding and leaf unfurling numbers) in 0 ppt, 5 ppt, 10 ppt and 15 ppt at the end of the experiment. Higher than 15 ppt, the

budding and unfurling numbers decreased when the salinity progressive increased, and the seeds could not unfurl in 35 ppt. Similarly, *S. caseolaris* also preferred low salinity. The budding and unfurling numbers of *S. caseolaris* were significantly higher in 0 ppt, 5 ppt, 10 ppt and 15 ppt than those in 25 ppt and 35 ppt. Although the seeds could bud in 25 ppt and 35 ppt but they could not unfurl later on.

Exceeding 15 ppt, the germination numbers decreased with the increasing salinity which suggested that *S. apetala* and *S. caseolaris* had a higher chance to distribute in area with relatively low salinity. In Hong Kong, salinity progressively increases from west to east in Hong Kong due to the influx of fresh water from Pearl River in the western side (Morton & Morton, 1983). The low salinity in Deep Bay area provided a suitable germination and nursery grounds for both *S. apetala* and *S. caseolaris*. It explained why these two species proliferated quickly and built up their communities in Deep Bay, also answered why they tended to grow along the water channels and tidal creeks (Chapter 2). The low salt tolerances of the *Sonneratia* spp. form a barrier to prohibit the dispersal of seeds to the eastern side of Hong Kong and explained why there was only one *S. caseolaris* individual in Tolo Area.

4.4.2 Substrate type effect on germination of *Sonneratia. apetala* and *S. caseolaris*

In Hong Kong, substrate types range from very sandy to very clayey. Mangrove plants showed different responses to the substrate, for example, *Kandelia obovata* can grow up to 8 m in Mai Po while those in To Kwa Peng can grow up

to 3 m only. Despite the factor of salinity, the substrate type might contribute to the different physiological responses.

From the result, both *S. apetala* and *S. caseolaris* showed no significant differences in germination numbers (in terms of budding and unfurling) between Tsim Bei Tsui and To Kwa Ping substrates. These suggested that substrate type was not a limiting factor to their germinations. In fact, seeds could germinate in water without any substrate as shown in the viability experiment in Chapter 3. There may be other physiological factors controlling the distribution of *Sonneratia* spp. Porter and Lawlor (1991) suggested that germination more depended on essential components such as water, temperature, stratification and sunlight than nutrient and texture. The experiment suggested that both *Sonneratia* species can develop on any type of substrate in case other biotic and physio-chemical factors met their requirements.

4.4.3 Shade tolerance on germination of *Sonneratia apetala* and *S. caseolaris*

Seeds of *S. apetala* could germinate in 0%, 56% and 90% and 100% shadings which indicated that it could grow in open mudflat and open canopy, as well as the closed canopy of the mangrove stand. There was no significant difference among the budding rates in 0%, 56% and 90% shadings. However, significant differences were found in term of unfurling rate, i.e. the development of first pair of leaves. At the end of the experiment, there was no significant difference among the budding and unfurling numbers in 0%, 56% and 90% shadings, suggesting that light intensity was only a limiting factor to the germination rate of *S. apetala*. *S. caseolaris* showed similar response to shading. Light intensities

affected the unfurling rate but not the budding rate. But in term of germination number (in terms of budding and unfurling), no significant difference was found. The faster unfurling rates of *S. apetala* and *S. caseolaris* favored them to distribute in place with high intensity, this explained why they were mainly distributed on mudflat, and individuals under the canopy were rarely found. Results also showed that there was a potential for the *Sonneratia* spp. to germinate under the canopy, especially, the open gap.

4.4.4 Effect on tidal level (submerging time) on germination of *Sonneratia apetala* and *S. caseolaris*

The result demonstrated that two species reacted similarly to the treatment, both of them could germinate under different tidal levels. At the end of the experiment, *S. apetala* had no significant differences ($p>0.05$) in germination numbers (in terms of budding and unfurling) among the three tidal levels. The experimental results indicated that *S. apetala* could establish at all tidal levels (submerging time). However, duration of submerging affected the germination of *S. caseolaris*. The germination numbers, including both budding and unfurling, were significantly higher in high tidal zone than low tidal zone. Therefore, *S. caseolaris* had a higher tendency to grow in high tidal zone with a shorter submerging time. Field observation was not consistent with the greenhouse experimental result in the present study. For example, Mai Po mangrove stand, most of the *S. caseolaris* individuals were distributed in the low tidal zone, such as the outer edge of the mangrove stand or mudflat area. It may be due to the high and mid tidal zones were occupied by the native species and *Sonneratia* were not able to invade into the stable and mature community. In other mangrove stands like Sha Kong Tsuen in Deep Bay, *S. caseolaris* were commonly found in

the high tidal zone. This implies if there are open gaps in the high tidal zone, the fast growing *Sonneratia* can rapidly colonize the gap.

4.4.5 Effect of cold period to *Sonneratia apetala* and *S. caseolaris*

Temperature can be a crucial factor which affects the geographical distribution of the plants. Zan *et al.* (2003) found that the seedlings of *S. caseolaris* could not survive the cold winter in 1993 while the seedlings of *S. apetala* could survive over that winter; nevertheless, the author thought that cold was not an obstacle to the introduction of *S. apetala* and *S. caseolaris.* In the present study, *S. apetala* seeds showed no significant difference in budding and unfurling numbers among different cold periods at the end of the experiment, while *S. caseolaris* seeds showed significant difference in budding and unfurling numbers between 0 hour and 48 hours cold periods. One interesting observation is the cold duration only affected the budding percentages of *S. caseolaris* but nearly 100% of the budded seeds were able to unfurl. These findings were consistent to the previous work by *Xiao et al.* (2004), indicated that *S. apetala* had a higher tolerance to cold stress than *S. caseolaris*, and the cold effect was more detrimental to *S. caseolaris*. However, the cold weather (less than 4°C) in Hong Kong is not long enough to kill all *S. caseolaris* seeds. Thus, cold weather in Hong Kong cannot block the invasion of *S. caseolaris.*

4.4.6 Comparing the germination conditions with native mangrove species

Tam & Wong (2004) had conducted a series of experiment on the effect of salinity, substrate type and tidal level to some native mangrove species. Result showed that their salinity tolerances declined in the order of *Avicennia marina*

(most salt tolerant) > *Kandelia obovata* > *Bruguiera gymnorrhiza* > *Aegiceras corniculatum* > *Excoecaria agallocha* > *Acanthus ilicifolius* > *Lumnitzera racemosa* > *Heritiera littoralis* (least salt tolerant). Both species of *Sonneratia* were salt sensitive, similar to *L. racemosa*, no germination occurred at salinities higher than 25 ppt but *Sonneratia* was more salt tolerant than *H. littoralis* which could not germinate at salinity higher than 10 ppt. For the substrate type, both *Sonneratia* species, *K. obovata* and *B. gymnorrhiza* showed no preference on substrate from Sai Kung and Mai Po. For the tidal level, *K. obovata* showed no preference on tidal level but *K. obovata* preferred low tidal level, opposite to *S. caseolaris.*

By comparing the germination conditions of *Sonneratia apetala* and *S. caseolaris* with the result of native mangrove species from Tam and Wong (2003), *Sonneratia* may pose threat to the rare mangrove plants *L. racemosa* and *H. littoralis* as they share the common niche of *Sonneratia* in term of salt tolerance. As *Sonneratia* is fast growing and highly reproductive, *Sonneratia* may out-compete these two species by occupying their common niche. However, both *L. racemosa* and *H. littoralis* mainly distributed on the eastern coast of Hong Kong which is sheltered from the invasion of *Sonneratia* (discussed in Chapter 3).

4.5 Conclusions

The germinations of *Sonneratia apetala* and *S. caseolaris* were determined by different environmental factors, including salinity, shade tolerance, tidal level and duration of cold period but not soil type. For salinity, both species preferred

low salinity (0 to 15 ppt). When salinity exceeded 15 ppt, their germination numbers decreased progressively and germination was virtually impossible in 35 ppt. Both species showed no preference to substrate type and germinated at the same rate and extent in Tsim Bei Tsui (clayer) and To Kwa Ping (sandy) substrate. In the shade tolerance experiment, light intensities affected the unfurling rate of *S. apetala* and *S. caseolaris* but not the numbers of germination (both budding and unfurling) at the end of the experiment. The faster unfurling rate at high light intensities favored them to establish on open mudflat than open or closed canopy. In term of tidal level (submerging time), *S. caseolaris* was more sensitive to tidal levels than *S. apetala*, as the budding and unfurling numbers of the former species was significantly higher in short period of submerging (high tidal level) than that in long period of submerging (low tidal level). For *S. apetala*, there was no significant difference among the three tidal levels. For the effect of cold period, *S. apetala* showed no significant difference among three cold periods (0 hour, 24 hours and 48 hours cold periods). On the other hand, *S. caseolaris* showed different degrees of frigid harm, the numbers of budding and unfurling in 48 hours cold period were significantly lower than that without cold period (0 hour). This indicated that the cold front in Hong Kong may potentially lower the viability of *S. caseolaris* seeds but not *S. apetala*.

Comparing the salt tolerance of *Sonneratia* species with the native mangrove species, results showed that *Sonneratia apetala, S. caseolaris, H. littoralis* and *L. racemosa* were all salt sensitive species and tend to germinate and establish below 25 ppt. If *Sonneratia* dispersed to the eastern side of Hong Kong, the two native species *H. littoralis* and *L. racemosa* might be threatening by the fast growing and highly reproductive *Sonneratia*.

CHAPTER 5

REMOVAL OF *SONNERATIA*

5.1 Introduction

In some case, the naturalized plant species become invasive plants and alter the composition of the vegetation by out-competing the native plant species, and hence reduce biodiversity. The detrimental effects are mostly irreversible. In this study, the distribution, dispersal ability and germination conditions clearly showed this exotic genus *Sonneratia* had been naturalized in Hong Kong, its fast growing, highly productive nature with adaptability to the environments in Deep Bay area give them a chance to proliferate. The vigor combined with a lack of natural enemies led to outbreak population and pose threat to the native mangrove species. Precautionary measures should be taken to remove the exotic species. To alleviate any undesirable impacts to the community structure of the mangrove stand, the growth and spread of *Sonneratia* should be carefully monitored. A control program with timely removal of the exotic plants is the only answer before the invasive species spreads widely.

There are many publications outlining the physical and chemical methods for controlling invasive species, most of these are based on basic research, and trial and error experiments (Cronk & Fuller, 1995; Myers & Bazely, 2003). Physical control methods can be divided into two categories, targeted and non-targeted (Cronk & Fuller, 1995). Targeted methods are more species-specific and have fewer disturbances to the native flora and fauna. Non-targeted methods are based mainly on burning, dredging and flooding, which kill all plants indiscriminately, thus it is only applicable to areas with a high density of exotic species. The physical methods include hand-pulling, cutting, ring barking/girdling (ring barking), levering/digging or mowing, and the last method is only confined to

herbaceous plants (Cronk & Fuller, 1995). There are some advance methods for physical removal by specifically designed machines like the harvesting vehicle for water hyacinth infested lakes and rivers (Wittenberg & Cock, 2005).

Chemical control methods involve the application of herbicide to decrease the population level of the exotic plants below a threshold of ecological tolerable impacts (Wittenberg & Cock, 2005). According to the definition of United States Environmental Protection Agency (USEPA), herbicide is a substance or a mixture which can prevent, destroy, repel or mitigate any pest. Uses of chemical control methods in areas of conservation importance are controversial. Firstly, the action of herbicides is not species specific and may affect the non-targeted flora if they use in spray (Caffrey, 1994). Before and after the application, one should carefully study the environmental effect. Secondly, most of the woody invaders can tolerate herbicide as they can regenerate fast and reinvade, thus cannot limit their spread. In this case, herbicide is ineffective unless applied continuously. In the past, there was no control on the use of chemicals. The broad-spectrum herbicides such as Dichloro-Diphenyl-Trichloroethane (DDT) were extensively used and led to detrimental impacts on the health of the animals and human (Wittenberg & Cock, 2001). Nowadays, most of the countries have banned the usage of DDT and restricted the use of other herbicides. In Hong Kong, the herbicide control is framed under the Pesticide Ordinance Cap. 133. The import, manufacture, formulation, distribution, sale and supply of all herbicides are regulated. Only the herbicides with the registered active ingredient(s) and conform to the specified maximum concentration are allowed to use in Hong Kong (AFCD, 2007b). The herbicides must also fit into two major considerations: personal and environmental safety (Stenstones & Garnett, 1994). There are nine approved aquatic herbicides by the USEPA, namely 2,4-D, Carfentrazone-ethyl, Copper, Diquat, Endothall, Glyphosate, Imazapyr, Fluridone and Triclopyr (Madsen, 2006). Glyphosate was chosen as the chemical control method in the present study. It is a registered herbicide in Hong Kong, the maximum concentration for retail sale is 50% active ingredient of the volume

(SL (50) w/v). Glyphosate is a broad spectrum systematic herbicide used to kill plants, especially perennials. It can inhibit the enzyme involved the synthesis of amino acids tyrosine, tryptophan and phenylalanine. Glyphosate can be absorbed through foliage and translocated to growing points. Glyphosate is a glycine derivative supplied as an amine salt. Once absorbed by soil, it is inactive and can be decomposed quickly with a half life of 60 days (Cronk & Fuller, 1995). Little or no residual activity has been noticed and it is approved for use in or near watercourses (Caffrey, 1994; Tiley & Philp, 1994). Glyphosate is slightly toxic to birds with LD_{50} of >3851 mg kg^{-1} body weight; moderately to very slightly toxic to fish, with 4-day LD_{50} values of 10 to >1000 mg L^{-1}; slightly to very slightly toxic to aquatic invertebrates with 2- to 4- day LC_{50} or EC_{50} values of $\geq$55 mg L^{-1} (WHO, 1994). Glyphosate has a very low acute toxicity and irritation potential to human, it does not cause mutation and induce cancer, and even repeated low dose exposure does not affect the fertility and the fitness of the offspring (Stensones & Garnett, 1994). It is comparatively safe to use glyphosate in Mai Po and Inner Deep Bay Ramsar Site due to the low toxicity to the fauna.

There are many methods of herbicide application, including frilling, stem injection, side branch reservoir application, basal bark application and cut stump application (Cronk & Fuller, 1995). Frilling involves the notching with an axe at the stem or penetrating the bark by a drill. At the frill, herbicide is applied to the moist sap wood by injection. Side branch reservoir application is a technique by injecting herbicides into the lowest part of the side branch. Basal bark application is to paint or spray the herbicide paint onto the bark at the base of the tree. Cut stump application is used in the stumps that are likely to sprout immediately after the cut to damage the sapwood. Effectiveness of the chemical control method varies from species to species, and from site to site. Methods of application, formulation of the herbicides and time of application are important factors affecting the effectiveness. As *Sonneratia* is a fast re-sprouting species, frilling and cut stump application were adopted.

In the past, the removal of *Sonneratia* species carried out by the Agriculture, Fisheries and Conservation Department of the Hong Kong Special Administrative Region (AFCD) was by means of cutting off the aerial plant part; however, the treated individuals were found re-sprouting after a short period of time. With this experience, AFCD eradicated the whole plant by levering to the ground level aiming to eliminate the chance of re-sprouting or re-growth. It was done by cutting the extensive root and pneumatophores, and then dredging out the whole plant from the mud. This method has numbers of downside. Firstly, it is relatively time ineffective five individuals could be removed in single man hour at most. Secondly, this application can damage the root system of non-targeted plants nearby. Thirdly, it can increase the suspended particles in the water column if implemented in a large scale. Inevitably, eradication of the exotic species by such simple levering method in areas with tall adult plants is ineffective and not environmental friendly.

The Civil Engineering and Development Department of the HKSAR (CEDD) also conducted a removal programme in Kam Tin Main Drainage Channel in 2002 as the mangrove patch blocked the outlet and led to flooding in Kam Tin Basin. The removal was not species specific, all the native and exotic mangrove plants were removed by dredgers. Inevitably, this method could effectively clear up all the mangrove plants; however, it causes disturbance to the substrate. The luxuriant forest of *Sonneratia* on the dredged site in recent years proves that the massive eradication of all mangrove plants could open up a suitable environment for *Sonneratia* as this genus has faster growth and more rapid colonization than the native mangroves.

The above methods adopted by the two government departments required large input of manpower and money, and were cost ineffective. The present study aims to try new removal methods and compare their effectiveness through field trial.

5.2 Materials and Methods

5.2.1 Study Area

Kam Tin River mangrove stand, Inner Deep Bay, Hong Kong Special Administrative Region, was chosen for the site to test different removal methods. Fringes of mangroves were developed on both sides of the channel after the construction of drainage channel in Kam Tin River in 1998. The field trial site was located at the western bund of the Kam Tin River, close to the outlet, and fall within the Mai Po and Inner Deep Bay Ramsar Site (Fig. 5.1). There were total 293 mature individuals of *Sonneratia* in the Kam Tin River mangrove stand, accounted for 17.3% of all the *Sonneratia* in Hong Kong. Of which, 63 and 230 were *S. apetala* and *S. caseolaris*, respectively. The density of *Sonneratia* in Kam Tin River was 23.50 per hectare, the densest place of *Sonneratia* in Hong Kong. The average height of *Sonneratia* was around 6 m tall.

5.2.2 Removal methods

Seven different treatments were applied in summer months as *Sonneratia* was found to be more biologically active at high temperature, thus the effect of the treatments could be more significant. They were I. “Hand pulling” (HP), II. “Cut only” (CO), III. “Cut and covered by mud” (CM), IV. “Cut and covered by plastic bag” (CP), V. “Cut and apply glyphosate” (CG), VI. “Ring barking” (RB) and VII. “Frill and inject glyphosate” (FG) methods. Bottles of glyphosate (Top chemical industry limited, 100/300c.c. Registration No.: 2P114 SL (41%) w/v) were purchased from Wong Yuen Shing Seed Company (G/F, 13 Connaught Road West, Hong Kong Telephone No: (852) 25431896). After the treatments, six monitoring were taken regularly throughout the 18 months, they were 1st, 2nd, 3rd, 6th, 12th and 18th months. The condition of the plants after treatments were evaluated, the presence of fungi and termite which indicate decay were recorded.

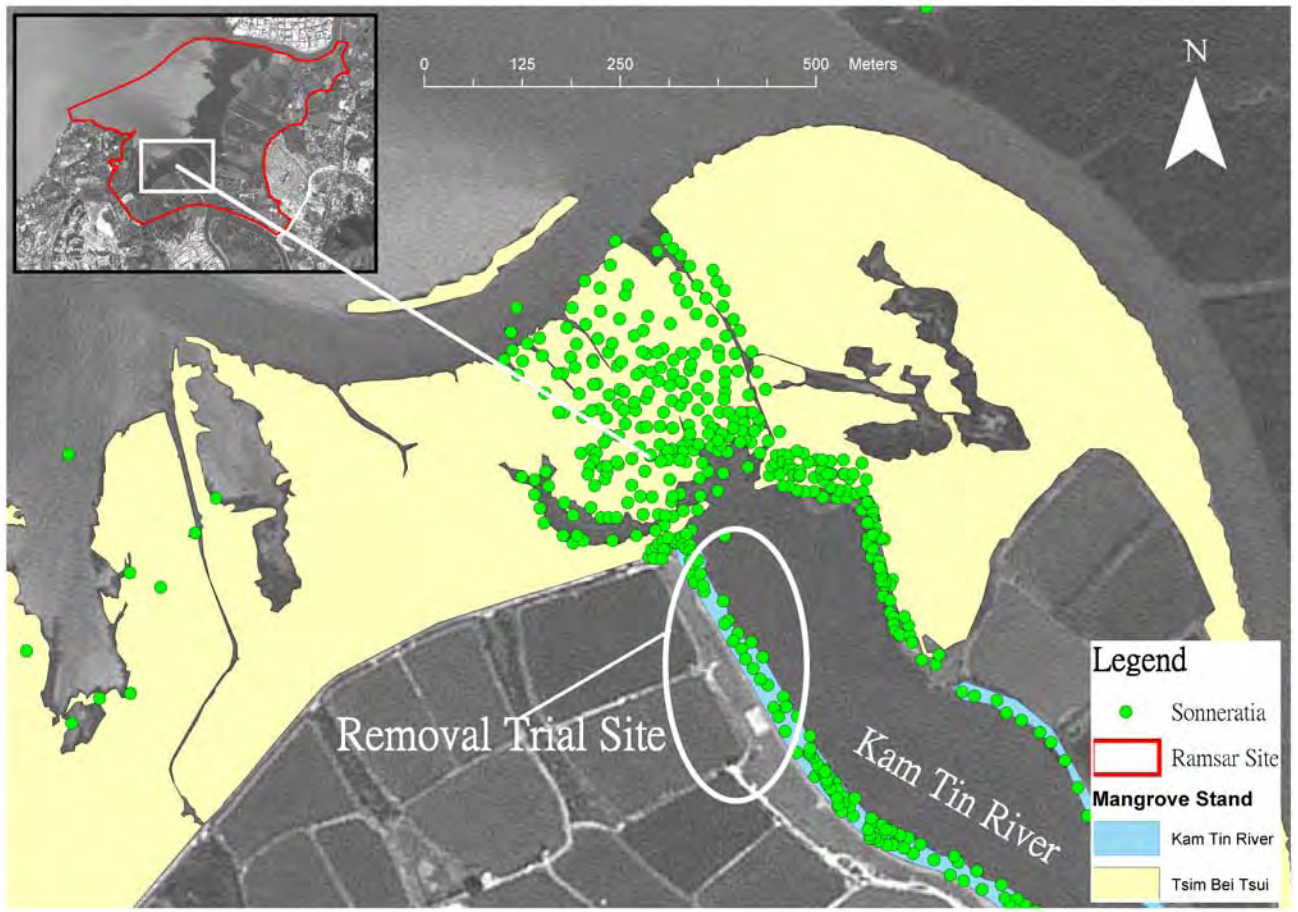


Fig. 5.1 Map showing the location of the field trial site in Kam Tin River mangrove stand, part of the Mai Po and Inner Deep Bay Ramsar Site

Photographic records were taken before and after the treatments for reference. The works were carried out when the tidal level on the mudflat was lower than 1.2 m. For simplicity, only *S. caseolaris* individuals were chosen for the field trial. “Hand pulling” (HP) method aimed at testing the applicable range while the other six methods were targeting the mature plants. The methodologies of each treatment were described in following subsections.

5.2.2.1 “Hand pulling” (HP) method

Thirty *Sonneratia caseolaris* individuals from seedlings of few centimeters tall to saplings of 3.5 meters were eradicated by “hand pulling” method (Photos 5.1 and 5.2). Ten individuals of each height group (<1.5 m, 1.5-2.5 m and 2.5-3.5 m) were selected from the study site. Individuals were removed by holding upper half of the plant and shaking them side by side for uprooting. The efficacy of this method to different height groups was evaluated.



Photo 5.1 *Sonneratia caseolaris* sapling on the mudflat



Photo 5.2 Sapling was removed by “hand pulling” method

5.2.2.2 "Cut only" (CO) method

Twelve individuals of *S. caseolaris* were randomly selected and cut by a chainsaw (Photo 5.3). Pneumatophores around the stumps were also cut. Stumps were left in the field without any further treatment (Photo 5.4). The cut stem was subdivided into log with < 1 m in length, left in the field for natural decay.



Photo 5.3 *Sonneratia caseolaris* individual was cut by a chainsaw



Photo 5.4 Stump remained after cutting

5.2.2.3 "Cut and covered by mud" (CM) method

Ten individuals were randomly selected and cut in the same way as the CO method described above except that a block of mud (20 cm) was piled up on the stump to create a dark and anaerobic environment, exert pressure to prohibit the cells from respiring and generating new buds (Photos 5.5 & 5.6). The cut stem was disposed in the way as the CO method. At each monitoring, mud was removed for inspection but was piled up again immediately.



Photo 5.5 Stump was covered by block of mud (20 cm)



Photo 5.6 Stump was completely covered by mud

5.2.2.4 "Cut and covered by plastic bag" (CP) method

Ten individuals were randomly selected and cut in the same way as the CO method described above except a plastic bag was placed on the top of the stump (Photo 5.7) and fixed with cable ties on the upper half, lower half and the base of the remaining stump (Photo 5.8). The cable ties were used to exert pressure on the stump while the plastic bag could block sunlight. A hole was drilled at the side of the plastic bag for inspection. The plastic bag covers of five individuals were removed after six months and the other five were removed after a year.



Photo 5.7 Stump was covered by plastic bag



Photo 5.8 The plastic bag was then fixed with three cable ties on the stump

5.2.2.5 "Cut and apply glyphosate" (CG) method

Five individuals were randomly selected and cut in the same way as the CO method. The herbicide, glyphosate, was poured on the freshly stump within 30 seconds after the cut (Photo 5.9) to ensure that the translocation from the damaged sapwood is still occurring (Cronk & Fuller, 1995). The stump was then covered by a plastic bag as the CP method to minimize the leakage of the chemical to the surrounding which may affect the non-targeted organisms (Photo 5.10).



Photo 5.9 Glyphosate was applied immediately after the cut



Photo 5.10 Stump was covered by a plastic bag to minimize the leakage of glyphosate to the surrounding

5.2.2.6 "Ring barking" (RB) method

Ten individuals were randomly selected. A bark strip of 15 cm wide and 1 cm deep was removed from the stem at 0.5-1 m high with a saw (Photo 5.11). If the tree had multi-trunk (co-dominant) stem, all the stems were ring barked (Photo 5.12). The cut should penetrate into the sapwood directly beneath the bark and the strip must be deep enough to remove any trace of vascular bundle, the growing region between the bark and the hardwood, and the vessels for transporting food and water.



Photo 5.11 Workers removed the bark by a saw



Photo 5.12 All the stems emerged from the multi-trunk individual were ring barked

5.2.2.7 "Frill and inject glyphosate" (FG) method

Five adult plants were randomly selected. A cordless drill (Bosch 9.6V Compact Tough Cordless Drill/Driver 32609) was used to penetrate 1-2 cm deep into the trunk at the breast height. Three holes were drilled vertically with each hole 2-3 inches apart (Photo 5.13). The above procedure was repeated four times at four different directions, East, South, West and North of the trunk. In each hole, 1 ml of glyphosate was injected into the moist sapwood by a syringe (Photo 5.14).



Photo 5.13 Holes were drilled on the trunk of the tree



Photo 5.14 Glyphosate was carefully injected into the hole by a syringe

5.2.3 Evaluation methods

The applicable range (in height) for "hand pulling" (HP) method was evaluated based on the success of pulling the individuals from the ground. The effectiveness of the other six removal methods was evaluated by monitoring the condition of the stump, degree of leaf shedding, the sign of rotting and the appearance of re-sprout/re-growth or emergence of buds. A scoring system was developed and summarized in Table 5.1 to compare the effectiveness of different treatments. The highest score 3 indicated the tree or stump was dead and could be removed; while the lowest score 0 suggested that the treatment failed to kill the plant and the method was ineffective. The average score of each treatment was calculated by the following formulae:

$$= \frac{\text{Sum of the score of the treated individuals}}{\text{No. of treated individuals in each treatment}}$$

Table 5.1 Scoring system to evaluate the effectiveness of the removal methods during 18-month monitoring of the removal trial

Score	Removal methods by "cut only" (CO), "cut and covered by mud"(CM), "cut and covered by plastic bag" (CP), "cut and apply glyphosate" (CG)	Removal methods by "ring barking" (RB), "frill and inject glyphosate" (FG)
0	Stump did not show rotting sign and could not be removed; with emerged bud(s) / re-sprouting	No sign of leaf shedding or tree rotted / Tree fell due to damage of typhoon with no signs of leaf shedding or rotting
1	Stump did not show rotting sign and could not be removed; no emerged bud(s) / re-sprouting	Some of the leaves shed, tree did not show rotting sign and did not fall
2	Stump showed rotting sign but could not be removed; no emerged bud(s) / re-sprouting	All leaves shed, tree showed rotting sign and did not fall
3	Stump rotted and could be removed; no emerged bud(s) / re-sprouting	All leaves shed, tree rotted and fell

5.3 Results

5.3.1 “Hand pulling” (HP) method

“Hand pulling” was very effective to remove *Sonneratia* individuals < 1.5 m height, and all 10 individuals were easily pulled out (Photo 5.15). For the group with 1.5-2.5 m tall, only one out of 10 individuals was pulled out while none of the individuals from the group of 2.5-3.5 m could be removed by “hand pulling”.



Photo 5.15 Individual < 1.5 m could be pulled out easily

5.3.2 "Cut only" (CO) method

The stumps of the treated individuals, ranging from 2.5 to 11 m height, did not show any rotting or re-sprouting sign after the 1st month (Table 5.2). In the 2nd month, all the stumps did not show rotting sign and could not be removed. Of which, eight (66.67%) stumps emerged new buds from the lateral side of the stump (Photo 5.16), the bud numbers varied from one to five. The number of stumps emerged buds decreased to seven (58.33%) in the 3rd month, and to three (25%) in the 6th month, the buds probably could not withstand the low temperature in the winter. For the individuals with emerged buds that survived throughout the monitoring period, the bud numbers increased. After a year of the treatment, nine (75%) treated individuals showed rotting sign and no buds were emerged, but the stumps still could not be removed as they were still very strong (Photo 5.17). A fungus was found on the stump of one individual, Individual CO 2 (Photo 5.18). In the last visit, the 18th month, the stumps were still too hard to be removed. Individual CO 3 was infested with termites.



Photo 5.16 New buds emerged from the side of the treated stump after two months of the treatment (Individual CO 2)



Photo 5.17 Buds probably could not withstand the low temperature and the stumps rotted after 12 months (Individual CO 2)



Photo 5.18 Fungi was found on the stump (Individual CO 2)

Table 5.2 Characteristics of the individuals treated by the "cut only" (CO) method and the monitoring results (Ht: Height; Dbh: Diameter at breast height; Bd: Basal diameter; Hts: Height of stump; ^ = scoring system refers to Table 5.1, number in bracket indicates the number of emerged buds found on the stump; * = with fungal infection, # = with termite infestation)

CODE	Characteristics of individuals before cutting and the height of stumps after cutting				Scores during the post-cutting period ^					
	Ht (m)	Dbh (cm)	Bd (cm)	Hts (cm)	1st Month	2nd Month	3rd Month	6th Month	12th Month	18th Month
CO 1	2.5	10	14	39	1	0 (2 buds)	0 (3 buds)	1	2	2
CO 2	5	11	16	45	1	0 (5 buds)	0 (5 buds)	1	2*	2*
CO 3	5.5	10	15	48	1	0 (4 buds)	1	1	2	2#
CO 4	4	6	12.5	38	1	0 (5 buds)	0 (6 buds)	1	2	2
CO 5	6	7.5	15	46	1	0 (1 bud)	0 (1 bud)	1	2	2
CO 6	11	23	31	9.5	1	0 (1 bud)	0 (1 bud)	0 (5 buds)	0 (6 buds)	0 (6 buds)
CO 7	7	12	18	9	1	0 (1 bud)	0 (1 bud)	0 (2 buds)	0 (4 buds)	0 (5 buds)
CO 8	10	27	37	13	1	0 (1 bud)	0 (1 bud)	0 (5 buds)	0 (7 buds)	0 (7 buds)
CO 9	7	21	28	11	1	1	1	1	2	2
CO 10	7	20	27	10	1	1	1	1	2	2
CO 11	7	17	22	8	1	1	1	1	2	2
CO 12	8	16	20	13	1	1	1	1	2	2

5.3.3 Cut and covered by mud" (CM) method

All the stumps did not show any rotting or re-sprouting signs after one month of the treatment (Table 5.3). In the 2nd month, two (20%) stumps (Individuals CM 1 & 4) showed rotting sign but no emerged bud was found, the rests remained unchanged. All individuals showed rotting sign and without new buds in the 3rd month, but the stumps were still too hard to be removed. Six individuals were infested by termites. In the 6th month, all the stumps showed rotting sign and no emerged buds, all of them were infested by termites (Photo 5.19). After a year, the termites were missing from the stumps probably due to the disturbance of the last two monitoring. The stumps were completely rotted and softened which could be easily removed.



Photo 5.19 Stump showed rotting sign and infested with termites (red circle (Individual CM 9)

Table 5.3 Characteristics of the individuals treated by the "cut and covered by mud" (CM) method and the monitoring results (Ht: Height; Dbh: Diameter at breast height; Bd: Basal diameter; Hts: Height of stump; ^ = scoring system refers to Table 5.1; # = with termite infestation)

CODE	Characteristics of individuals before cutting and the height of stumps after cutting				Scores during the post-cutting period ^					
	Ht (m)	Dbh (cm)	Bd (cm)	Hts (cm)	1st Month	2nd Month	3rd Month	6th Month	12th Month	18th Month
CM 1	8	14	22	12.5	1	2	2#	2#	3	3
CM 2	8	20	32	9.5	1	1	2	2#	3	3
CM 3	10	24	33	9.5	1	1	2	2#	3	3
CM 4	9	20	34	9	1	2	2#	2#	3	3
CM 5	8	23	26	14	1	1	2#	2#	3	3
CM 6	5	12	14	9.5	1	1	2#	2#	3	3
CM 7	7	22	32	14.5	1	1	2#	2#	3	3
CM 8	7	21	29	12	1	1	2	2#	3	3
CM 9	10	21	31	11	1	1	2	2#	3	3
CM 10	10	22	32	9	1	1	2#	2#	3	3

5.3.4 "Cut and covered by plastic bag" (CP) method

In the 1st month, only two (20%) of the 10 treated individuals (Individuals CP 4 & 10) showed rotting but not re-sprouting signs, and the remaining did not rot nor re-sprout (Table 5.4). In the 2nd month, individuals with rotting sign increased to three (30%) (Individuals CP 4, 7 & 10) and further increased to six (60%) (Individuals CP 3, 4, 6, 7, 8 & 10) in the 3rd month but these individuals were still not completely rotted and could not be removed. Half a year later, all the stumps showed rotting sign but no emerged buds except Individual CP 9, which had then developed three buds at the side of the stump, close to the inspection hole of the plastic bags (Photo 5.20). Individuals CP 6-10 were found infested with termites. Even the plastic bags of Individuals CP 6-10 were removed after six months, the stumps did not re-sprout in the subsequent months, the stumps were still too hard and could not be removed at the end of the monitoring period. Termites were not found in the 12th and 18th month, probably due to the disturbances of the last two monitoring. Similarly, for the other five individuals (Individuals CP 1-5), their plastic bags were removed one year later, all the stumps showed rotting sign but still could not be removed in the 18th month (Photo 5.21). Fungi was found on Individual CP 2 in the 12th month but disappeared in the 18th month with unknown reason. Two individuals (Individuals CP 3 & 4) were infested by termites in the 18th month.

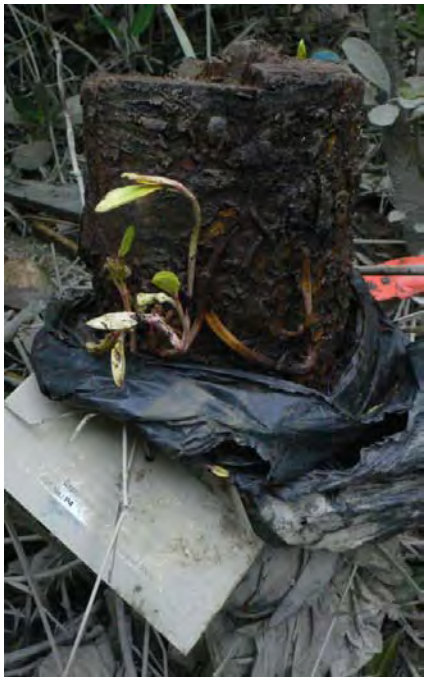


Photo 5.20 Individual developed bud at the side of the stump, close to the inspection hole of the plastic bag (Individual CP 9)



Photo 5.21 Stump showed rotting sign but were too hard to be removed (Individual CP 3)

Table 5.4 Characteristics of the individuals treated by the "cut and covered by plastic bag" (CP) method and the monitoring results (Ht: Height; Dbh: Diameter at breast height; Bd: Basal diameter; Hts: Height of stump; ^ = scoring system refers to Table 5.1, number in bracket indicates the number of emerged buds found on the stump and grey box indicates the monitoring result after the removal of the plastic bags; * = with fungal infection; # = with termite infestation)

CODE	Characteristics of individuals before cutting and the height of stumps after cutting				Scores during the post-cutting period ^					
	Ht (m)	Dbh (cm)	Bd (cm)	Hts (cm)	1st Month	2nd Month	3rd Month	6th Month	12th Month	18th Month
Plastic bags were removed after one year										
CP 1	2.5	6	7	24	1	1	1	2	2	2
CP 2	3.5	13	18	43	1	1	1	2	2*	2
CP 3	5	7.5	11	37	1	1	2	2	2	2 #
CP 4	4.5	9.5	13.5	40	2	2	2	2	2	2 #
CP 5	4.5	6	10	49	1	1	1	2	2	2
Plastic bags were removed after six months										
CP 6	6.5	15	20	33	1	1	2	2#	2	2
CP 7	3.5	7	9.5	45	1	2	2	2#	2	2
CP 8	8	10	15	56	1	1	2	2#	2	2
CP 9	8.5	13	23	25	1	1	1	0(3 buds)#	2	2
CP 10	5.5	20	28	26	2	2	2	2#	2	2

5.3.5 "Cut and apply glyphosate" (CG) method

All cut stumps did not show any sign of re-sprouting throughout the monitoring period (Table 5.5). Two (40%) of the five treated individuals (Individuals CG 2 & 5) showed rotting sign in the 2nd month but the stumps were still too hard to be removed. After half a year, all the stumps showed rotting sign. The plastic bags were removed after a year and fungi was found on the Individual CG 4 (Photo 5.22). At the end of the monitoring period, three stumps (CG 3, 4 & 5) rotted and could be easily removed (Photo 5.23), the fungi on Individual CG 4 was disappeared due to unknown reason.



Photo 5.22 Fungi was found on the stump (Individual CG 4) in the 12th month



Photo 5.23 After 18 months, stump rotted and could be easily removed (Individual CG 4)

Table 5.5 Characteristics of the individuals treated by the "cut and apply glyphosate" (CG) method and the monitoring results (Ht: Height; Dbh: Diameter at breast height; Bd: Basal diameter; Hts: Height of stump; ^ = scoring system refers to Table 5.1; * = with fungal infection, grey box indicates the monitoring result after the removal of the plastic bags)

CODE	Characteristics of individuals before cutting and the height of stumps after cutting				Scores during the post-cutting period ^					
	Ht (m)	Dbh (cm)	Bd (cm)	Hts (cm)	1st Month	2nd Month	3rd Month	6th Month	12th Month	18th Month
CG 1	4	18	20	68	1	1	1	2	2	2
CG 2	4	7	14	35	1	2	2	2	2	2
CG 3	4	9	12	37	1	1	1	2	2	3
CG 4	4.5	7	11	49	1	1	1	2	2*	3
CG 5	5	8	12	60	1	2	2	2	2	3

5.3.6 "Ring barking" (RB) method

After one month, three (30%) of the 10 treated plants (Individuals RB 2, 3 and 4) fell without signs of leaf shedding or rotting (Table 5.6). They were all < 5 m tall and their falls might due to the treatment itself that severely striped away the supporting tissue and the remaining tissue was not strong enough to give support to the weight of the plant part above the "ring barking" region. Buds were developed in the "ring barking" strip afterward and the number of buds progressively increased throughout the 18-month monitoring period. Seven (70%) individuals (Individuals 1, 5, 6, 7, 8, 9 & 10) had 10% of leaf shedding, tree did not show rotting sign and did not fall. In the 2nd month, seven treated *Sonneratia* shed 20%-60% leaves. Individual RB 8 developed a bud in the "ring barking" region. After six months, two (20%) individuals (Individuals RB 1 & 9) shed all their leaves and trees showed rotting sign while the five individuals (RB 5, 6, 7, 8 & 10) shed 50%-70% of their leaves but tree did not show rotting sign. In the 12th month monitoring, Individual RB 1 was found fall after the typhoon (Photo 5.24) and two new buds emerged from the stump (Photo 5.25). Three (30%) individuals (Individuals RB 5, 8 & 9) shed all the leaves, trees showed rotting sign but did not fall (Photos 5.26), no new buds were developed at the "ring barking" region (Photo 5.27). At the end of the monitoring period, 18 months after the treatment, all leaves of the treated individuals were completely shed and tree showed rotting sign except Individual RB 10 with 20% leaves hanging on the tree. However, the two buds on Individual RB 1 were disappeared in this month as bud could not withstand the low temperature in the winter.



Photo 5.24 Individual RB1 was broken after a typhoon



Photo 5.25 Two new buds emerged from the stump (Individual RB 1)



Photo 5.26 All the leaves shed after a year (Individual RB 5)



Photo 5.27 No new bud was emerged in the ring barking region (Individual RB 8)

Table 5.6 Characteristics of the individuals treated by the "ring barking" (RB) method and the monitoring results (Ht: Height; Dbh: Diameter at breast height; Bd: Basal diameter; ^ = scoring system refers to Table 5.1, number in bracket indicates the percentage of leaf shedding and/ or the number of emerged buds found on the stump; ※ = Tree fell due to damage of typhoon with no signs of leaf shedding or rotting)

CODE	Characteristics of individuals before treatment			Scores during the post-treatment period ^					
	Ht (m)	Dbh (cm)	Bd (cm)	1st Month	2nd Month	3rd Month	6th Month	12th Month	18th Month
RB 1	7	22	25	1 (10%)	1 (50%)	1 (50%)	2	0 ※ (2 buds)	0 (no buds)
RB 2	4	8	13	0 ※	0 (1 bud)	0 (1 bud)	0 (5 buds)	0 (5 buds)	0 (5 bud)
RB 3	4	10	16	0 ※	0 (1 bud)	0 (1 bud)	0 (2 buds)	0 (4 buds)	0 (4 bud)
RB 4	4	6	10	0 ※	0 (1 bud)	0 (1 bud)	0 (2 buds)	0 (6 buds)	0 (5 bud)
RB 5	5	20	28	1 (10%)	1 (50%)	1 (50%)	1 (70%)	2	2
RB 6	5.5	15.5	21	1 (10%)	1 (20%)	1 (60%)	1 (70%)	1 (80%)	2
RB 7	6	12.5	17	1 (10%)	1 (50%)	1 (50%)	1 (70%)	1 (70%)	2
RB 8	6.5	15	20	1 (10%)	1 (50% + 1 bud)	1 (50%)	1 (60%)	2	2
RB 9	9	15	21	1 (10%)	1 (40%)	1 (50%)	2	2	2
RB 10	11.5	30	42	1 (10%)	1 (60%)	1 (50%)	1 (50%)	1 (50%)	1(80%)

5.3.7 "Frill and inject glyphosate" (FG) method

In general, the effectiveness of the herbicide decreased when the height of the plants increased. After one month of the treatment, leaves of two (40%) individuals (Individual FG 1 & 5) were completely shed, while the remaining three individuals had 10%-50% leaf shedding (Table 5.7). In the 2nd month, one (20%) individual (Individual FG 1) recovered from the treatment and showed signs of re-sprouting, new leaves were found on the tip of the branch (Photo 5.28), while three (60%) treated individuals (Individuals FG 2, 3 & 4) had 10%-50% leaf shedding. Individual FG 5 shed all the leaves and showed rotting sign. Glyphosate was further injected into individuals (Individuals FG 1, 2, 3 & 4) after this monitoring. In the 3rd month, two individuals (Individuals FG 1 & 5) shed all leaves and trees showed rotting sign (Photo 5.29) while the others three had 20%-70% leaf shedding. After one year, Individual FG 2 fell after a typhoon and buds were found on the broken edge in the 18th month. Individual FG 1 was found completely recovered in the 12th month, new leaves were re-sprouted. After 18 months, new buds were found on four (40%) individuals (Individuals FG 1, 2, 3 & 4), while the Individual FG 5 had all the leaves shed, tree was completely rotted and fell (Photo 5.30).



Photo 5.28 New leaves were found on the tip of the treated individual (Individual FG 1)



Photo 5.29 All leaves shed after a year (Individual FG 5)



Photo 5.30 After 18 months, Individual FG 5 withered and tree fell

Table 5.7 Characteristics of the individuals treated by the "frill and inject glyphosate" (FG) method and the monitoring results (Ht: Height; Dbh: Diameter at breast height; Bd: Basal diameter; **I** = further injection of glyphosate; ^ = scoring system refers to Table 5.1, number in bracket indicates the percentage of leaf shedding and/ or the number of emerged buds found on the stump)

CODE	Characteristics of individuals before treatment			Scores during the post-cutting period ^					
	Ht (m)	Dbh (cm)	Bd (cm)	1st Month	2nd Month	3rd Month	6th Month	12th Month	18th Month
FG 1	6	14	15	2	1 (70%) + **I**	2	2	0	0
FG 2	7	20	25	1 (10%)	1 (10%) + **I**	1 (20%)	1 (20%)	0 ^	0 (2 buds)
FG 3	5.5	37	41	1 (50%)	1 (50%) + **I**	1 (60%)	1 (60%)	1 (20%)	1 (10%)
FG 4	5.5	20	28.5	1 (30%)	1 (40%) + **I**	1 (70%)	1 (70%)	1 (60%)	1 (40%)
FG 5	4.5	11	18	2	2	2	2	2	3

5.3.8 Ranking different removal methods by a scoring system

Among all the seven removal methods in the present study, clearly, the "hand pulling" (HP) method was the best choice to remove seedlings or saplings with size < 1.5 m tall. For tall individuals with pneumatophores, the "cut and covered by mud" (CM) method had the highest score after 18-month monitoring period (Fig. 5.2). This method got 3 marks after a year indicating that it could successfully kill *Sonneratia*. The "cut and apply glyphosate" (CG) method got >2 marks indicated that it was the second most effective method but this method should be avoided due to the unknown impact of herbicide to the native flora and fauna. The "cut and covered by plastic bag" (CP) method for six and twelve months plastic bag coverage both scored 2 marks at the end of the monitoring period, indicating this method could also control the *Sonneratia* but was not as effective as the CM and CG methods. The "cut only" (CO) method had the lowest score among the treatments as 25% of the treated individuals re-sprouted, indicating the CO method was not reliable. Both the "ring barking" (RB) and "frill and inject glyphosate" (FG) methods had a score lower than 2, indicating that they failed to control *Sonneratia* (Fig. 5.3).

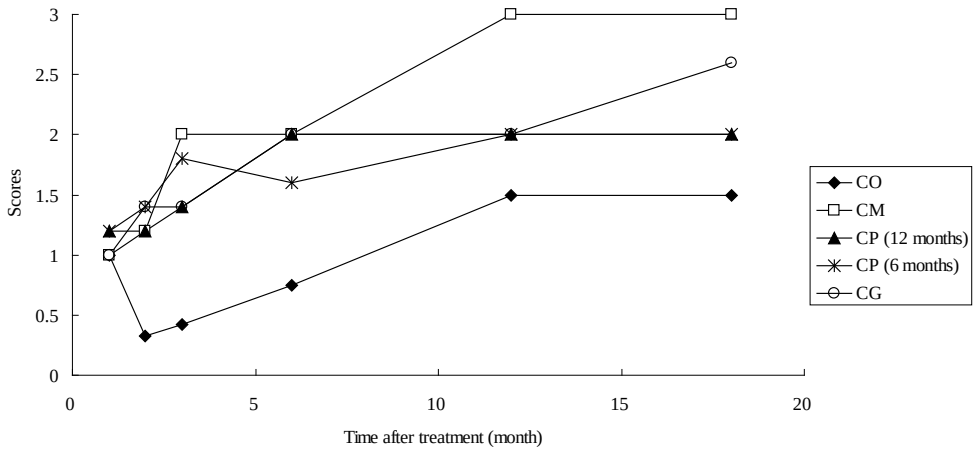


Fig. 5.2 The average scores of different cutting methods “cut only” (CO), “cut and covered by mud” (CM), “cut and covered by plastic bag” (CP) for 6 and 12 months and “cut and apply glyphosate” (CG) methods (scoring system refers to Table 5.1)

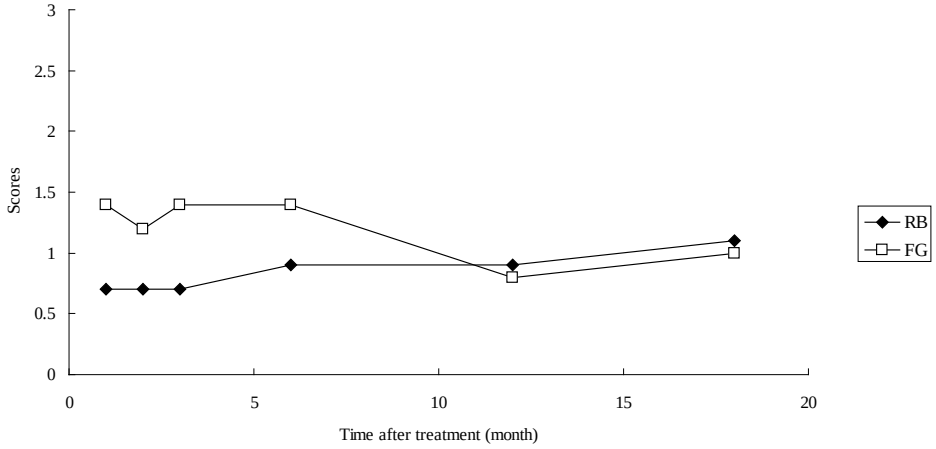


Fig. 5.3 The average scores of the “ring barking” (RB) and “frill and inject glyphosate” (FG) methods (scoring system refers to Table 5.1)

5.4 Discussion

5.4.1 Methods to control invasive plants

Invasive plants grow, adapt, proliferate without respect for boundaries, they live and reproduce whenever opportunity arises. Since the first record of *Sonneratia* in Mai Po mangrove stand in the beginning of this century, *Sonneratia* spp. expand their territory and spread as far as to Lantau area on the southern side of Hong Kong in recent years (Chapter 2). As *Sonneratia* is fast growing species which can reach >10 m tall when they are fully grown (Tomlinson, 1994), there is a possibility for them to become invasive and affect the growth of native plants, particularly, they will overshadow the shorter native plants in Hong Kong. Precautionary actions have been taken by the government of Hong Kong and other green groups such as the World Wide Fund for Nature (Hong Kong) (WWFHK) who are responsible for the management of Mai Po Marshes Nature Reserve (MPMNR).

According to Westbrooks & Eplee (1999), there are four lines of defense against invasive plants. The first and crucial line is early detection. The survey of *Sonneratia* in Chpater 2 served as the first line of defense as it can serve as (1) a reference guide for removal work, and (2) a baseline data to compare the abundance, distribution and the spread of *Sonneratia* in the future. The second line is to contain and eradicate the colonizations as soon as they are detected. AFCD played the major role to fight at the second line, the colonization of *Sonneratia* in the mangrove stands of Mai Po and Inner Deep Bay Ramsar Site,

Hong Kong Wetland Park and Tai O were removed by "hand pulling" method and levering from time to time (Table 5.8). The WWFHK also eradicate the *Sonneratia* seedlings colonized along the channels within MPMNR. In addition, there were two projects involved the clearance of *Sonneratia*. Both were managed by the Civil Engineering and Development Department (CEDD), one at the outlet of Kam Tin Main Drainage Channel (MDC) and another one at the construction site of the Deep Bay Link. At least 16,496 individuals of *Sonneratia* were removed by the above parties in Hong Kong from 2001 to 2008. In spite of these removal exercises, *Sonneratia* were found spreading to non-colonized areas, possibly of their tiny seeds and hard to detect their saplings when they are shorter than the native mangroves. The third line is to prevent *Sonneratia* spreading to new areas. The clearance of *Sonneratia* in Lantau area could remove the most southern individuals in Hong Kong and thus prevent their further expansion to Hong Kong, Sai Kung, Tolo and Northeast New Territories areas. The fourth line of defense is to develop effective removal methods to control the large colonization, the most effective method was tried out in this chapter. On top of this, a long term management plan should be established for the long battle against *Sonneratia* that discussed in Chapter 6.

Cronk & Fulller (1995) suggested that no single removal method is superior to the others and applicable to all situations. Some are more expensive but have better control of the reproductive individuals. Some are inexpensive but with low effectiveness. The best practice to manage an exotic species is by a system of

Table 5.8 Removal work of *Sonneratia* in Hong Kong from 2001-2008 (CEDD: The Civil Engineering and Development Department, HKSAR; AFCD: The Agriculture, Fisheries and Conservation Department, HKSAR; HK-SWC: Hong Kong-Shenzhen West Corridor Project and WWFHK: World Wild Fund for Nature Hong Kong) (Sources of information: Personal communication with Dr. Kwok, P.W.W. & Dr. Tam, T.W., AFCD, Mr Smith, B., WWFHK and http://www.hyd.gov.hk/eng/major/road/projects)

Government Department/ Organization	Location	Time of removal (Month/ Year)	No. of *Sonneratia*			Total no. of *Sonneratia* removed
			Seedlings <1.5 m	Saplings 1.5-2.5 m	Adults >2.5 m	
CEDD	Outlet of Kam Tin Main Drainage Channel, Deep Bay area	4/2002	N/A	N/A	N/A	N/A
AFCD	Mai Po and Inner Deep Bay Ramsar Site, Deep Bay area	7/2001	N/A	N/A	N/A	23
		3/2002	N/A	N/A	N/A	400
		2/2003	N/A	N/A	N/A	650
		3-9/2006	450	200	100	750
		10-12/2007	100	1126	1294	2,520
		6-10/2008	4995		5723	10,218
	Wetland Park, Deep Bay area	9/2001	0	251		251
		10/2006	20	0	0	20
	Tai O Salt Pan, Lantau area	11/2006	N/A	10	3	13
		11/2007	10	N/A	N/A	10
HK-SWC	Deep Bay Link, Deep Bay area	11/2004	783	249	521	1,553
WWFHK	Mai Po Marshes Nature Reserve, along the channels, Deep Bay area	Since 2003/2004	>50	>33		>88
						Total: >16,496

integrated management, the combination of different removal methods (Wittenberg & Cock, 2005). Integration of various removal methods can strikingly reinforce one another, for example, biological control of *Chondrilla juncea* by rust fungus gave 55% control and the improved pasture competition gave 35%, the combination of the two methods gave 95% of the control (Cronk & Fuller, 1995). The indirect impacts of the selected removal method to the native species, including flora, fauna and the ecosystem, must also be considered (Wittenberg & Cock, 2005). The most effective exotic species removal method should be species-specific and has the least impact on non-targeted plants.

5.4.2 Pros and Cons of different removal methods

Currently there is neither literature nor study on the removal methods on *Sonneratia*. The present field trial investigated the application of seven removal methods. With the experience obtained by AFCD in the past and the results from this study, pros and cons of different removal methods are summarized in Table 5.9.

"Hand pulling" (HP) method is the best method to eradicate seedlings and saplings. This method has been effective against some exotic species, for example, hand pulling by volunteers has successfully controlled *Centaurea diffuse* (Diffuse Knapweed) in America (Cronk & Fuller, 1995). In the past, WWFHK used this method to successfully control the recruitment of

Table 5.9 The advantages and disadvantages of various removal methods investigated in the field trial and previous works adopted by AFCD and/or WWFHK (**Adopted in the removal works done by AFCD or WWFHK in the past)

Removal methods	**Description**	**Advantages**	**Dis-advantages**	**Recommended applied area**	**No. of ind. treated per man hour & Applicable range**
"Hand pulling" (HP) method **	Direct pulling by hand / Stepping down the plant into the substrate	● Completely remove the plant and avoid re-sprouting ● Easy to apply, little training is needed	● Limit to seedlings (< 1.5 m) ● Labour intensive for taller individuals ● Disturb substrate ● Seedlings are difficult to detect and distinguish from that of the native mangroves	● Mudflat	● **360 ind.** ● Applicable to seedlings, ideal for individuals < 1.5 m tall
Digging/ Levering **	Digging up the plant with a mattock or a crowbar	● Completely remove the plant and avoid re-sprouting	● Labour intensive ● Disturb substrate ● Increase suspended particles in water column ● Damage nearby root system of non-targeted plants	● Mudflat and moderately infested area	● **5 ind.**

Cont'd Table 5.9 The advantages and disadvantages of various removal methods investigated in the field trial and previous works adopted by AFCD and/or WWFHK (**Adopted in the removal works done by AFCD or WWFHK in the past)

Removal methods	**Description**	**Advantages**	**Dis-advantages**	**Recommended applied area**	**No. of ind. treated per man hour & Applicable range**
"Cut only" (CO) method **	Cut the aerial part by a saw or chainsaw	● No limitation on the sizes of tree ● Require less time and man power ● Stump remained can stabilize the substrate	● The fallen plant parts may devastate the surrounding environment ● Difficult to clear up the plant parts ● 25% of cut individuals re-sprouted	● Not recommended as re-sprout may occur few months after removal	● **15 ind. (chainsaw)** ● Applicable to all saplings and trees
"Cut and covered by mud" (CM) method	After cutting, cover the stump by mud	● Prevent re-sprouting ● Same as the CO method	● The fallen plant parts may devastate the surrounding environment ● Difficult to clear up the plant parts ● Mild disturbance to the substrate nearby	● Open mudflat to heavily infested area	● **10 ind** ● Applicable to all saplings and trees

Cont'd Table 5.9 The advantages and disadvantages of various removal methods investigated in the field trial and previous works adopted by AFCD and/or WWFHK

Removal methods	**Description**	**Advantages**	**Dis-advantages**	**Recommended applied area**	**No. of ind. treated per man hour & Applicable range**
"Cut and covered by plastic bag" (CP) method	After cutting, cover the stump by plastic bag for half a year	● Prevent re-sprouting ● Same as the CO method	● The fallen plant parts may devastate the surrounding environment ● Difficult to clear up the plant parts ● Input of man-made material into the natural environment, require follow up action to remove the plastic bag	● Open mudflat to heavily infested area	● **10 ind.** ● Applicable to all saplings and trees
"Ring barking" (RB) method	Bark strip of 15 cm wide and 1cm deep is removed from the stem at 0.5-1 m high with saw	● Require less time and man power ● Tree remained can stabilize the substrate	● The tree may fall after "ring barking" and re-sprout ● Slow process, not effective in prevent re-sprouting, buds can develop at the breakage point	● Not recommended as re-sprout may occur after fall	● **1.5 ind.** ● Applicable to saplings and trees, but not to individuals shorter than 4 m

Cont'd Table 5.9 The advantages and disadvantages of various removal methods investigated in the field trial and previous works adopted by AFCD and/or WWFHK (**Adopted in the removal works done by AFCD or WWFHK in the past)

Removal methods	Description	Advantages	Dis-advantages	Recommended applied area	No. of ind. treated per man hour & Applicable range
"Frill and inject glyphosate" (FG) method **	Grill holes into the sapwood and inject herbicide	● Same as the RB method	● Potential harmful to native flora and fauna ● Expensive ● Required repeated application ● May develop resistance in long-term use	● Not recommended as re-sprout may occur and herbicide has unknown impact(s) to non-targeted organisms	● **2 ind.** ● Applicable to saplings only, ineffective for plants taller than 5 m
"Cut and apply glyphosate" (CG) method	Application of herbicide on the stump	● Prevent re-sprout ● Same as the RB method	● Potential harmful to native flora and fauna ● Expensive ● May develop resistance in long-term use	● Not recommended as herbicide has unknown impact(s) to non-targeted organisms	● **10 ind.** ● Applicable to saplings and trees

mangrove seedlings on the mudflat out of the bird hides in Mai Po mangrove stand. The HP method is highly effective as complete removal of the whole plant can eliminate the chance of re-sprouting. It is also easy to apply. The method is most suitable to apply extensively on mudflat where the seedlings are mostly congregated and easily spotted. However, the HP method is only ideal to *Sonneratia* seedlings that are shorter than 1.5 m. The work can be labour intensive for tall individuals especially if their pneumatophores have fully grown. The work should be done with gentle shaking to avoid unnecessarily disturbance of the top soil. Another problem is the difficulty in distinguishing the newly emerged *Sonneratia* seedlings (without pneumatophores) from those of the native species such as *Aegiceras corniculatum* and *Kandelia obovata* (Photo 5.31). The worker must be trained to identify the seedlings before the removal job is carried out.



Photo 5.31 The resemblance of seedlings of *Sonneratia caseolaris* (Left), *Kandelia obovata* (Center) and *Aegiceras corniculatum* (Right)

Digging/levering was previously adopted in the management works conducted by the AFCD, the whole plant was dug up with a mattock or a crowbar in this method. The effectiveness, advantages and disadvantages of this method could be learnt from the past experiences; therefore, it was not tested in the present study. It has a wider applicable range than the HP method, individuals up to 12 m could be removed (Photo 5.32). Digging/levering is best to apply on mudflat and moderately infested area where the density of the mangrove plants are not too high and the process does not damage the roots of non-targeted plants. This method can completely remove the plant and avoid the chance of re-sprouting. However, as mentioned in the introduction section, levering method is comparatively labour intensive and the process can disturb the substrate. It also increases the suspended particles in the water column. This method may potentially damage the root system of non-targeted plants nearby in the high densities area as roots from different individuals can intercross with each other.



Photo 5.32 Levered individuals

Both HP method and levering are labour intensive, the “cut only” (CO) method using saw or chainsaw to cut through the stem of the adult *Sonneratia* is the possible means. The remaining stump and root system can still stabilize the substrate and hence reduce the impact to the ecosystem. With the use of an electrical machine, time and manpower required will become less. The disadvantage of the CO method is the fall of the cut off aerial plant part may devastate the surrounding environment, in particular, the native mangrove plants nearby. To minimize the disturbance to the native mangroves nearby, side branches of the selected individual should be

removed before cutting. In addition, cutting process should be carefully planned to control the direction of the fallen plant part. The surrounding of the selected individual should be inspected to identify the directions which have no or only few native mangroves. Sometimes, the leaning direction of the tree might affect the falling direction. Workers should carefully assess the leaning direction and try to use gravity as the help of fall. Another disadvantage is the difficulty to remove the cut logs from the muddy environment of the mangrove stand. To facilitate the removal process, the plant part should fall on the same direction and try to point it to the water channel. Stem of *Sonneratia* should be cut into small logs to facilitate the removal. New buds and branches can be re-sprouted from the cut stump, the present field trial showed that 25% of the cut individuals were re-sprouted at the end of 18-month monitoring period (Table 5.2). This method was therefore not recommended for removing *Sonneratia*.

To reduce the chance of re-sprouting, the CO method was modified to the "cut and covered by mud" (CM) and "cut and covered by plastic bag" (CP) methods. Same as the CO method, both methods have large applicable range, require less man power and time than other removal methods and the stump remained can stabilize the substrate. They do not damage the root systems of the non-targeted mangroves. According to the result, both the CM and CP methods could prevent re-sprouting, and the former method was more effective as stumps of all CM individuals rotted and were easily removed after 12 months while the stumps of CP individuals were still very tough

and could not be removed after 18 months (Tables 5.3 & 5.4). These two methods can be applied to the open mudflat to the heavily infested area as they can effectively kill the adult plants. Same as the CO method, the fallen plant parts may devastate the surrounding environment and the plant parts are difficult to clear up. One additional disadvantage of the CP method is the introduction of plastic bags into the environment, but they can be removed after six months according to the field trial.

The "ring barking" (RB) method slowly kills the plant. By cutting through the vascular bundle, the flow of nutrients is interrupted, leading to death. However, the RB method alone may not be sufficient for killing the exotic species in a short period of time as the movement of water and nutrient is not restricted to the outermost layer of the trunk (Wittenberg & Cock, 2001). The present field trial showed that RB could not effectively damage the vascular bundle and the transportation process. Half of the treated individuals re-sprouted or still had leaves at the end of the 18-month monitoring period (Table 5.6). Some individuals fell during the monitoring period, especially the small individuals (<4 m), were probably due to the loss of the supporting tissues through the ring barking process and new buds were developed on the breakage point. The RB method is not effective in controlling *Sonneratia* even though the method require less time and man power and the tree remained can stabilize the substrate.

Chemical control has a long lasting effect and can be advantageous over physical methods (Weber, 2003). WWFHK conducted a small-scale field trial in 2005, glyphosate was injected into the plant through the drilled holes on the stem, and the result showed that glyphosate was an effective means for controlling *Sonneratia* (Personal communication with Mr. Smith, B., WWFHK). However, the effectiveness of glyphosate was not demonstrated in this study. The "frill and inject glyphosate" (FG) method was only effective to the saplings of *Sonneratia*, the taller individuals (>5 m) only had some of their leaf shed off but were still alive (Table 5.7). The field trial result also showed that some individuals might lose all the leaves after the treatment but new leaves then re-sprouted. Sometimes, herbicides are ineffective unless continuously applied. In the present study, the repeated application of glyphosate in FG method still could not effectively kill the plants. The effect only last for a short period of time. After then, the plants re-sprouted. Although the "cut and apply glyphosate" (CG) method killed all the individuals at the end of the monitoring period (Table 5.5), the application of herbicide on the stump did not show any significant advantage over the modified cut methods (CM and CP methods).

Uses of chemical control methods such as FG and CG methods in areas of conservation importance are controversial. The action of herbicides is often not species specific and may affect the non-targeted flora and fauna (Cronk & Fuller, 1995). The application of herbicides should be avoided and must

be carefully planned as there are potential impacts to the native flora and fauna (Weber, 2003). However, very little information is available on the possible adverse effects of herbicides on coastal community. The effect of herbicides on the mangrove ecosystem had seldom been reported. Therefore, chemical methods should be avoided. Apart from environmental safety, human safety should be noted. The long-term application of herbicides may induce resistance on some plants (Wittenberg & Cock, 2005). When applying the herbicide, the worker must wear a watertight cloth, rubber gauntlets and face protection (Lundström & Darby, 1994). Moreover, most of the woody invaders can tolerate herbicides as they can regenerate fast, the chemical method may not prevent re-invasion (Wittenberg & Cock, 2005). In conclusions, both FG and CG methods were not recommended as the herbicide might have unknown impact to the native flora and fauna.

To consider the effectiveness of a removal method, one should evaluate the time required to treat an individual. The removal methods described above mainly involve large input of manpower with simple machinery involved such as chainsaw and saw. Thus, number of *Sonneratia* treated per man hour was the most critical factor to determine the cost. Time to remove the logged individual from the site was not included as it depends on (1) the distances between the logged individual and the forest edge which involved large input of manpower to drag the log to the boat and (2) the distance between the treated area to the nearest pier. The efficiency was determined

in term of number of individuals treated in each man hour. In this study, hand pulling method was the most effective as it could remove 360 individuals per man hour (Table 5.9). However, this method only limited to individuals that are less than 1.5 m high. For individuals taller than 1.5 m, levering/ digging, the method adopted by the Government of Hong Kong SAR, could only remove five individuals per man hour. While the most effective method-"Cut and covered by mud" identified in the field trial could treat 10 individuals per man hour, the third highest among the methods. And the most time consuming method was "Ring Barking" which could only treat 1.5 individuals per hour.

By reviewing the effectiveness and individuals treated per man hour, "Cut and covered by mud" method was most suitable for individuals over 1.5 m tall while "hand pulling" method was the most reliable in removing individuals that are less than 1.5 m tall.

5.4.3 Other control methods

The physical and chemical removal methods stated above are conventional, and these techniques are the vertebrae of invasive plant management with numbers of national guidelines being published. Another possible solution is biological control, it has numerous advantages over the physical and chemical removal methods because it is a self-sustaining and inexpensive

method, the disturbance to the community where the plants colonized is small and the exotic species might probably control within a short period of time (Weber, 2003). It involves the introduction of natural enemies from the original home range of the exotic species, such as parasites, parasitoids, pathogens, predators, insects, antagonists or competitors that will not reproduce and survive effectively in the ecosystem (Oduor, 1999; Wittenberg & Cock, 2005). By introducing them to the colonized area, they can maintain the population balance and suppress the natural dispersion of the exotic species. Previous experiences showed that most of the biological control agents are host-specific fungi and insects. For example, Barreto & Evans (1995) found that the fungi *Mycosphaerella micrantha* and *Puccinia spegazzinii* were harmful to Mile-a-minute (*Mikania micrantha*) in Southern Brazil and these fungi could be introduced to control the spread.

Biological control can be a potential method for controlling *Sonneratia* but it involves a high upfront cost and in-depth research. Before the implementation or introduction of the control agents, research includes extensive ecological studies, pre-release study based on laboratory experiments and careful risk-benefit assessment must be properly carried out to select the right candidate and to avoid undesirable risks to non-targeted species (Weber, 2003). The International Plant Protection Convention's Code of Conduct for the Introduction of Exotic Biological Control Agents (IPPC, 1996) provides guidance on the procedure for

introducing control agents. However, no research has been done on the biological control of *Sonneratia*.

5.4.4 Prioritizing area for removal

Sonneratia has been widely distributed from the Deep Bay to Lantau areas in Hong Kong and covered a large area. Completely eradication requires large inputs of man power and is likely impractical. As the aims of the control are to reduce the impact of the exotic species and to prevent their spread to non-colonized areas, it is important to prioritize the areas required management and apply appropriate control methods. The ecological value, the socio-economic impact and the seriousness of colonization of area are important considerations. For instance, the Mai Po and Inner Deep Bay Ramsar Site and the MPMNR have the richest biodiversity among all the colonized areas in Hong Kong. The Ramsar site comprises of 280 hectare of inter-tidal mangrove which is the largest stand in Hong Kong and the sixth largest in China (Lock & Cheung, 2004). They are situated on the migratory route of shorebirds which serves as an important over-wintering and stop-over site. High priority should be given to the Ramsar site and nature reserve to maintain the condition and avoid overtaking of the native plants by the aggressive extoic plants. Focus should also be placed on the area that has been heavily colonized by *Sonneratia*. These areas are usually favorable to the growth of *Sonneratia* and most trees are tall and reproductive,

producing massive numbers of fruits and hundred thousands of seeds. They become sources of new plants and increase the spreading rate. Therefore, priority and resources should be allocated to remove the reproductive plants first to reduce the spreading.

Among the colonized areas, >50% of the *Sonneratia* found in Hong Kong was in Mai Po mangrove stand (refer to Section 2.3.2). Two hotspots situated at the outlet of the Sham Chun River and the channel close to the *Gei Wei* Ponds 16 and 17 of MPMNR were identified for clearance (Fig. 5.4). Mangrove stands at Tsim Bei Tsui and Kam Tin River had the second and the third highest percentage of *Sonneratia*, and these areas were also identified as hotspots for clearance.

Wittenberg & Cock (2005) stated that the best chance for successful eradication is at the early phase of invasion while the exotic populations are still small. If resource is sufficient, effort should be paid to the individuals found in the Lantau Area (Fig. 5.5), as the areas had only nine individuals recorded and they were easy to eradicate. The removal of *Sonneratia* from this area would restrict the distribution in Lantau area and prevent the spread to other remote areas. If resource is available, the *Sonneratia* seedlings on the mudflat should be removed every year to prevent their colonization.

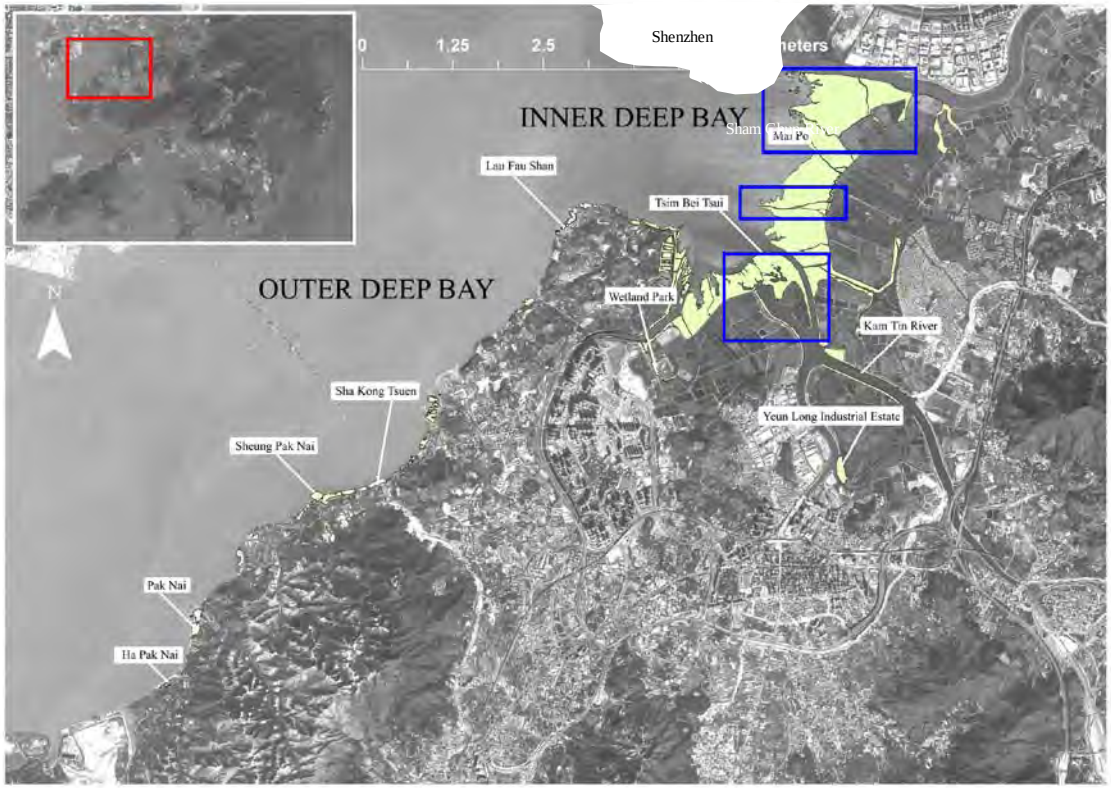


Fig. 5.4 Three *Sonneratia* hotspots in the Inner Deep Bay (Blue square indicates the hotspots, the upper two are situated within the Mai Po mangrove stand while the lowest square include the Tsim Bei Tsui and Kam Tin River mangrove stands)

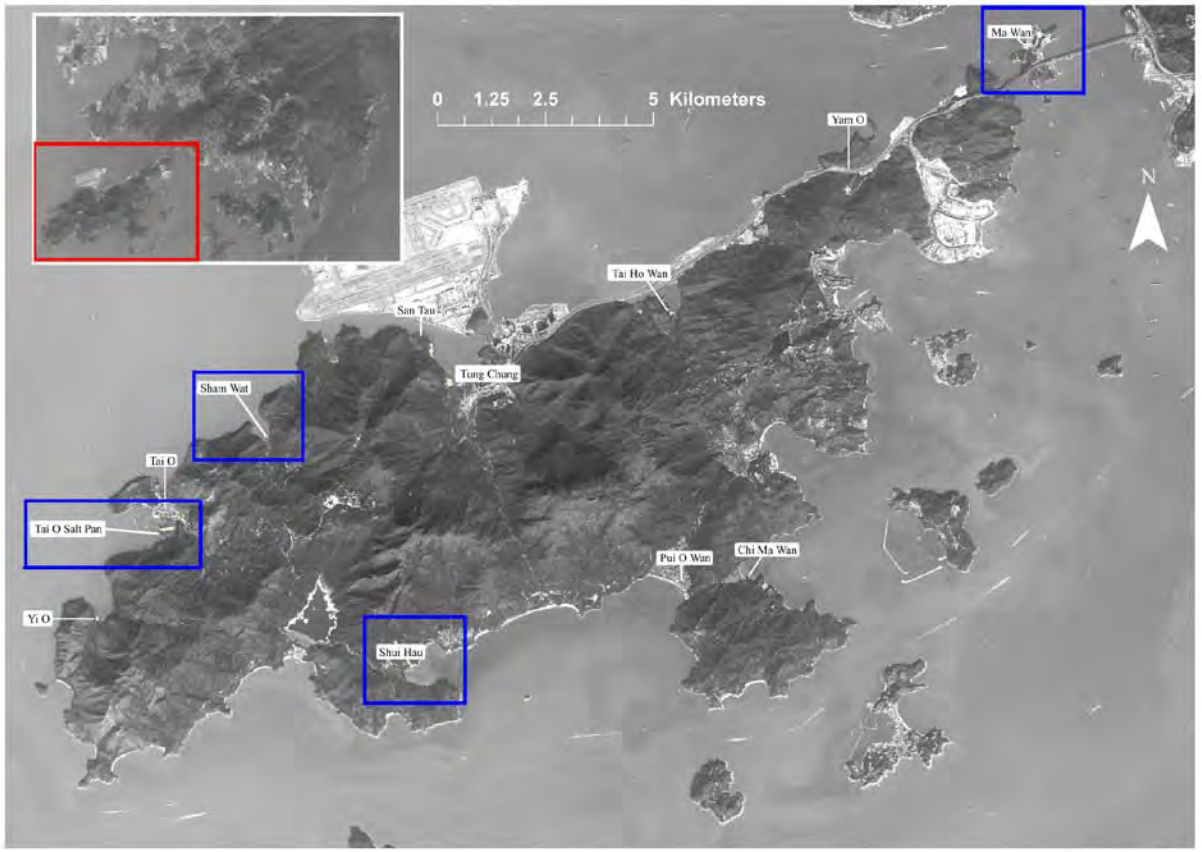


Fig. 5.5 The stands with *Sonneratia* infestation in Lantau Area (blue square indicates the stands infested with *Sonneratia*)

5.4.5 Timing for removal

The timing for removal is another important factor for successful clearance. Trees should not be pulled or cut while they are flowering or fruiting as this action would help pollination and seed dispersal. As the peak fruiting seasons of both *S. apetala* and *S. caseolaris* were after July (refer to Section 2.3.3.1), the removal exercise should be carried out before July to avoid the spread of fruits and seeds. In addition, caution should be taken in the ecological important area. Management work should be carried out when the number of waterfowl is the lowest. In Mai Po, the number of water birds was lowest in June and July, about 1,163 and 1,822 birds were counted, respectively (Yu, 2006). When considering these two factors together, the best time for the removal work should be between June to July.

5.4.6 Post-removal monitoring

In order to evaluate the success of the removal work, regular monitoring program, similar to the present post-removal monitoring work, should be established to evaluate the results, find out the last survivors, and check any re-sprouting or re-colonization of the exotic species (Wittenberg & Cock, 2005). Since *Sonneratia* is a fast growing genus that the seedlings can grow

about 1 m per year, monitoring should be done regularly to evaluate their spread.

5.5 Conclusions

History proved that naturalized exotic plant species is hardly eradicated completely. *Sonneratia*, a potential invasive genus should be removed before they naturalized and affected the composition and ecological values of native mangroves in Deep Bay and Lantau Areas. The present field trial showed that the non-intrusive “hand pulling” method was most effective to remove seedlings and saplings with height <1.5m. For the larger saplings and adult trees, the “cut only” method failed to control *Sonneratia* as 25% of the treated plants re-sprouted after the cut. The “cut and covered by mud” method was the most effective method, and could successfully prevent *Sonneratia* from re-sprouting, all individuals were dead at the end of the 18-month monitoring period. The second most effective method was “cut and apply glyphosate” method, but the application of herbicides should be avoided due to its uncertain impact to the native flora and fauna in the mangrove habitat. The “cut and covered by plastic bag” method was also effective but it has a disadvantage of putting man-made material into the natural environment and the bags must be removed as soon as possible. “Ring barking” method was proven failed to control *Sonneratia*, the bark stripping process could potentially remove the supporting tissue, leading to

the fall of the plant part above the ring barking position and buds could be developed at the broken edge. Similarly, the "frill and apply glyphosate" method also failed to kill the plants, re-sprouting of leaves were found after a year. Number of *Sonneratia* treated per man hour was used as a evaluation method to determine the cost. Resulted showed that "hand pulling" were most efficient as 360 individuals could be removed but this method was only restricted to individuals < 1.5m. For taller individuals, "cut and covered by mud" was the most suitable method as 15 individuals could be removed.

Three hotspots in the Mai Po and Inner Deep Bay Ramsar Site were identified for removal, they were located at the outlet of Sham Chun River, the channel close to *Gei Wai* Ponds 16 and 17 in Mai Po Marshes Nature Reserve and the mangrove stands at Tsim Bei Tsui and Kam Tin River. They were the patches with tall trees which could produce numerous fruits and seeds. In order to reduce disturbance to wildlife, management work should be carried out from June to July when the number of migratory birds is comparatively low and before the fruiting seasons of *Sonneratia* spp. If resource is available, *Sonneratia* in Lantau area should be removed to prevent their further spread.

CHAPTER 6

RECOMMENDATIONS AND CONCLUSIONS

Mangrove conservation is of vital concern as mangrove swamps represent rich and diverse living resources with high ecological, environmental, social and economical values. However, the mangrove area is decreasing worldwide and mangroves in tropical area are particularly threatened by human activities, one of the threats is the introduction of exotic plant. Alien species can be invasive and disturb the balance of ecosystem. Invasive is considered as global threat to biodiversity and it is more pervasive than loss of natural habitats and anthropogenic pollution.

6.1 Impacts of *Sonneratia* to Hong Kong

Sonneratia is an exotic species to Hong Kong, they were indirectly introduced to Hong Kong by human. Before the implementation of the removal program, one should consider the potential impacts of *Sonneratia* to Hong Kong. Is *Sonneratia* good or bad to Hong Kong? By listing out and balancing the possible/potential adverse impacts and advantages of *Sonneratia*, a decision could be made.

Adverse impacts of *Sonneratia* to the native flora and fauna

The exotic *Sonneratia* may pose threats to our native species in number of ways:

I. Mapping of *Sonneratia* in Hong Kong showed that *Sonneratia* tended to establish on mudflat. The fast growing nature (1 m per year) of *Sonneratia* can reduce the area of open mudflat which is used as the feeding ground for migratory water birds.
II. Mass seed production and long fruiting seasons with suitable environmental conditions (low salinity) in Deep Bay area allowed *Sonneratia* to proliferate, rapidly colonize the open mudflat and the forest gap in the mangrove stand.

The gigantic size of the mature plant can shadow out and even out-compete the native mangrove species and turn the mixed-species mangrove ecosystem into a mono-species forest. Decrease in the plant species will in turn decrease the diversity of animals.

Adverse impacts of *Sonneratia* to human

I. The fast growing nature and the adaptability of low tidal zone of *Sonneratia* allowed them to colonize the mudflat, especially the area in Deep Bay area. They may potentially block the view of the birdwatchers.
II. Their adaptability of long submerging time allows them to establish at the outlet of streams, such as Yuen Long Main Drainage Channel. If left unmanaged, the tall *Sonneratia* individuals would form a wall and trap the rubbish bringing in by tides. Eventually, it will block the flow of water within the channel and flood the Yuen Long, Kam Tin and Ngau Tam Mei areas.

Advantages of *Sonneratia* to the native flora and fauna

I. *Sonneratia* can be a food source for native animal. *Sonneratia* was reported as a chiropterophilous plant, its flower provided nectar for the nectarivorous bats such as Lesser Short-nosed Fruit Bat (*Cynopterus brachyotis*) in Malaysia and pollen grains of *Sonneratia* were found in their stomach (Gould, 1987; Start & Marshall, 1975). Hong Kong has a species from the same genus *Cynopterus*, the Greater Short-nosed Fruit Bat (*Cynopterus sphinix)* which may potentially feed on *Sonneratia*.
II. Weda & Wowor (1989) reported that ocypodid crabs forage the pneumatophore of *Sonneratia*. In Hong Kong, ocypodid crabs are common and dominate the seaward edge and *Sonneratia* may be a possible food source for them.
III. *Sonneratia* species could improve the quality of the substrate in the mudflat by increasing nitrogen, potassium, calcium and organic materials, reducing the pH and even promoting the growth of the native species (Li *et al.,* 2003)

Advantages of *Sonneratia* to human

I. *Sonneratia* is regarded as a food source. The ripe fruits are eaten by people from Africa, Malaysia and Java (Mastaller, 1997).
II. The fast growth, high vigor and good adaptability to foreshore habitats make *Sonneratia* an ideal species for afforestation and thus protect the coastline by stabilizing the substrate.
III. *Sonneratia caseolaris* is used in poultices for cut, bruises (Burma) and sprains and swelling. In Malaysia, ripe fruits are used to expel intestine parasites and cure coughing (Mastaller, 1997).
IV. *Sonneratia* is also an effective mean for treating municipal sewage due to its fast growing nature (Yang *et al*., 2008)

Although *Sonneratia* can act as a food source for human and animal consumption, and an ideal species for afforestation and potentially for medical use and sewage treatment, adverse impacts have not been fully evaluated. The fast growing, highly reproductive and adaptable nature of *Sonneratia* can pose threat or even out-compete the native species and turn the mixed-species mangrove ecosystem into a mono-species forest. The decrease in the complexity at the plant level can then affect the diversity of animals. The adverse impacts are irreversible but their advantages to human have alternatives. Clearly, *Sonneratia* have more negative impacts than positive ones, a precautionary and more conservative approach should be adopted and eradication is the only solution.

6.2 Long-term management strategies

This study revealed that the exotic mangrove species, *Sonneratia apetala* and *S. caseolaris* had established a population in the mangrove stands of Hong Kong.

Both *Sonneratia* species are fast growing, have long fruiting season and high productivity. Their germination requirements match with the environmental conditions in northwestern part of Hong Kong, thus Deep Bay provided a base for *Sonneratia* to proliferate. The tidal prediction in this study also demonstrated that there was a tendency for *Sonneratia* to disperse into the southern part of Hong Kong. To cease their expansion, a removal and controlling program is the only answer.

On top of single large-scaled removal work discussed in Chapter 5, proactive and long-term management strategies should be developed to ensure that *Sonneratia* will not re-colonize and proliferate in Hong Kong. The following strategies should be included in long-term management:

6.2.1 Prevention of *Sonneratia* invasion

Preventing the colonization of exotic species is always more effective than eradication afterwards. Early detection of individuals particularly at the seedling stage before the development of pneumatophores and before it becomes a problem is the most effective control strategy and it is the front line of defense. Procrastination can lead to a further spread of *Sonneratia* and it is generally more difficult to tackle tall and strong individuals.

To make early detection successful, *Sonneratia* must be able to distinguish from native mangrove plants in Hong Kong. A simple key is developed to help identification of adult trees of *Sonneratia* and distinguish them from native true mangrove plants species (Appendices I). This key is easy to use and can pass to the public and frontline worker for the correct identification of *Sonneratia*. Annual monitoring of *Sonneratia* in Deep Bay area, in particular the Mai Po mangrove stand, possibly after winter, is necessary for timely follow-up action.

A wide-territory field survey on the occurrence of *Sonneratia* in all mangrove stands in Hong Kong should be conducted every three to five years to review the distribution and abundance of *Sonneratia*. This will ensure that *Sonneratia* will not colonize new mangrove stands in Hong Kong and are unlikely to become exotic invasive plants.

6.2.2 Communications with relevant parties

Hong Kong and Shenzhen share the same water at Deep Bay and the presence of *Sonneratia* in Hong Kong was probably come from those *Sonneratia* fruits in Futian, China or other areas in Guangdong. It is clear that the goal and objectives of planting and managing mangroves in Hong Kong are different from that in Mainland China, especially in terms of exotic species. It is suggested that the Hong Kong government may consider discussing with the relevant parties in the Guangdong Province on the concern of *Sonneratia* in Deep Bay area. Regular meetings and constant dialogue between officers in relevant government departments in Hong Kong SAR and Mainland China for information sharing and idea's exchange would be useful.

6.2.3 Education

Eradication or complete removal of the invaded species needs long-term funding and commitment. To reduce the cost of removal, the removal strategies must consider the total biology of the species as well as the political and economic issues (Westbrooks & Eplee, 1999). The involvement of participants to thwart the invasive species can result in a large economic payback. This can be done at all levels, ranging from schools, public seminars and pamphlets.

Education should focus on raising public awareness on the potential threat of *Sonneratia* species to the natural mangrove stands and foreshore mudflat areas, and the local flora and fauna. Local birdwatchers can be the first target group as this group of people frequently visit the renowned bird reserve in Mai Po and have a chance to encounter the exotic *Sonneratia* individuals. Message of "*Sonneratia* can colonize the mudflat area and diminish the size of the bird feeding table" can be conveyed to this group. The Hong Kong Wetland Park and the World Wide Fund for Nature (Hong Kong) organize regular group and school visits to the mangrove stands in Deep Bay area, they can introduce *Sonneratia* to the public. If the public aware the adverse impacts of *Sonneratia*, the cost of removing handy seedlings can be economized by recruiting volunteers. Amateur can also act as the watchdog that helps the government by reporting the latest distribution of *Sonneratia*.

Materials and information pack such as leaflets, promotion video and pamphlets should be produced for school and publics. In this few years, the Agriculture, Fisheries and Conservation Department have published a few articles of *Sonneratia* in the *Hong Kong Biodiversity: Issues 10* & *14*. Various workshops or seminars could be organized to raise public awareness including ecological consultants about conservation and problems of *Sonneratia*. The result of this research can be disseminated in scientific and conservation publications, as well as to relevant stakeholders in Hong Kong and Shenzhen.

6.2.4 Suggestions for future study

Scientific research can provide more understandings of *Sonneratia* and provided additional information for management of *Sonneratia*. This can be done by the government, academics, green groups or the collaboration of the above parties.

(i) From the *Sonneratia* removal experience in Kam Tin River MDC of CEDD in 2001, the area was found replenished with *Sonneratia* in the dredged area after few years. The massive removal of *Sonneratia* from the site can generate open mudflat or gap which induces re-colonization. Due to the difference of the growth rates among the native and exotic species, *Sonneratia* dominated the open area and grow taller than the native species. Plantation of native mangrove species in the removal area might be a solution to reduce the chance of re-colonization. To evaluate the effectiveness, a field trial should be conducted before large-scaled implementation. Selection of the right species according their habitat requirements is crucial. A mixed species planting is preferable to mimetic the natural environment. Saplings or even trees are welcomed and preferable as they are strong and might out-complete the *Sonneratia* seedlings. And the planted area should be managed to remove *Sonneratia* once detected.

(ii) It is hard to determine the relationships and interactions between exotic *Sonneratia* and native mangrove species in Hong Kong at this early stage of invasion. Further study can be focus on the mature patch of *Sonneratia* in China. This includes examining competition for resources between the two *Sonneratia* species and native mangrove plants especially pioneer species *Avicennia marina*, *Kandelia obovata* and *Aegiceras corniculatum*, the dominant species in Deep Bay area.

(iii) Impacts on the ecosystem such as their effects on composition and abundance of flora and fauna, substrate properties, food and habitats for water fouls, which the Mai Po Inner Deep Bay Ramsar targeting for.

(iv) The removal trial in this research is a preliminary study. It is necessary to conduct a systematic field trial with *S. apetala* and *S. caseolaris* for

different age groups and habitat conditions to compare the effectiveness of different removal methods.

(v) Establishment of the seeds is limited by abiotic and biotic factors. In the present study, only few physical factors were investigated due to the limitation of time and resource, they were salinity, substrate type, duration of cold, submerging time and shade tolerance. In fact, there are abiotic factors (temperature, pH, Nitorgen: Phosphorus: Potassium ratio and oxygen availability) and biotic factors (intra-specific, inter-specific, predation and disease) that may affect the establishment of seeds

(vi) The interactions with native fauna (e.g. predator) also limit the distribution of both native and exotic mangrove species. Seed predation in the field should be examined. These provide additional information to evaluate the invasiveness of these exotic plants. The future studies should focus on the fate of the fruits and seeds after they detach from the plants, including dispersal rate and distance, rate of predation and survival of fruits and seeds.

6.3 Conclusions

Sonneratia apetala and *S. caseolaris* belong to the Family Sonneratiaceae are exotic mangrove species in Hong Kong. Because of their fast growth, high survival and good adaptability to foreshore habitats, *Sonneratia* have been widely adopted for coastal afforestation in Deep Bay since 1993. Since 1996, *Sonneratia* planted in Futian Mangrove Forest Nature Reserve, Deep Bay produced fruits and seeds which were dispersed, germinated and established. In early 2000, *Sonneratia* were found on the exposed mudflats close to the mouth of Sham Chun River in Hong Kong. In addition, *Sonneratia* were also found

among native mangrove species along the embankment of the downstream section of the Kam Tin Drainage Channel (MDC) in 2001. It was suspected that seedlings of *Sonneratia* might have sold to the contractor responsible for the mangrove planting project, one of the mitigation measures for the loss of mangroves due to the construction of the MDC.

Sonneratia species not only have fast growth nature, they start to reproduce two to three years after transplanting or germination. In Hong Kong, they produce flowers and fruits all year round with peak fruiting season in autumn. One mature tree of *S. apetala* has more than 8,000 fruits, each has 100 seeds, thus having 0.8 million seeds per tree. Similarly, *S. caseolaris* bears more than 1,500 fruits and each fruit has more than 1,000 seeds, producing more than 1.5 million seeds. Seeds of *Sonneratia* are very small (0.1-.0.2 cm in length) and easily floated and dispersed by water currents and tides. Dispersal studies suggested that seeds released between May and August are likely to remain in Deep Bay area while those produced in other months may move to outer Deep Bay, Lantau area and even southern Hong Kong for establishment. The viability under changing salinity test showed that seedlings of *S. apetala* and *S. caseolaris* would remain viable when they reached different stands in Lantau area. But if the seeds were remained in the water column (35 ppt) for more than 40 days, their viable percentages were halved.

The survey in 2005-2006 showed that there were total of 1,693 individuals of *Sonneratia* (25.6% were *S. apetala* and 74.4% were *S. caseolaris*) were found in 14 mangrove stands in Hong Kong. Mai Po had more than 900 individuals of *Sonneratia*, mainly in the outlets of Sham Chun River, along the water channel around *Gei Wai* 5, and the foreshore mudflat, while none was found in the Mai Po Marshes Nature Reserve. Kam Tin (the west bunds) and Tsim Bei Tsui (the mouth of the Kam Tin River) also had more than 200 *Sonneratia* individuals in each stand.

It is clear that *Sonneratia* are pioneer species in mid to low tidal zones, and they favor habitats having thick soft mud, high organic matter and nutrients, low salinity and open area with strong sunlight. This explains why most *Sonneratia* found in Deep Bay, Hong Kong are concentrated in the open mudflat at the seaward fringe, bunds along river, drainage and water channels, and river mouth. *Sonneratia* are also able to colonize any open gap within the existing mangroves at mid to high tide position.

Experimental results showed that high salinity, shaded environment, long time submergence and cold weather would affect the germination of *Sonneratia* in Hong Kong. However, recent publication suggested that *Sonneratia* appeared to be gradually developed their resistance to cold and saline environment. It is likely that *Sonneratia* will be more and more in Inner Deep Bay, especially in mudflat, river mouth and along water channels, if they are not controlled. Their long-term invasive potential must not be overlooked. Precautionary approach should be adopted to avoid any invasion of *Sonneratia* to native mangroves and open mudflat, especially in ecological sensitive areas such as nature reserves, Ramsar sites, etc.

The present study demonstrated that “hand-pulling” is the most suitable and effective method for removing seedlings or saplings less than 1.5 m tall. For individuals taller than 1.5 m and have well-developed pneumatophores, the “cut only” method failed to control *Sonneratia* as there was chance for the plants to re-sprout. For this case, “cut and covered by mud” method was suitable. The plant should be cut by chainsaws leaving a small stump close to the ground, and the stump is covered with mud to prevent re-sprouting. The best time for removing *Sonneratia* is June and July, these months with comparatively low number of migratory birds and before the major fruiting seasons of *Sonneratia*.

Post-removal monitoring is essential to ensure no re-growth and no new introduction of *Sonneratia* to the removal site, and evaluate the long-term effectiveness of the removal work.

It is essential to eradicate seedlings, saplings and adult trees of *Sonneratia apetala* and *S. caseolaris* in Deep Bay area as soon as possible. Three hotspots were identified for top priority, two are situated in Mai Po mangrove stand, including (1) the outlet of Sham Chun River, (2) the channel close to *Gei Wai* Ponds 16 and 17of Mai Po Marshes Nature Reserve and (3) the mangrove stands at Tsim Bei Tsui and Kam Tin River. This will ensure that the native mangroves will not be overtaken by the exotic *Sonneratia*.

After a thorough elimination, long-term management measures for *Sonneratia* should be carried out, including:

(i) Prevention of further *Sonneratia* invasion by routine monitoring and removal, building up a database to update the distribution of *Sonneratia;*

(ii) Communications with relevant parties

(iii) Education to raise the concern of the public

(iv) Conduct further scientific research to have a better understanding of *Sonneratia apetala* and *S. caseolaris*, particularly the removal methods of *Sonneratia*

Clearly, the fast growing and highly productive ability of *Sonneratia* will hazard the native mangrove species and its invasion is unavoidable. Battle against *Sonneratia* requires long term management strategies and commitment, sufficient resources must be allocated for consistent and continuous management work.

APPENDIX

Identification key for mangrove species in Hong Kong

1a	Leaves opposite 	2
1b	Leaves alternative 	7
2a	Leaves spiny; stem green 	*Acanthus ilicifious*
2b	Leaves with entire margin; stem not green 	3

3a	Pnematophores (vertical aerial roots) present 	4
3b	Pnematophores (vertical aerial roots) absent 	6

4a	Upper and lower leaf surfaces have different colour; lower surface grey; tree bark grey; fruits heart-shaped   	*Avicennia marina*

4b	Upper and lower leaf surfaces are green; tree bark brown; fruits globule   	5

5a	Leaves broad and ovate; short petioles (< 1 cm) and red; flowers with 6 petals and red stamens; fruits large (up to 8.5 cm)	***Sonneratia caseolaris***

5b	Leaves narrow and taper towards the apex; long petiole (> 1 cm) and green; flowers with 4 petals and white stamens; fruits small (1.5 – 2.5 cm)   	***Sonneratia apetala***

6a	Leaves elliptical with rounded apex 	*Kandelia obovata*
6b	Leaves elliptical with pointed apex 	*Bruguiera gymnorrhiza*
7a	Stalk petiole red 	*Aegiceras corniculatum*
7b	Stalk petiole but not red 	8

8a	Leaves bright green, a small notch at the apex of leaves margin 	*Lumnitzera racemosa*
8b	Leaves pointed and without notch at the apex of leaves margin 	9
9a	Leaves undersurface silvery white; buttress root  	*Heritiera littoralis*

9b	Lower leaf not silvery; no buttress root  	*Excoecaria agallocha*

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