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DRAFT
Genetic resources for farmed freshwater macrophytes

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Genetic resources for farmed freshwater macrophytes

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Cover photo: Cultivation of water mimosa, Binh Chanh district, peri-urban Ho Chi Minh City. Photo courtesy of William Leschen.

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It should also be noted that any views expressed in this review are purely those of the author and not necessarily representative of FAO.

Contents

ACRONYMS AND ABBREVIATIONS

BCE	Before the Common Era
DBP	di-n-butyl phthalate
FAM	freshwater aquatic macrophyte
FAO	Food and Agriculture Organization of the United Nations
GUS	beta-glucuronidase gene
HACCP	Hazard Analysis Critical Control Point
ICLARM	International Center for Living Aquatic Resources Management (now WorldFish Center)
PAPUSSA	Production in Aquatic Peri-Urban Systems in Southeast Asia (European Commission project)
RIA 1	Research Institute of Aquaculture 1

CHAPTER 1

1.1 Introduction

The cultivation and consumption of edible cultivated freshwater macrophytes and their impact on food security has long been under-recognized and under-recorded in both scientific and grey literature. In a geographical context, they have largely been unrecognized outside South and Southeast Asia, where for centuries they have provided millions of often lower-income communities with a low-cost, nutritious foodstuff for both themselves and their associated livestock, including cultured fish (Korkut *et al*., 2016). Freshwater macrophytes are often used to recycle "waste" nutrients, but they also provide significant employment and incomes. It could be said that freshwater aquatic macrophytes (FAMs) are the most forgotten form of freshwater aquatic food production, as they continually remain unrecorded in most government and (inter-) national agriculture and/or aquaculture statistics and planning documents despite their significant contribution to food production and nutrient recycling. In terms of the global aquaculture development community, the range and scale of edible cultivated aquatic plant production is little known or practiced outside South and Southeast Asia, and is rarely taught in curricula or addressed in the research agenda of the major academic aquaculture schools and agriculture and international non-governmental research organizations.

Edwards (1980) estimated that there are more than 40 species of edible FAMs, of which around 25 percent either are already being cultivated for food at a scalable level or have the potential to be developed into commercially viable cultivation species. In terms of their genetic improvement and species selection for improvements in growth performance, productivity, phytoremediation of wastewater and even disease resistance despite the significant translocation of germplasm between countries or regions over the last 600 years, there is relatively little information either in the research literature or at the grassroots production level to indicate selective breeding programmes and/or selection or genetic modification towards improved strains occurring. However, owing to their scale and their importance, particularly in Southeast Asia, FAMs can be considered a key tropical and subtropical cultivatable crop that can contribute to sustainable food production in developing countries in the future in a financially viable and environmentally responsible way. And while this review includes a number of references related to the global historical context and impact of these aquatic macrophytes, its main content relates to South and Southeast Asia where their cultivation has been, and currently is, far more significant both culturally and financially.

This review primarily concentrates on the potential of FAMs for human food production in the tropics. There are many other roles that they do and can fulfil, which include being key components in multipurpose integrated production systems. The incorporation and use of FAMs in aquaculture and other wastewater treatment and remediation in China continues to be developed (Zhang, 2014), and Korkut *et al.* (2016) analysed their potential as aquaculture feed ingredients. Zhou (2016) further discussed the often-close relationship of aquatic plant production between aquaculture and agriculture/horticulture, giving as an example the huge global market for ornamental aquatic plants, and therefore the need for clear differentiation and clarity in the future collection and presentation of global production statistics for different use categories of FAMs. This data collection is further complicated with particular species such as water morning glory (*Ipomoea aquatica*) being cultivated in different geographical locations for different purposes with different beneficial outcomes.

This review first identifies and presents the available literature, which although from a range of sources (in English) is still relatively sparse. This paucity of written materials over a period of more than 50 years is undoubtedly due to the main concentration of FAM cultivation (measured in metric tonnes produced and consumed per annum) being primarily carried out in different scales in waterbodies, canals and irrigation channels in South and Southeast Asian countries, such as Cambodia, China, India, Indonesia, Malaysia, Thailand and Viet Nam. In these countries, some of the key documents and publications, both research/academic and more private-sector, trade-orientated publications, have been in the past written in the local language, thus precluding them to be included in this review. This problem within the global academic research and development sectors of sharing and learning from the now hundreds of countries developing their aquaculture sectors is particularly highlighted by the world leader in aquaculture – China – where key publications, especially going back to the twentieth century and earlier, have yet to be translated and therefore have limited accessibility outside of China.

The review goes on to address key themes, including the food and occupational health safety for those who consume the plants and for those who work in wastewater environments to produce them. The recorded progress and levels of genetic development and improvement of aquatic plants are then discussed.

Further primary data collection and a series of four case studies, including interviews with key stakeholders, from the European Commission-funded project Production in Aquatic Peri-Urban Systems in Southeast Asia (PAPUSSA project 2003–2006) identify changes since 2006 in the region's peri-urban production and consumption of FAMs. The PAPUSSA project has been one of the few holistic interdisciplinary research or development-based initiatives to document the current status and importance of peri-urban freshwater aquatic plant production across a geographical region while also looking into the future potential of cultivation of FAMs within the region and translocation elsewhere internationally. The review then concludes in drawing together the overall findings to discuss the future role and potential of edible freshwater aquatic macrophytes in global food production. It should be noted that rice, the most important single crop in the world, is an aquatic macrophyte, but owing to its copious literature, research and commercial history is not included in this review. Rice is included in the *State of the World's Plant Genetic Resources for Food and Agriculture*.[1]

1.2 Definition of freshwater aquatic macrophytes

Before going on to chart the known history of freshwater aquatic plant consumption and cultivation, it is pertinent to define and understand what aquatic macrophytes actually are. Aquatic plants form an ecological rather than taxonomic group and cannot be defined with any degree of precision. Though there are no standard definitions for freshwater macrophytes in the literature, they are generally considered plants that either require a fairly continuous supply of freshwater or are present in soils that are covered in freshwater for a significant proportion of their growing cycle (Mitchell, 1974). They are distinguished as macrophytes by their size compared with phytoplankton, but can also include filamentous algae, which sometimes grow into larger floating mats and which can then be harvested. FAMs can be categorized broadly into three groups, or categories, by their methods of growth within the water column, although some species at different stages in their life cycle can move between the different categories (Edwards, 1980). The three categories are: (i) emergent species; (ii) submersed species; and (iii) floating species.

1.2.1 Emergent species

Emergent species normally grow in shallow water of less than 1 metre, with their vegetative growth above the water surface and their lower stem parts below the water and basally rooted into the soil substrate. Examples include *Phragmites* sp. (Figure 1) and *Typha caduciflora* L. (Figure 2).

T. caduciflora, the common cattail, originated in China where it has been cultivated for centuries as a food crop and is now widespread globally (Li, Teixera da Silva and Cao, 2007). It belongs to the *Typha* genus of the Typhaceae family and has other closely related species and varieties. Jianshui grass sprout, a rhizome edible plant, comes from the broadleaf common cattail genus (*T. caduciflora* L.), while the "Huai'an common cattail" and "Minghu common cattail", which are pseudo-stem edible types, belong to the water-candle species (*T. angustifolia*) and also known as narrow-leaf common cattail (Kong, 2005). Common cattail is widespread throughout China and has been recorded in almost all regional county annals.

[1] www.fao.org/agriculture/crops/thematic-sitemap/theme/seeds-pgr/sow/en

The common reed *Phragmites* sp. is used widely as a roofing and housing construction material, thus reinforcing the fact that aquatic macrophytes are also grown and used for purposes other than food production.

Figure 1: Common reed (*Phragmites australis*). Photo courtesy of Darkone under CC-BY-SA-2.0; https://commons.wikimedia.org/wiki/File:Phragmites_australis_Schilfrohr.jpg

Figure 2: Cattail (*Typha* sp.). Photo courtesy of Derek Jensen (Tysto); https://commons.wikimedia.org/wiki/File:Typha-cattails-in-indiana.jpg

1.2.2 Submersed species

Submersed species have their vegetative growth tissues mainly below the water surface and are normally also rooted into the soil substrate at no more than 1.25 metre water depth. Commercially important examples of these include water morning glory (*Ipomoea aquatica)*, sometimes also known as water spinach, and water mimosa (*Neptunia oleracea*), see Figures 3 and 4, respectively. Both species are commercially grown by thousands of producers and households and consumed by millions of people across Southeast Asia.

Figure 3: Water morning glory, or water spinach (*Ipomoea aquatica*). Photo courtesy of Eric Guinther under CC-BY-SA-3.0-migrated; https://commons.wikimedia.org/w/index.php?curid=253457

Figure 4: Water mimosa (*Neptunia oleracea*). Photo courtesy of Kurt Stüber under CC-BY-SA-3.0-migrated; https://commons.wikimedia.org/wiki/File:Neptunia_oleracea0.jpg

1.2.3 Floating species

Floating species have no physical contact with the soil substrate below, although they do have an extensive root network that is suspended in the water column to a depth of 0.25–0.75 metres. Depending on the productivity and the nutrient content of the waterbody in which they grow, these plants can successfully colonize or be grown in much deeper water columns, sometimes up to 15 metres in depth. Examples of these species include the invasive water hyacinth (*Eichornia crassipes*) (Figure 5), which is non-edible for humans. This FAM originated in South America, but has spread globally and has caused significant detrimental effects on native habitats and their ecology, human activity such as navigation, and to other forms of aquaculture such as commercial cage culture in Lake Victoria in Kenya and Uganda. More valuable floating FAMs include *Lemna* (Figure 6) and *Wolfia* spp., the former of which has been repeatedly put forward as a key aquaculture species, especially as a potential aquaculture fish feed ingredient or subsidiary feed. Though useful at hobby and extensive production levels, there have been mixed research findings on its usefulness at a commercial scale (Iqbal, 1999).

Figure 5: Water hyacinth (*Eichornia crassipes*). Photo courtesy of Wouter Hagens; https://commons.wikimedia.org/w/index.php?curid=1864500

Figure 6: Duckweed (*Lemna* sp.). Photo courtesy of Christian Fischer under CC-BY-SA-3.0-migrated; https://commons.wikimedia.org/wiki/File:LemnaGibba.jpg

CHAPTER 2

2.1 The cultural heritage of edible aquatic plants

In the development of the human race in meeting its demand for food and thus survival, our species has evolved from the original hunter-gatherer to become farmers. This has involved the development of both plant and livestock production systems, which have endeavoured over the centuries to provide a regular, accessible and affordable supply of food for the different infrastructural levels of human organization and habitation: household, village, regional, and more latterly in our development increasingly urban. Humans throughout their history have consumed over 3 000 species of plants, initially collected and subsequently through a process of selection for suitability, and then cultivated on increasingly larger scales. Up to the modern day, this number has been reduced, so that now the majority of the world's population is being fed by around twenty key crop species. The most important single crop species in the world is an aquatic macrophyte – Asian rice (*Oryza sativa*) – which is still providing the staple diet for over 50 percent of the world's population. China has both the history, and to the present day, the large-scale production and consumption of a range of FAMs. Because of climatic and environmental water availability factors, they are mainly found and cultivated in the south, south-west and eastern regions of the country, with Li, Teixera da Silva and Cao (2007) estimating there to be twelve main freshwater plant classes/families currently produced and consumed within these areas.

Perhaps one of the earliest recorded users of FAMs documented in the English language were the Egyptians with the making of papyrus, an early 2 500-year-old form of paper from the *Cyperus papyrus,* variously known as sedge, paper reed, Indian matting plant or Nile grass (Parkinson and Quirke, 1995). While the younger tender shoots of the plant were eaten by Egyptians, the plants were mainly dried and processed into a form that could be used for papyrus scrolls and also for making baskets and floor matting. In more modern times, the plant has become a lot less common in Egypt around the Nile Delta, but is found widely across the lower continent, especially in the rift valley east African lakes and wetlands, as well as in Florida and Mississippi in the southern United States of America where it is now considered an invasive species.

The Romans and Persians were the first to use watercress (*Nasturtium* sp. of the Cruciferae family), which originated in the eastern Mediterranean, with the edible plant then spreading into France and England by the fourteenth century. It later spread to Australia, South Africa and the United States of America, and was taken to Japan around 1780 (Li, Teixera da Silva and Cao, 2007). Before the colonization of the North American continent, the indigenous people would regularly gather and eat the grains of the native *Zizania aquatica,* commonly known as wild rice, found in swampy and waterlogged areas. This species has more recently been introduced into high elevated land in the tropics. Another native South American emergent aquatic macrophyte, the yellow burrhead (*Limnocharis flava*) (Figure 7), was introduced into southern Asia in the 1800s and is now widespread, being grown in Malaysia in rice paddies and in west Java as part of an integrated polyculture system in conjunction with carp ponds (Cook *et al.*, 1974).

Figure 7: Yellow burrhead (*Limnocharis flava*).
Photo courtesy of User:BotBln under CC-BY-SA-3.0-migrated; https://commons.wikimedia.org/wiki/File:Limnocharis_flava_HabitusFlower_BotGardBln0906.jpg

Figure 8: Chinese water chestnut (*Eleocharis dulcis*). Photo courtesy of Xiaowei Zhou.

Figure 9: Lotus flower (*Nelumbo nucifera*). Photo courtesy of J.M. Garg under CC-BY-3.0; https://commons.wikimedia.org/wiki/File:Nelumbo_nucifera_(Indian_Lotus)_in_Hyderabad_W_IMG_8736.jpg

The perennial water chestnut (*Eleocharis dulcis*) (Figure 8), belonging to the family Cyperaceae, has been cultivated for hundreds of years throughout southern areas of China (Herklots, 1972), often in polyculture with paddy rice, and seasonally rotated with other crops such as lotus and arrowhead. Likewise, since the 1950s, it has been translocated for trials in Australia, Indonesia (Java) and the Philippines where it is considered to have potential as a higher value crop. It is cultivated for its tasty undersoil cormels, which can be used as a vegetable or a fruit, fresh or canned, or processed to extract the starch within. The earliest documented record of water chestnut is found in the book *Erya* (or *Erh-ya*) around the second century BCE (Kong, 2005). Currently, it is spread widely over the whole of China except in the colder regions. The leading production areas are the Yangtze Valley and the south-east coastal regions. The popular cultivars of water chestnut are regionally based, with “Su water chestnut” found and grown in Jiangsu, “Hangzhou Big Red Coat” in Zhejiang, “Xiaogan water chestnut” in Hubei, and “Guilin Mati” in Guangxi provinces.

The lotus flower (*Nelumbo nucifera*) (Figure 9), which has considerable religious significance throughout South Asia, has been recorded in China since the twelfth century and is mainly cultivated for the flowers but also for food from the different parts of the plant. The tubers and seeds are used in a range of cooked and fresh dishes. Its rhizome is nutritious, with 100 grams of fresh underground stem containing 1 gram protein, 19.8 grams of carbohydrates, 19 mg calcium, 51 mg phosphorus, 0.5 mg iron and 25 mg vitamin C (Wang, 1991). These underground rhizomes can be harvested all year-round, allowing them to remain viable after being transported long distances (Zhao, 1999). Lotus is also considered a medicinal plant with the leaves being used to feed fish or castor silkworms, and it is used as a food packaging material.

Figure 10: *Trapa* sp. Photo courtesy of Xiaowei Zhou.

Figure 11: Water bamboo (*Zizania caduciflora).* Photo courtesy of Shizhao under CC-BY-3.0; https://zh.wikipedia.org/wiki/File:Water_bamboo.JPG

Water caltrop, *Trapa* spp. (Figure 10), is a floating aquatic herbal plant, which is found wild and can be cultivated in lakes and ponds as well as shallow waters such as channels and rice fields. The edible fruit is rich in carbohydrates, proteins, various vitamins and minerals and is eaten both cooked and processed to include in noodles and wine. It belongs to the *Trapa* genus of the Trapaceae family and contains the compounds ergosterol and sitosterol, which have been recorded as treatments against stomach cancer and cancer of the womb (Li, Teixera da Silva and Cao, 2007). Although now spread across at least three continents, its main cultivation and consumption is in China, south of the Yangtze River.

Water bamboo *Zizania caduciflora* (Figure 11) is a persistent, wild-growing perennial aquatic plant that prefers shallow water and now grows across Asia and the American continents. It belongs to the wild rice/grass family, with an edible, fleshy stem and is a well-known cultivated specialty aquatic vegetable in China. It is believed to relieve coughs and, when boiled, also treats children's diarrhoea (Kong, 2005). In China, it is now commonly cultivated across the south in Guangdong, Jiangsu, Zhejiang and Taiwan Province of China.

Perhaps the most cultivated and economically important FAM of all globally is water morning glory (*Ipomoea aquatica*). Geographically, it is known by many different names, such as *rau muong* in Viet Nam, *pukbung* in Thailand, *keng xin cai* in China, *kalmi* in Bangladesh, *kangkong* in Sri Lanka, *kanzon* in Myanmar, and water spinach, water convolvulus and (confusingly) kale in English. Nutritional values of water morning glory are superior compared with many other vegetables such as amaranth, celery, cucumber, spinach or gourds. It is an excellent source of vitamin A, and also fairly rich in a range of other vitamins as well as calcium, iron, potassium and phosphorus (Rahman, Yakupitiyage and Ranamukhaarachchi, 2006). Being a relatively short duration crop, it can be harvested regularly after 25–30 days, with the vines of the crop also used in fodder for cattle and swine as well as in supplementary aquaculture feeds.

In much of the literature *I. aquatica* has been known to originate from three main continents: Africa, Asia and the south-western Pacific Islands. Austin (2007), in his ethnobotanical review of *I. aquatica*, endeavoured to ascertain the original distribution of the species historically, as well as the date and location of its domestication, before which time it was collected as an edible and nutritious wild plant. He found that in southern Asia it had been gathered from the wild and used as a medicinal and food aquatic vegetable as far back as 300 BCE, as recorded by Ji Han (304 BCE) during the Chin Dynasty (290–307 BCE) in the areas now known as modern Kwangsi (Guangxi) and Kwangtung (Guangdong) provinces of southern China, and in the central and northern parts of Viet Nam.

With the arrival of Europeans in these regions in the 1400s, the new colonists recognized the importance of this aquatic plant for its low production costs and ease of cultivation and began transporting water morning glory with them on major trade routes, first around Asia and subsequently further afield to other tropical and semi-tropical locations where they could then disperse and grow it. This included the Dutch and Portuguese colonists in the 1400–1500s in present-day Indonesia and Malaysia, who were certainly aware of the plant and by the 1800s were cultivating water morning glory at larger scales. Often grown on the outskirts of towns and cities, it became the second most popularly consumed green vegetable in the region behind pak choi (*Brassica rapa* subsp. *chinensis*). In Africa, the literature is sparser on determining if water morning glory was indigenous or introduced. However, it is more likely that it was introduced into the north-eastern side of the continent in the 1700s through the recorded travels of Chinese mariner Cheng Ho (and other explorers) who carried on his ships, among other cargo, morning glory in huge earthenware pots containing soil to Egypt, Saudi Arabia, Somalia and Yemen (Lee, 2002).

Austin (2007) identifies the common names of the plant in different dialects going back as far as 300 BCE, which offers linguistic evidence of the species historic use. The original Sanskrit name *Kalamba* is similar to that used in present day northern and central India. In China, the earliest recorded mention is around 200 CE, though it is still unclear where water morning glory was first significantly cultivated or farmed, as opposed to being collected from the wild. However, the remaining known records and available research literature related to regions of cultivation, medicinal use, phylogenetic studies and common names suggest that *I. aquatica* was first cultivated on a significant scale in Southeast Asia. The plant may have been domesticated in China and/or India first, or simultaneously, but the remaining available information and literature remain ambiguous towards making a definitive conclusion where this FAM was first cultivated at scale.

Moving into the twentieth century, there is more in the literature on FAMs being used in peri-urban contexts alongside major and growing urban populations, often in wastewater-fed ponds and wetlands on the outskirts of urban centres, both for water treatment and income generation from the plants as food or for other purposes. Strauss (1997) estimated that at the end of the twentieth century there were over 130 sewage-fed aquaculture schemes across the Indian subcontinent, covering a total area of 12 000 ha. Perhaps the most famous of all are the wastewater aquaculture ponds on the outskirts of Kolkata, commonly known as the East Kolkata Wetlands, which are designated a wetland of international importance under the Ramsar Convention. Over 20 000 low-income and economically marginalized families depend on the various biological products of these wetlands, including fish and vegetables for their livelihoods (Ghosh, 2005). These wetlands, which have been operational since around 1930, are the world's largest wastewater aquaculture scheme, comprising an area of approximately 4 000 ha. Despite the protected status, these wetlands are continually shrinking due to land pressures, especially urban development. The series of ponds and linking waterways receive around 550 000 m^3 of untreated wastewater per day (Edwards and Pullin, 1990). In the early part of the twentieth century, 70 species of plants were recorded between the wetlands embankments, including *Fimbristylis ferruginea*, *Suarda maritime*, *Acanthus ilicifolius*, *Excoecaria agallocha*, *Avicennia officinalis*, *Phragmites karka*, *Aegiceras majus* and *Typha elephantina*, among others. In addition, 34 halophilic plant species were documented, including mangrove species confined to saline or brackish-water habitats (Biswas, 1927). Later studies (Dasgupta, 1973) identified over 92 plant species, strongly indicating changing and fluctuating salinity levels between freshwater and brackish-water in the wetlands over the past 50 years. In terms of more economically important plant species, the wetlands harbour a variety of FAMs. Local lower-income communities have cultivated *Ipomoea aquatica*, *Bacopa monnieri*, *Enhydra fluctuans* and *Marsilea minuta* (Ghosh, 2005) since the 1930s, often in the channels leading into the main fish ponds, or depending on the season, directly in the first of a series of ponds to clean the wastewater before entering into the lower fish ponds. Some are harvested and cooked as vegetables, and others are valued as medicinal plants. Still other more fibrous emergent FAMs such as *Cyperous rotundus, Phragmites karka* and *Typha angustifolia* are used by local communities for thatching their roofs, making furniture, mats and basketware, and as a pulp for waterproofing in house construction. In addition, apart from their continual function for water purification, these plants are used as fish and livestock feeds, and some are also used as green compost and manures depending on the seasonal water volumes and quality of the wastewater (EKWMA, 2011). The indigenous knowledge throughout India of FAMs having specific medicinal properties is well recorded (Mandal *et al*., 2008).

The use of FAMs in the Taiwan Province of China is also well documented, where by the twentieth century freshwater aquatic plants were important in the phytoaccumulation, regulation and removal of pollutants from wastewater, as well as in the cultivation for food and medicinal products. Liao and Chang (2004) described the 320 ha Erh-Chung wetlands, located south of Taipei city and adjacent to the Tang-sui River, which were originally formed in the 1960s when overpumping of groundwater caused this peri-urban land to sink and invasive tides from the river then inundated the existing farmland. By the early 1970s, the area became a wetland into which seepage of adjacent domestic and factory effluents began to flow causing significant pollution problems. Introduction of water hyacinth (either intentionally or accidentally) and its rapid growth to cover over 60–70 percent of the wetlands area reduced the levels of a range of heavy metals in the water table to levels well within the World Health Organization guidelines for safety to humans and wildlife within six months. This potential for phytoremediation by different species of aquatic plants of heavy metals and other pollutants from wastewater in the Taiwan Province of China and elsewhere has been trialled and shown to have beneficial outcomes by a number of researchers (Reddy and DeBusk, 1987; Lee *et al*., 1999; Lee *et al*., 1998).

Other South Asian countries in which edible FAMs developed in their importance creating incomes and food throughout the twentieth century included Indonesia, particularly *Ipomoea aquatica* grown in the small rivers and canals of peri-urban areas such as Jakarta (Purnomohadi, 1999). Also, *I. aquatica* cultivation in China, Hong Kong Special Administrative Region and the outside provinces was developed in the late 1960s where it supplied up to 15 percent of the local vegetable production as a summer leaf vegetable. Two methods of cultivation were commonly used: in wetland flooded plots (up to 0.75 metre depth) in former paddy fields, and on dry land using raised irrigated beds, the latter which was more commonly used at the nursery stage for the plants. Annual production of *I. aquatica* in China, Hong Kong Special Administrative Region has been estimated at 3–5 million kg (Edie and Ho, 1969), which at the time would have an estimated value of USD800 000 at productivities of up to 100 000 kg/ha. Under optimum conditions, the plant can grow up to 16 cm per day (Gilbert, 1984), and under upland cultivation, yields range from 7 to 30 tonnes/ha of fresh produce per crop. Annual production of water morning glory in Thailand is reported to be 90 tonnes/ha. In Malaysia, water morning glory is cultivated commercially on 600–1 100 ha with a total production of 60 000–220 000 tonnes/year. In 1992, in Malaysia, Singapore and Thailand, farmers' revenues from production of water morning glory ranged between USD0.05 and USD0.40 per kg (Westphal, 1992).

One of the earlier, and perhaps still the most comprehensive reviews of FAMs, is Edwards' (1980) ICLARM publication, which systematically describes their classification, potential contribution for food production (for both humans and livestock), and food safety, all described within the context of growing populations in Southeast Asia and the associated food production considerations. The author concentrated on *I. aquatica* (water morning glory) and *Neptunia oleracea* (water mimosa) because of their potential for large-scale, financially viable production. Indeed, Edwards documented productivity of up to 100 tonnes per hectare per year owing to their rapid vegetative growth and regular monthly harvesting when grown in sewage stabilization ponds and former irrigated peri-urban shallow ponds or rice paddies (McGarry and Tongkasame, 1971). These two species became particularly prominent in the 1980s and 1990s for their commercial cultivation in four rapidly urbanizing cities in Southeast Asia: Ha Noi and Ho Chi Minh City in Viet Nam, Phnom Penh (Beung Cheung Ek Lake) in Cambodia, and Bangkok in Thailand. The first three cities primarily cultivated aquatic plants using recycled peri-urban wastewater, while Ho Chi Minh City, Phnom Penh and Bangkok had the added advantage of being able to produce water morning glory and water mimosa throughout the year because of their year-round higher temperatures. Conversely, aquatic plant growers in more seasonally variable Ha Noi rotated their production to grow water morning glory and water mimosa in the warmer eight months, and then changed over to the slower growing watercress (*Rorippa nasturtium-aquaticum*) (Figure 12) and water dropwort (*Oenanthe javanica*) (Figure 13) in the four cooler winter months to maintain their incomes and cash flows.

Figure 12: Watercress (*Rorippa nasturtium–aquaticum*). Photo courtesy of Masparasol under CC-BY-3.0; https://commons.wikimedia.org/wiki/File:Watercress_(2).JPG

Figure 13: *Oenanthe javanica* (semi-domesticated cultivar). Photo courtesy of Xiaowei Zhou.

Water dropwort is a perennial FAM belonging to the *Umbelliferae* family, which has a preference for growing in more temperate climates. Just 100 grams of this aquatic plant contains 2.5 grams of protein, 0.6 grams of fat, 4 grams of carbohydrate, 3.8 grams of crude fibre as well as vitamins, carotenoids, nicotinic acid and minerals (Wang, 1991). It is believed to originate from East Asia, with China being one of its original regions. It can be found growing wild in rice fields, streams and wetlands bordering the Yangtze River and areas south of it, with Sichuan and Yunnan provinces being areas where it is found regularly.

The role of FAMs in providing on-site livestock and fish feeds has been documented by Northcott (1982) and Mandal *et al.* (2011). In terms of their composition and proximate analysis, FAMs have relatively high water content at 84.2–94.8 percent (Boyd, 1968), and documented crude protein values (dry weight) of 8.5–22.8 percent for 12 submerged species, 9.3–23.7 percent for 19 emergent plants, and 16.7–31.3 percent for 8 non-planktonic algae. These protein values are lower than those for duckweed (*Lemna* sp.), at 42.6 percent. However, these figures should be taken as an example in comparison with pasture grass, for which it takes 2.5 times less live weight to obtain the same dried matter weight as FAMs (Little and Henson, 1967).

Duckweed is one of the more popularly published FAMs in the literature, and in more recent years the information is distributed online from the scientific aquaculture community. Iqbal (1999) produced his comprehensive review in which he describes past and existing uses of duckweed in countries such as Bangladesh, China and India, primarily in systems recycling and treating both urban and rural wastewater to produce a dried feed supplement that has been used for raising fish, poultry and pigs. While duckweed has been recommended and promoted widely over the years as a low-cost environmentally sustainable means of protein production, the evidence base by 2017 shows that it has rarely been taken up commercially at any significant scale in developing or other countries. One important constraint is the requirement of sufficient land and water to produce the quantities of duckweed needed for a commercially viable business. Moreover, the operational labour of collecting, drying and processing the duckweed into meal is a significant cost. Figure 14, adapted from Edwards (1980), summarizes the main uses and resource utilization pathways of FAMs.

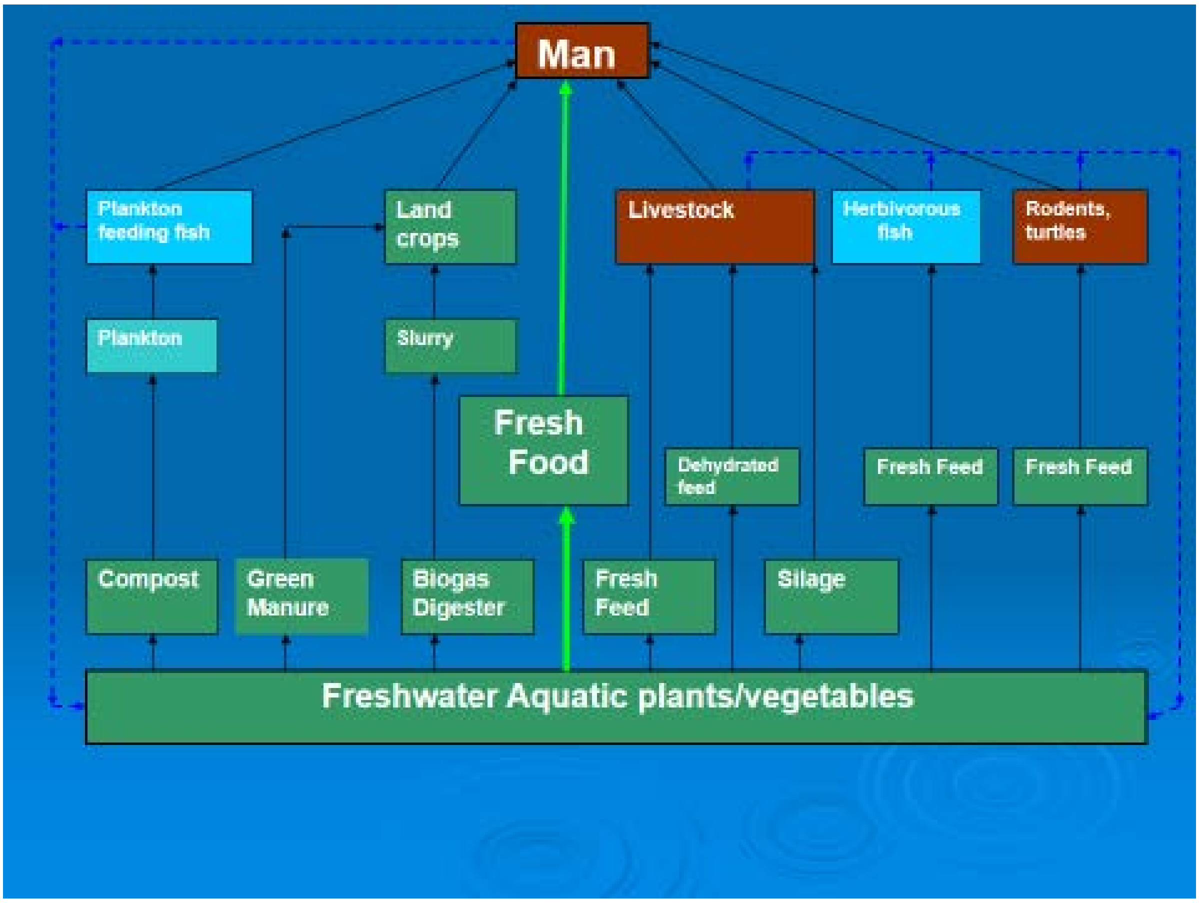

Figure 14: Major pathways involving freshwater aquatic plants in food production. Dashed line indicates potential for recycling human and livestock wastes – nutrient retrieval systems. Adapted from Edwards (1980).

Aquatic macrophytes are also planted in ponds and used as shelter areas and supplementary feed within certain aquaculture production systems in Southeast Asia and also in the southern United States of America. First, in South Asia, FAMs are planted as feed for cultured mitten crabs, *Eriocheir sinensis* (Zeng *et al*., 2012). During the nursery stage, farmers use rectangular ponds with one metre high mesh fence structures on their banks to prevent predators (frogs and toads) from entering. They also dig deeper 60–90 cm channels in the nursery ponds in which, before stocking, they plant aquatic macrophytes such as *Vallisneria spiralis, Hydrilla verticillata* and *Elodea* species, which serve as both refuges and also supplementary food. Before the juveniles are ready to be stocked into the larger grow-out ponds up to 1.5 ha in area, these ponds are disinfected with lime, and 10 days after disinfection, aquatic plants such as *Vallisneria spiralis*, *Hydrilla verticillata*, *Ceratophyllum demersum, Potamogeton maackianus* and *Myriophyllum spicatum* are introduced to the ponds. These again serve as hiding areas for the crabs from predators, but also provide an abundant source of supplementary food that provides variety and nutritional diversity to the diets of the animals. In the southern United States of America, the extensive production systems developed in the 1960s for the red swamp crawfish (*Procambarus clarkia*), before stocking, planted production ponds with a series of aquatic plants such as alligatorweed (*Alternathera philoxeroides*) and smartweed (*Polygonium* spp.), which provided cover as well as a low-cost supplementary source of food. If managed correctly and not overstocked with crawfish juveniles, these aquatic plants can continue to grow vegetatively, providing continuous food throughout the crawfish production cycle.

There is also a lucrative, largely unregulated, global trade in (ornamental) aquatic plants for the aquarium and pond hobbyist sector, which has increased its sales volume and diversity since the 1970s. This has led to significant concerns over the introduction of unwanted species (such as molluscs and other invertebrates often associated with the roots and stems of FAMs), and the release of imported ornamental plants into the wild and the potential subsequent negative effects on local aquatic ecosystems (Padilla and Williams, 2004). The aquarium trade and also ship ballast water have long been implicated in the arrival and then establishment of non-native, so-called "invasive" aquatic plant species into North America. Cohen, Mirotchnick and Leung (2007) described the unwanted introduction into North America of Eurasian milfoil (*Myriophyllum spicatum*), giant salvinia (*Salvinia molesta*) and Brazilian waterweed (*Egeria densa*). The detrimental introduction and then subsequent widespread establishment of *M. spicatum* and water chestnut (*Trapa natans*) in the Great Lakes is estimated to cost over USD800 million per year to the local ecology. While this is one example of an unwanted introduction of invasive aquatic plants into North America, there have been many others across Europe and globally.

2.2 Food safety and occupational health

One of the key factors that has potentially limited the scaling up and further spread of FAMs beyond Southeast Asia has been the concerns over the food safety of human consumption of FAMs grown in wastewater and the associated occupational health issues for those working in wastewater FAM production systems.

The keystone publication on this topic is the wastewater public health guidelines from Mara and Cairncross in 1989, which started this field of study, as well as related publications for the safe use of wastewater and excreta in agriculture and aquaculture. Reilly and Kaferstein (1997) reviewed food safety hazards associated with both farmed fish and edible aquatic plants and proposed the application of the Hazard Analysis Critical Control Point (HACCP) systems as an overall strategy to control the food safety and health hazards identified.

The European Commission funded the PAPUSSA project (2003–2006) and carried out an interdisciplinary, holistic overview of FAM value chains in four cities in Southeast Asia, which included an occupational health review of those working daily in these systems (van der Hoek *et al*., 2005) and an assessment of food safety of edible aquatic plants and fish raised in wastewater-fed ponds (Dalsgaard *et al.*, 2006). While the latter found some concerns over two specific heavy metal concentrations of wastewater-grown morning glory in Ha Noi and Phnom Penh, these were still well within the safe World Health Organization guidelines for human consumption, with the authors recommending initial washing of the plants in clean water, followed by at least two to three minutes of boiling or cooking to destroy potential bacterial or parasitic pathogens. A further study (Marcussen, Dalsgaard and Holm, 2009) was carried out on Phnom Penh's Beung Cheung Ek Lake, which is located 6 km south of central Phnom Penh, Cambodia. Following a Japanese International Development Agency development project in the early 2000s, the lake received over 80 percent of the city's wastewater (industrial and domestic wastewater) through a network of concrete channels joining together to flow into the lake at two main inlets. Households that had previously settled around the lake in the late 1980s quickly began to realize the potential of cultivating FAMs, particularly water morning glory, which flourished in the nutrient-rich wastewater. The 2009 study determined concentrations of 35 elements in the tissues of the cultivated water morning glory and sediment that were collected along transects of the two wastewater inlets to the lake outlet leading into the main river estuary; samples were also taken from a nearby non-wastewater exposed fish pond which was used as a reference. While elevated concentrations of potentially toxic elements like cadmium, copper, nickel, lead, antimony and zinc were found in the water morning glory and sediment samples collected near the wastewater inlets, the intake of these elements from consumption of water morning glory was significantly lower than the maximum tolerable intake level set by the FAO Codex Alimentarius for an adult person. The study, therefore, concluded that the consumption of water morning glory from Beung Cheung Ek Lake constituted a low food safety risk with respect to potentially toxic elements.

In terms of potential human parasites, the Marcussen, Dalsgaard and Holm 2009 study of eight samples of water morning glory taken from different points in Beung Cheung Ek Lake found that the protozoan parasites *Giardia* spp. and *Cyclospora* spp. were present at a range of 0–30 oocysts/gram, and that *Cryptosporidium* spp. oocysts and helminth eggs were not detected in any of the eight samples. There were no apparent differences in protozoan oocysts numbers in plants washed in wastewater compared with plants with no direct wastewater exposure during harvesting. The study found that the pathogenic parasites identified would be a problem for human health only if the plants are not washed and cooked properly by boiling in water or heated in stews and soups before being consumed.

The bacterial loading of the lake was examined using *Escherichia coli* as an indicator organism. Mean numbers of *E. coli* in wastewater at the initial inlets and the final lake outlet were recorded at 3.7 million *E. coli* per 100 ml and 35 500 *E. coli* per 100 ml, respectively. A nearby fish pond that did not use wastewater was used as a control, and *E. coli* was recorded as 43 300 *E. coli* per 100 ml. These results clearly illustrate the efficacy of wastewater treatment of the lake, considering the drastic reduction of the bacterial load from inlet to outlet, with final water quality similar to that of the control pond.

The van der Hoek *et al.* (2005) occupational health household survey (n = 154) around the periphery of Beung Cheung Ek Lake found contact dermatitis to be the main occupational health risk for those working in these production systems, with the condition being typically found on hands, lower arms and legs. Contact dermatitis normally is caused by dermal irritation or allergic reactions to specific waterborne chemicals or substances which can cause rashes, oedema and subcutaneous haemorrhaging. If not treated, these conditions can develop into dermal lesions that can become infected by secondary bacterial pathogens such as *Staphylococcus* spp. While the specific irritants and allergens were not identified in this study, contact dermatitis is often associated with exposure to waterborne metals such as nickel and zinc (Basketter *et al*., 2006). Van der Hoek found that 62 percent of interviewees who worked in the lake experienced skin problems between January and February each year, which are the two peak months of the dry season. This declined to 42 percent for the months of July and August. Less than 1 percent of the control population of people not exposed to wastewater reported dermatitis. Of those who were diagnosed with contact dermatitis, 56 percent experienced symptoms on their hands, 36 percent on their feet, and 34 percent on their legs. The survey also found that only 2 percent of people working in the lake consult doctors, with 47 percent relying on home treatments because local health care is cost prohibitive. While these external dermal conditions were clearly indicated, the survey also found that most of the workers interviewed considered the skin conditions not to be serious. Workers often applied lime and orange juice to their arms and legs to treat themselves before entering the water and at the end of the day following wastewater exposure; this procedure showed that it could be effective in reducing the incidence of bacterial infections developing within open cuts and lesions.

Anh *et al.* (2007) carried out a similar occupational health study with the wastewater aquatic plant growers in peri-urban Ha Noi and found that contact dermatitis was the main acute health issue that workers had. However, both studies had limited time scales and were therefore unable to assess a range of other potential longer term or chronic medical conditions related to daily wastewater exposure such as hepatitis, *Leptospirosis*-infections, or cholera, as well as other more immediate potential risks such as food poisoning from *Campylobacter* spp. and *E. coli*. This is an area where further research is needed to understand the dynamics and potential human pathogen loading under different environmental conditions of the different FAM production systems, an area of research which needs to be prioritized in the future.

2.3 Genetic resources and the development of freshwater aquatic macrophytes

While the cultivation and consumption of certain species of edible FAMs is well recognized in a number of countries in South and Southeast Asia, the development of their genetic resources, strain selection and selective breeding programmes, both actual and recorded in the literature, are far less apparent. Li, Teixera da Silva and Cao (2007) stated that, in China, there were 12 main freshwater plant classes belonging to 12 families, with an estimated 1 700 germplasm resources all over the country. The historical translocation and spread over hundreds of years of five to ten key species from their endemic range is well documented. Many FAMs have been transported to new locations in northern Africa, Australia and the Middle East, often under similar climatic and environmental conditions, and has opened up the potential for production and associated benefits. By their very nature of rapid vegetative growth in tropical climates of 27 °C and above, certain FAMS such as water mimosa (*Neptunia* *oleracea*) and water morning glory (*Ipomoea aquatica*) are repeatedly grown, harvested and then replanted from (asexual, clonal) cuttings as nursery stock year after year without any obvious noticeable decline in their productivities. From findings of the PAPUSSA project, the growers of Ha Noi, Ho Chi Minh City, Phnom Penh and Bangkok reported that they were content with the available germplasm they repeatedly grow, harvest and then propagate from cuttings on land nursery plots (Salamanca, personal communication, 2006); however, some growers noted that they would be interested in trialling out more saline tolerant varieties if they were available to them. While this review has carried out a comprehensive literature review on the genetic resources, selection and strain development of well-known FAMs, there is little evidence that genetic improvement has been undertaken, or even deemed necessary, for the development of the sector towards larger-scale production and consumption across significant areas of southern Asia.

Egbert (2010) described a lack of cultivars as a possible constraint to further uptake and benefit to populations in other countries, including how FAMs fit into existing production systems. By 2010, the World Vegetable Center had conducted activities in collaboration with national partners in Indonesia, Taiwan Province of China and the Philippines to promote the conservation and use of indigenous vegetables, some of which included FAMs. Their activities focused on the rescue, improved conservation, seed production of promising varieties, cultivar trials and participatory evaluation of selected accessions, as well as training personnel in germplasm management. Then, also within their research strategies, the centre sought to disseminate prioritized certain key crops, differing from country to country, but identifying and then working with these key species to develop and promote their culture and benefits to other countries. Water morning glory (*Ipomoea aquatica)* is one FAM being promoted by the centre in the region.

The Indian researchers Tiwari and Chandra, 1985, in their review of water morning glory, its varieties and their cultivation, categorized and named three main cultivars on the Indian subcontinent by the colour of their stems: (i) light green, with tender, smooth, even-surfaced shoots and oblong, narrow oval-shaped leaves tapering to a point at each end, spreading densely in shallow water; (ii) red green, the most commonly grown, with tender, glabrous shoots, thick, narrow triangular shaped leaves, and long, trailing branches; and (iii) red stem, with soft, glabrous shoots and sagittate leaves, preferring to grow and spread on more firm but moist soils. They also described two cultivars commonly grown in China, Hong Kong Special Administrative Region, also reported by Edie and Ho (1969): Ching Quat 1 is a green-stemmed and more cold-resistant cultivar of *I. aquatica* than the three main Indian cultivars, but tends to give lower yields and lower quality and more textured plants, which are commonly used for livestock feeds. The other cultivar, Pak Quat, is a typically white-stemmed variety that can be grown in both shallow water and in more moist soil-based systems; it is a large, good quality plant, giving a high number of harvests each year.

There are also other mentions of different cultivars of water morning glory in publications, which examine the potential for phytoremediation and biodegradation of contaminated soils and sediments. Cai *et al.* (2008) examined comparative potentials for five different genotypic cultivars of *I. aquatica* to clean soils contaminated with the industrial effluent di-n-butyl phthalate (DBP). The results clearly indicated differential cultivar tolerance to DBP uptake, with the local Chinese white-skin (cultivar V_5) and Taiwan Province of China filiform-leaf *I. aquatica* (cultivar V_1) presenting the highest phytoremediation potential in soils containing DBP. Li *et al*. (2007) also carried out a study looking at the potential for nitrogen removal from eutrophic waterbodies using floating beds of three different cultivars of water morning glory. The experiments were performed with three cultivars: Thailand angustifoliate cultivar, Jiangxi big leafage cultivar, and Panteng native cultivar. All three cultivars were obtained from a Chinese-Thai commercial seed company. Despite the proactive use and future role of (edible) FAMs for phytoremediation of potentially hazardous substances in industrial effluents, as reported above, the clear risk of human consumption of the associated plant tissues should be controlled. Or, within such systems, other non-edible FAMs could be used for other non-food applications (e.g. construction, roofing).

For certain of the more popular and historically significant FAMs such as water lotus there are reports that indicate up to 600 cultivars in China (Chen, 2008). However, there is some confusion over the botanical classification of cultivars, as different scholars have adopted different morphological traits such as flower colour, flower shape and flower size, and then given these traits have recorded different numbers of cultivars. Wang and Zhang (2004) described 98 different cultivars of water lotus. Despite the differences in the literature, this does indicate, especially in China, a certain level of genetic diversity in some of the key aquatic macrophytes. For watercress (*Rorippa nasturtium-aquaticum)*, Sheridan *et al.* (2001) measured the genetic diversity in two commercially cultivated cultivars using a fingerprinting technique called RAPD-PCR. They found little genetic diversity between different commercial watercress populations; however, watercress was clearly a unique cluster genetically distinct from other *Rorippa* species.

While most of the available literature on the genetics of FAMs is based around the most important commercial species, *Ipomoea aquatica,* Indian-based researchers (Ikakkar, Mohan and Ram, 1986) demonstrated that they could regenerate the commercially important FAM water mimosa (*Neptunia oleracea*) through standard tissue cell culture procedures using the hypocotyl and cotyledon tissue from aseptically grown seedlings cultured in a specialized medium to produce an undifferentiated callus that could be subcultured and maintained in this state for thirteen passages. Shoot elongation was then stimulated in specialized liquid media, which could then be rooted and the regenerated plants transferred to ponds to grow and develop nodules to become adult plants. Although it is not a practical, cost-effective method for commercial storage of different FAM cultivars, it can allow plant researchers a facility for keeping a stock of different FAM cultivars in low-space storage research facilities for further use in trials.

There are few documented examples of genetic modification of FAMs. Khamwan *et al.* (2005) developed a laboratory-based protocol for stable genetic transformation (transgenesis) of *I. aquatica* by infecting cut cotyledons with an *Agrobacterium* harbouring a specific beta-glucuronidase gene (GUS), commonly used as a reporter gene to demonstrate successful gene transfer. The resulting transgenic plants grew normally to maturity and exhibited stable GUS activity. Yuri *et al.* (2001) similarly developed genetic transformation protocols for two species of duckweed, *Lemna gibba* and *L. minor*, also using *Agrobacterium* gene transfer; the authors hypothesized that these transformation protocols could facilitate genetic engineering of duckweed, with improved strains being tailor-made for bioremediation and larger-scale industrial production of biomass and recombinant proteins. Both studies indicated that genetic modification of commercially important FAMs can be readily achieved, thereby improving their genotypic qualities for potentially whatever beneficial traits are desired. By 2015, Van Hoeck *et al.* (2015) had produced the first draft genome and annotation of *Lemna minor*, with the view that this could provide new insights into the biological understanding and biomass production applications of the species.

This review, however, found no evidence indicating the wider spread use of genetically modified FAMs in commercial or other food production systems. Globally, the contentious issues and the potential of genetically modified crop species are well known, but in terms of their application in FAMs for food production this has not occurred, which is probably due to the current acceptable productivity levels and commercial viabilities for food production of existing FAM varieties. Their genetic modification and improvement for other non-food usages such as water treatment, bioremediation and even biofuel are applications will no doubt be put forward and discussed in the future.

CHAPTER 3

3.1 Introduction to the case studies of commercial producers of FAMs

The following four individuals are commercial FAM farmers and were each a stakeholder in the original European Commission-funded PAPUSSA project (2003–2006). They were interviewed in 2004 and followed during the project in order to better understand their own household involvement in aquatic plant cultivation, and then, more broadly, how they interacted with and fitted into the wider aquatic plant value chain in each of the major cities. For the purposes of this review, twelve years later, in 2016, they were each contacted again, and using a semi-structured format they were informally interviewed to find out what they were currently doing, if they were still involved in aquatic plant production, and for their thoughts on the future of aquatic plant production in peri-urban areas of their cities. The format for each of the case studies below is divided into two: first, the information, status and reflections of the individual and the associated value chain in 2004 during the PAPUSSA project; and second, their status and associated information from the more recent interview twelve years later in 2016.

3.2 Lu Hung Lanh – Bang B village, Thanh Tri district, Ha Noi, Viet Nam

Figure 15: Lu Hung Lanh beside his wastewater-fed water morning glory and water mimosa plots, Bang B village, Ha Noi, Viet Nam. Photo courtesy of William Leschen.

3.2.1 Lu Hung Lanh (2004)

In 2004, Mr Lu Hung Lanh (Figure 15) was 44 years old and a father of three. He was born and raised in Bang B village in Thanh Tri district of Ha Noi, which is located 7 km from the centre of the city on one of the city's five main wastewater rivers, the Tor Lich River. In his late teens, Hung Lanh entered the army, and at 25 years old left to get married and to work with his brother-in-law in a small, local artisanal steel and metal galvanizing workshop in Bang B village. At that time, the extensive local fields in Bang B were all used collectively for growing rice for the commune and were irrigated with wastewater (a mixture of human sewage and other domestic effluents) pumped from the Tor Lich River using small portable Chinese petrol and diesel pumps. Hung Lanh recalled those early years and the gradual improvement in living standards in the village as electricity arrived, and telephone lines, better roads and also improved irrigation canals were constructed. He remembered some of the villagers growing aquatic plants in a rather ad hoc manner within the wastewater rivers themselves; however, he pointed out that there was always friction over ownership, as well as the unnecessary blocking of the river courses, which caused accumulation of wastes and flooding during the rainy seasons. It was, he said, the changes in the local land-tenure systems in the 1980s and 1990s – when the government and the local commune committee level opened up (*Doi Moi*) and began to give households responsibility and land plots that had been previously classed as government and state land adjacent to the wastewater river – that gave households more flexibility and security of ownership to cultivate other crops. By the mid-1990s, a transparent and transferable landownership and leasing scheme was enacted at the commune level and aquatic plants were no longer cultivated in the wastewater rivers. Each local commune also had an electric-powered water-pumping station installed next to the Tor Lich River (Figure 16), for which local households paid a regular fee, but small, if they were using the wastewater to irrigate their plots.

Figure 16: One of the electric-powered wastewater pumping stations for Bang B village at the Tor Lich River. Photo courtesy of William Leschen.

Mr Lu Hung Lanh recounted a story of one of the first persons to test growing aquatic plants. His neighbour, Ms Nhuan, grew water morning glory. He said: “She dug the soil levels in her adjacent plots deeper and then constructed enclosed ponds into which wastewater was then pumped via the new commune pumping stations.” He remembered that Ms Nhuan was the first person in Bang B village to build a new house on the proceeds from her water morning glory production. Subsequently, households and farmers learned from each other and gradually discovered the optimum techniques of growing aquatic plants in such a system themselves, and the former rice plots gradually and then completely became converted to growing edible aquatic plants. He said that one by one local households realized that they could earn between three to five times the income per hectare by growing aquatic plants rather than rice, with the labour requirements far less onerous and time consuming.

In 1996, Hung Lanh became involved in aquatic plant cultivation when his household was granted an 800 m^2 area of land adjacent to one of the concrete irrigation feeder channels. He divided this land into smaller individual plots of 200 m^2, which then allowed him to sequentially plant, crop and harvest throughout a normal eight-month cycle. During the summer months from March to October, he and his wife grew water morning glory and water mimosa, harvesting the vegetative growth every 25–30 days; in the colder winter months, they switched the plots to the slower growing watercress and water dropwort. The young nursery plants for each of the four species were freely available, and once in production, Hung Lanh learned to take cuttings at the end of each cycle to propagate new stock in a small nursery plot nearby. At the beginning, he was unaware of any other different seed or nursery stock. In terms of other inputs, he used supplementary inorganic fertilizer and urea and also limed and fallowed the plots between cycles. After only a few years, he realized that even with the full-time work of his wife and the help of his child he had to, at least in the water morning glory season, stop working in his brother-in-law’s metal workshop and concentrate full time on the plants. Selling the plants was not a problem, as at least once a fortnight he and his wife harvested either the water morning glory or water mimosa, washed it and cut it into bundles (Figure 17).

Figure 17: Following harvesting, water morning glory growers in Bang B village prepare and wash bundles in freshwater ready for transporting to market. The removed waste leaves are collected and used in the commune as pig and fish feed. Photo courtesy of William Leschen.

Mr Lu Hung Lanh would then transport up to 30 bundles (approximately 45 kg wet weight) early in the morning on his motorbike to the local wholesale market 3 km away, where it was all sold within 30 minutes. By 2003, from the proceeds of his venture, he was able to acquire a new motorbike and a further 600 m^2 area of land in the village, which he also developed into aquatic plant cultivation and achieved an annual income from his plants of VND 44.6 million (USD2 900). This, in 2003, represented 90 percent of the total income coming into the household from him and his wife; she also worked part time as a tailor making and altering clothes while their three children were still at school. At this time, he estimated that in Bang B village alone there were over 250 households (50 percent of the total) involved in the cultivation of aquatic plants with approximately 50 others (mainly women) who were solely involved in the marketing and selling of the plants. Hung Lanh recounted that by the early 2000s industrial construction and development was beginning to impinge on the wastewater aquatic plant cultivation fields, with textile, shoe and leather-tanning factories setting up, and further new residential housing being constructed on formerly cultivated land. He added that since these factories had come, he and his fellow aquatic plant growers had noticed definite “disease” signs (e.g. yellowing and withering of leaves) on the plants, particularly the water mimosa, which made some of the growers transfer all their plots to water morning glory production. He worried that this was due to the declining quality of the wastewater and that, despite representations of the growers to the local commune committee and the Ministry of Agriculture, nothing was being done to monitor or regulate it.

Although Hung Lanh was optimistic for the future, he was concerned not just about the worsening quality of the wastewater, but also about the dwindling volumes available in the main rivers each year during the dry season. He believed that the now standard price fluctuations in local markets every year created uncertainty and was not good for producers like him. He wished that the government in some way could regulate this. He also added that the ever-increasing urban construction for primarily domestic residential housing would likely reduce the land areas under cultivation in Bang B village within the next five years, and as a result he would have to start looking for available land further away along the Tor Lich River to continue cultivating plants or look for alternative suitable jobs, such as making household fittings and furniture from inox steel or setting up a small business selling mobile phone accessories.

3.2.2 Lu Hung Lanh (2016)

Mr Lu Hung Lanh, when contacted again by telephone in June 2016, was now a grandfather of two, aged 57 and healthy, and still living with his wife and one of their children in their original house in Bang B village. Two of the daughters, now in their 20s, had married and left home, one working in a glassware factory and the other a student at Ha Noi University. Hung Lanh and his wife still grew water morning glory and some watercress and water dropwort in winter months, but on a much-reduced landholding of 400 m^2, their previous land and that of their neighbours having been compulsorily purchased by a development company in 2011 for construction of an office complex. With money from this land sale and their other savings from growing aquatic plants, Hung Lanh and his wife bought a small car, which they used to visit one of their daughters and family relatives in neighbouring Hai Duong province. Hung Lanh recounted that by 2008–2009, it was becoming difficult for them to cultivate water mimosa due to disease and die-off of plants, which he believed was due to the increasingly contaminated wastewater from surrounding factory effluents. Therefore, at this time, he and most other growers concentrated on growing the hardier water morning glory even though the market prices were lower (by 10–25 percent) per kg than for water mimosa. Although he and his neighbours joined a local commune action group in 2010 to try to prevent the purchase of their land, they were unsuccessful and in the end accepted a remuneration payment from the local government.

Hung Lanh began working almost full time again in 2012 in his brother-in-law's steel workshop, which by this time had diversified into producing specialized reinforcing brackets and rods for construction. His wife still worked on the remaining water morning glory plots, on average, three hours a day, with Hung Lanh coming to assist her every three weeks when they harvested. He said that in 2016, perhaps over 60 percent of the original land in Bang B village under aquatic plant cultivation was now built over (not much green left he said), and the remaining households, including themselves, were still growing aquatic plants but now numbered around fifty. In terms of proportions of their overall household income, he estimated that his metal workshop job now brought in 60 percent, the plants 25 percent, and his wife's tailoring work 15 percent. He believed they were now comfortably off and he had not regretted buying a new larger house since they had put his two daughters and son through schools and university largely with the money he and his wife had made from culturing aquatic plants. When asked about the future of aquatic plant cultivation in cities like Ha Noi, Hung Lanh thought urbanization and the increasing value of land for building on was inevitable. He had heard that there were a number of new aquatic plant growers in the further away provinces of Bac Giang and Son Tay who were able to grow water mimosa and water morning glory in much larger plots of up to 1 000 m^2, and that he had seen these crops being transported to Ha Noi city markets in small Chinese trucks. He finished by saying that he now missed his days out in the fields working with the plants, but understood that when living on the periphery of a large city things are always likely to change.

3.3 Minh Thuy – Phong Phu commune, Binh Chanh district, Ho Chi Minh City, Viet Nam

Figure 18: Minh Thuy, water morning glory grower, Binh Chanh district, Ho Chi Minh City. Photo courtesy of William Leschen.

3.3.1 Minh Thuy (2004)

In 2004, Ms Minh Thuy (Figure 18) was 38 years old and a mother of two. She was was born in Dalat, Lam Dong province and moved to Ho Chi Minh City with her family in 1975. After leaving school at 17, she went to a vocational college in District 3, where she learned hairdressing, and then met and married her husband who worked on the docks and cargo boats on the Saigon River. After living with his parents, they settled in Binh Chanh district in the early 1990s. There they rented a 1 200 m^2 plot of land with a house in an area close to a wastewater canal network where local households were already involved in the cultivation of water morning glory on former rice fields, though some households had fish ponds and others raised pigs. They were told that back in the 1960s, wastewater aquatic plant cultivation had been carried out intensively in District 6 (closer to the city centre), but had decided against it because the land was being bought and developed for residential housing.

Minh Thuy said rental rates were cheaper in areas of Binh Chanh where wastewater was more abundant, which was one of the reasons why they had settled there. She and her husband quickly learned from others already cultivating water morning glory. They divided their land into three plots of 400 m^2, where they set up a rotational system for cropping most weeks (Figure 19). They were able to harvest 12 months of the year because the temperatures in Ho Chi Minh City are over 27 °C all year-round. The previous person renting the land had also grown water morning glory, so Minh Thuy had little initial work to do in preparing the plots other than purchasing a small petrol water pump and other chemical inputs, such as urea, triple superphosphate fertilizer and builder's lime. She also arranged with one of her neighbours who bought and sold aquatic plants to collect and sell her regular harvests using his motorbike. Most of the aquatic plants grown in Binh Chanh were sent daily in the early morning to a particular collection point 2 km away, where they were sold and then transported in small trucks to other wholesale and retail markets all over the city (Figure 20). Following the births of her two children, Minh Thuy went back to part-time hairdressing in her house to supplement the household income while continuing to work on the aquatic plant plots. At this time, she also hired one of her nieces to work on the aquatic plants, mainly helping her with harvesting and preparing the water morning glory in bundles for transport and selling. Her income from the plants averaged VND 600 000 (USD50 per month), which equated to around 40 percent of her and her husband's total monthly income; he was often away working on the boats for 1–2 weeks at a time. In terms of productivity, her plots produced around 30 000 kg (fresh wet weight) of water morning glory per hectare per year.

Figure 19: Water morning glory cultivation in wastewater Phong Phu commune, Binh Chanh district, Ho Chi Minh City. Photo courtesy of William Leschen.

Figure 20: A small truck is a typical mode of transport for aquatic plants in Ho Chi Minh City. Photo courtesy of William Leschen.

Ms Minh Thuy said that the major challenge with growing water morning glory was that the increased salinization of groundwater was affecting the growth and financial viability of her business. This was, she thought, due to the continual pumping of groundwater by residential and industrial users over the years. This was particularly evident during the dry season, when the young plants replanted from the nursery exhibited darkened curled-up leaves and took two months to reach the necessary size to harvest. This affected her cash flow, as she found it more difficult to afford the necessary inputs such as fertilizer and urea. She and her neighbours sought advice and a potential solution from the local government agriculture extension office, but found the staff to be unhelpful – other than to say that they believed there was a more saline-resistant strain of water morning glory grown in Thailand, but were unable to import it into the country due to the strict disease and non-native plant importation regulations.

Although Minh Thuy and her husband had heard rumours about the potential development of their land from the beginning, in early 2003 they were informed by their landlord and then by the government transport ministry that a new feeder road was going to be built through their aquatic plants plots, as well as their neighbours, by 2006, though their rented house would be allowed to remain. The land would be compulsorily purchased with a reimbursement to each landowner. Those leasing the land like Minh Thuy and her husband had no legal rights or security to stay. By June 2006 when the PAPUSSA project finished, the road had still not been built, but a series of engineers and surveyors had visited in preparation for the road construction.

3.3.2 *Minh Thuy (2016), substituted by Anh Bay*

When we tried to recontact Ms Minh Thuy in 2016 we had problems finding her and her family. The site where they had lived, her rented house and her associated water morning glory plots had disappeared and was now a busy dual carriageway road with adjoining new office and residential housing and small stores. The surrounding land appeared to be in various stages of new construction, with the previous wastewater streams having been channelled into concrete culverts going under and alongside the new road. However, in between the construction there were still some water morning glory and water mimosa plots, and also a new ornamental fish farm with net enclosures (Figure 23) and concrete tanks had been set up on the former aquatic plant site.

We met and spoke to one of the remaining water mimosa growers, Mr Anh Bay (Figure 22), who was 38 years of age, born locally, married with two children, and had been cultivating aquatic plants on the site for 20 years. He took us to his shop and house, where a team of eight women were processing water mimosa and morning glory ready to send to market. For the previous five years, Anh and his wife had also gone into buying and selling mimosa from other growers. After some years and initially renting the property, he bought his own land of 1 ha, where he grew aquatic plants. It was divided into $10 \times 1\ 000\ m^2$ plots with a relatively new water supply channel being built directly from the Saigon River (3 km away), allowing him and the remaining growers to mix the river water and wastewater to the necessary quality to enable the water mimosa to grow well. Anh Bay added that the water quality he now worked with was much better than ten years earlier. Unlike then, he now applies daily inorganic fertilizer to all ten of his ponds and also sprays at least once in a 25–30 day production cycle to remove insect pests. He now employed eight women, four days a week (Figure 21) to process and pack the aquatic plants in his shop below his house, which are then sent by small truck to wholesale markets (70 percent), directly to restaurants (30 percent), and canteens every two days. His wife works nights from midnight to 05:00 hours, five days a week, selling at one of the wholesale markets, returning to sleep, and then helping him in the afternoons with work on the plots. He works full time on the plots and was not willing to share with us the amount he earns from both his own aquatic plant production and the sales of others. An approximate estimate from just his 1 ha area compared with other growers for water mimosa over 12 months would be around VND 70 million (USD4 780 per year); however, their household income is likely to be far higher since they now buy and sell the plants of others. Before leaving, he told us that the market for edible aquatic plants in Ho Chi Minh City was buoyant, and that even in future if he ended up getting moved off his land he would continue production by using the compensation money to rent land further outside the city. He also added that he was now exploring new contracts with two supermarket chains with whom he had been in talks for regular supply contracts.

Figure 21: Processing of water mimosa ready for sale at Anh Bay's shop. Photo courtesy of William Leschen.

Figure 22: Interviewing entrepreneurial Anh Bay, aquatic plants' grower and trader, Binh Chanh district. Photo courtesy of William Leschen.

Figure 23: A new ornamental fish farm set up on former aquatic plant cultivated land, Binh Chanh district, Ho Chi Minh City. Residential construction is ongoing in the background. Photo courtesy of William Leschen.

Through Anh Bay, we obtained a telephone number for Minh Thuy and were able to carry out a follow-up interview with her. She and her family were now living in a small rented flat over her new hairdressing business in a retail area of Binh Chanh. Her two children were still living at home, with her daughter going to university and her son having an apprenticeship with a local car mechanic. Her husband continued to work on the docks, although he now had a more administrative post. For herself, she had set up a small hairdressing business in partnership with another woman in a rented shop, which contributed 30 percent to their total household income. Minh Thuy said the land clearance and road construction had started in late 2007 and they had to move. For four months they stayed with her sister-in-law before finding the flat where they now lived.

Ms Minh Thuy reflected on the gradual demise of the aquatic plant culture in her previous home area, saying that while it had lasted for 15 years she had made a good income from growing water morning glory, the money from which had helped her put her children through school and now her daughter in university. She had also been able to save for the rainy days she knew were coming and to put at least some capital towards a hairdressing shop, which had always been one of her dreams. When asked further about the future of aquatic plant production in cities, she said that green areas within cities are always good, and wondered if city planners and politicians could set aside some areas for nature parks, including aquatic plant and fish cultivation, birds and other wildlife, where people and families could walk, go fishing and enjoy nature on the weekends. She also added that she and her neighbours had always struggled to get help or technical advice about FAMs from the different government agriculture or advisory services and suggested that it would be beneficial for the government to set up a new body that specialized solely in urban food production within cities.

3.4 Phan Kim – Tam Phu commune, Thu Duc district, Ho Chi Minh City, Viet Nam

3.4.1 Phan Kim (2004)

Figure 24: Phan Kim with his water mimosa fields, Thu Duc district, Ho Chi Minh City. Note another aquatic macrophyte duckweed *Lemna sp.* also grown in conjunction with water mimosa. Photo courtesy of William Leschen.

In 2004, Mr Phan Kim (Figure 24) was 42 years old and married with one daughter. He was born in Bac Giang province, northern Viet Nam, where he had grown up, married and became a rice farmer, but one who also cultivated fish and raised pigs. In 1987, following the lead of a cousin, he and his wife moved to Ho Chi Minh City to find work in hopes of increasing their income. He had heard that the government in the south had opened up possibilities for people to own or lease land instead of the government-owned, commune-based system of the past. Also, he heard that municipal authorities in Ho Chi Minh City had put aside areas in certain districts in the city for agricultural farming. He, his wife and daughter initially found a room to rent in Thu Duc district, which was one of the so-called "green" designated peri-urban areas. After a few months, he rented a 1 000 m^2 plot in Tam Phu commune, a government-owned land area that was beginning to develop from former rice fields into aquatic plant cultivation. In starting the venture, he needed little equipment, initially shovels and spades and a portable petrol water pump. His family and brother, who had also moved to Ho Chi Minh City, renovated and modified the rice paddy dykes to produce 2 × 500 m^2 plots in which they began to cultivate water mimosa and selling the plants to a nearby wholesale market in bundles.

Phan Kim said the early years were hard, but they learned from their mistakes, such things as overfertilizing with urea or adding too much wastewater into the plots during the dry season, both of which caused significant losses of plants. By the early 1990s, he was able to rent an adjacent field of 7 000 m^2, which took his production area up to 8 000 m^2. This now involved more labour, and two of his cousins arrived from northern Viet Nam to supplement what was already a family workforce. By 2004, when he was interviewed by the PAPUSSA project, the family was earning VND 50 million (USD3 250) per year from mainly water mimosa production and sales. Phan Kim had been able to buy a residential plot and build a new house nearby in which his extended family all lived. At this time, he was confident about the security of the leased agricultural land, as the government had maintained their undertaking to keep certain areas of Thu Duc district "green". He said he had no major problems growing mimosa and thought the water mimosa had provided himself and his family a steady income. He wished that the prices in the wholesale market sector could be more stable, as these tended to fluctuate, considerably affecting their cash flow and margins at certain times of the year.

Figure 25: Water mimosa transported by motorbike at Thu Duc district wholesale market, 03:00 hours. Photo courtesy of William Leschen.

3.4.2 Phan Kim (2016)

Mr Phan Kim was still very much involved in aquatic plant production in 2016 when we contacted him by phone. He still produced water mimosa and some water morning glory from his original plots, although two years earlier he had also gone into ornamental fish culture in ponds and a hatchery in a neighbouring commune that took up to two to three days of his week. His wife was now running the aquatic plants on a daily basis with the two cousins and two other locals who worked part time. Phan Kim also employed a former army driver to transport both the harvested fresh plants and ornamental fish by motorbike (Figure 25) or a hired small truck to markets. When asked about what had been the major changes for growing aquatic plants in the 10–12 years since we last spoke to him, Kim said he was well aware that cultivation in some of the neighbouring urban districts had declined due to land pressures and construction. But this, he said, had not affected the price or demand in city markets, as a series of new growers from Ho Chi Minh City's outlying districts/provinces such as Cu Chi had begun to produce at scale and were now regularly supplying significant volumes of fresh produce into the city, some undercutting the prices of the older more established growers. Saline intrusion, i.e. more brackish groundwater, was increasingly causing the growers problems, but the best sites he now said were the ones with access to Saigon River water, which, particularly in the dry season, when pumped into the plots two to three times per week reduced blackening of plants and die-off. He suggested that the government and university scientists should work on producing more saline-tolerant water mimosa and morning glory plants, which he thought would greatly benefit aquatic plant growers and also potentially affect in a positive way the taste of the plants for consumers. Phan Kim also noted that the majority of growers, including himself, were now using more inorganic fertilizers and less wastewater in order to increase the productivities of plot areas. Although this meant more in input costs, He said that from an average harvesting frequency of 30 days for water mimosa when he started back in the 1990s, he and others were now achieving faster growth and harvesting, on average, every 25 days. For the future, he thought mechanization in some form, in both production and processing, would further lower costs, and also, potentially, lower the prices of the finished products. Phan Kim believed there would be increased competition and pressure on water availability for agriculture in peri-urban areas, and therefore as technology developed and prices dropped, solar water-pumping setups would become viable so as to allow more flow-through of water in the systems, higher productivities per unit area, and possibly complete recirculation systems that would only need topping up from time to time.

3.5 Boengchueng Congdoen – Sainoi district, Nonthaburi province, Bangkok, Thailand

Figure 26: Boengchueng Congdoen packing water morning glory for Talat Thai wholesale market, Bangkok. In the background, chemical-free morning glory trial for the European Commission PAPUSSA project. Photo courtesy of William Leschen.

3.5.1 Boengchueng Congdoen (2004)

In 2004, Mr Boengchueng Congdoen (Figure 26) was a 51-year-old father of three. He came from Pathumthani province, some 45 km from Bangkok. After finishing secondary school, he attended a local agricultural college, where he discovered his interest and passion in horticulture and growing vegetables. After leaving school, he worked for a while in north-east Thailand as a lorry driver, delivering fertilizers and other farm inputs, but he returned to the Bangkok area in 1978 to work on a seasonal fruit and vegetable farm in Nonthaburi province. He worked his way up from being a driver and labourer to be a supervisor by the mid-1980s; he got married and bought his first house with some small adjoining land where he grew vegetables about 20 km from the centre of Bangkok. In 1987, he obtained a 10-year lease on a further 3 ha of rice paddy land close to his house and began to grow vegetables including tomatoes, chilies and okra on a converted 0.5 ha area. He and his wife grew the vegetables part time, employing one other person for assistance. The vegetables were sold directly to local retail markets, and he was responsible for the marketing, transport and sales. After a few years, he was able to buy a pick-up vehicle from the sales of his vegetables, which broadened his sales networks and access to other buyers.

In 1990, Congdoen decided to leave his farm supervisor's job to work full time on his own vegetable business, which was now thriving. In the years, he had seen the beginnings of aquatic plant cultivation in neighbouring Pathumthani province, morning glory in the irrigation canals, and water mimosa and water lotus in shallow plots converted from former rice production. These local growers were having no trouble selling the plants to markets and restaurants across the city, so he converted his now remaining 2 ha of land for aquatic plants cultivation. By 1993, he was employing eight people on aquatic plant cultivation, and the income from his aquatic plants surpassed his original land vegetable production by two to one. His production system for aquatic plants was based on using water from one of Bangkok's local transport and irrigation canals, which while not "wastewater" did contain nutrients from runoff from the surrounding agricultural land. From the early 1990s up to 2004 when PAPUSSA interviewed him, Congdoen steadily intensified production through increasing levels of inputs, including triple superphosphate fertilizer and sprays to control pests, with the productivities of his water morning glory production increasing from about 20 tonnes per hectare per year (wet weight) to over 70 tonnes per hectare per year by 2004. At this time, he was transporting and selling up to 2 tonnes (wet weight) of morning glory and water mimosa per week in Talat Thai market, which is one of Bangkok's two large fruit, vegetable and fish wholesale markets (Figures 27 and 28). He estimated that this market received and sold between 80 and 100 tonnes of FAMs daily, mainly water morning glory, water mimosa and lotus, at an approximate value of USD35 000 each day, thus illustrating the size and scale of this food production sector in Thailand. When asked about the future of aquatic plant cultivation in and around Bangkok, he believed growing market demand would ensure people like him could continue to produce it profitably. However, he was concerned about the continuing expansion of the city outwards and the inevitable disappearance of agricultural land to buildings. He also thought the increasing influence of supermarkets, some of which he had contracts to sell both land vegetables and aquatic plants, would through consumer pressure, prefer to see more chemical-free healthier "organic" vegetables. In the last few years, he had started to trial chemical-free land vegetable production, which although having lower yields, could sell for higher premium prices in the big Bangkok supermarkets.

Figure 27: Harvesting water morning glory, Nongpraongai village, Nonthaburi province. Photo courtesy of William Leschen.

Figure 28: Collection point and transport of morning glory to wholesale markets, Sainoi district, Nonthaburi province, peri-urban Bangkok. Photo courtesy of William Leschen.

3.5.2 Boengchueng Congdoen (2016)

By 2016, when we contacted Boengchueng Congdoen by telephone, he had actually semi-retired because of ill health, handing over his farming business to one of his daughters. The original 3 ha of land had been reduced to just 1 ha, where his daughter had continued to grow land vegetables. He said he had been made a very good offer for the other 2 ha by developers and in 2014 he sold the land, which had now become a residential housing estate. While he said he and his wife were now relatively comfortably off, he thought aquatic plant cultivation around Bangkok had become more intensive and more specialized than when he had started in the 1990s. He had heard of the now much larger farms (10–15 ha) further away from the city that were able, through the use of tractors, mechanical sprayers, etc., to produce water morning glory at lower production costs. Boengchueng Congdoen added that he had heard that there were now a number of different varieties of water morning glory available commercially, which had improved yields and allowed growers to trial them under different growing conditions. When asked about his health, he said he had increasingly suffered from respiratory-related issues, which he believed might have come from his many years using sprays and different chemicals while working in the horticulture sector. He added that his daughter had developed the chemical-free land vegetable and some similar "organic" morning glory production that he had been interested in the early 2000s and was selling these to a supermarket chain in Bangkok. However, in terms of the proportion of these organic products to her total sales, these were still niche products, representing he said, probably less than 10 percent of her total sales.

CHAPTER 4

4.1 Discussion and conclusions

This review has mainly concentrated on the relatively limited number of FAMs which have over the centuries to the present day been collectively or commercially cultivated for food, or in certain cases, for other uses such as bioremediation, water treatment and construction materials across South and Southeast Asia. Both the available literature (peer reviewed and grey), as well as the specialized government and research institutions involved in FAM production are limited, with little information available on the scale, importance and benefits from FAM production even though significant numbers of people are either directly or indirectly involved. The often under-reported successes and impacts of these relatively few aquatic plant species are perhaps a result of their fairly simple, fast vegetative growth, low start-up cost production cycles, which are relatively risk averse. They can be produced on the doorstep of huge urban centres of dense population, where there is almost unlimited demand, and, historically, also being able to recycle, treat and recover nutrients from urban wastewater to produce food. Other than land, water and some form of nutrient inputs, FAMs require few expensive inputs or complicated technical management. At the same time, there is a large and growing market across the region for the relatively cheap but nutritious fresh green-leaf products.

With the possible exception of water morning glory, and despite the historical wide-scale translocation and spread of FAMs overseas, borders and cultures, nationally or regionally, there seems to be little genetic development, improved cultivars, breeding programmes or genetic modification of the other main cultivated FAMs. This is likely because the established varieties that growers have been using over the past 50–100 years for plants like water mimosa have had the necessary growth rates and productivities for significant numbers of growers to make a living from them and because growers have been using cuttings of their own plant stocks for propagation. However, in more recent years, the growing intensification of these systems and increasing challenges within peri-urban environments of industrial contamination of wastewater, pests and salinization of water tables has led to calls for more research into not just faster-growing cultivars, but also pollutant and saline-tolerant, pest-resistant varieties of the plants. Likewise, comparative research trials using different cultivars of particular FAM species have clearly shown differential bioremediation and water treatment capabilities, findings which may be used to commercial effect in years to come. Considering the documented lack of extension and technical support for aquatic plant growers across the region from government and research sectors, any effort for varietal improvement would need also to build in access pathways for farmers. Currently, the private sector in China and Thailand, as well as international vegetable research institutes, is investing some funds in producing better water morning glory varieties available to growers. It is hoped that in future the importance of good seed stock will be recognized in allowing FAM production to continue to be profitable and to increase the food that is produced for urban populations in both existing and new locations in what are changing environmental and socio-economic conditions.

In the past 30 years, the key findings, as presented in the case studies, clearly indicate the transitory nature of FAM production, with some of the original peri-urban production sites having disappeared as a result of domestic residential and commercial business construction, a direct result of the increasing pressure of urbanization and ever-rising values of urban land. However, there is positive evidence that shows certain countries like Viet Nam, government urban planners have taken action and designated greenbelts, or green areas, where agriculture or other environmental development can continue while appropriate land is protected from further urban construction, such as in Thu Duc and District 11 in Ho Chi Minh City. FAM production, especially of water mimosa and water morning glory, still flourishes there in 2016, but the general picture over the region has been for FAM production areas to radiate out of cities to the peripheries where land is more affordable and good road and transport links still allow the fresh plants to be harvested, where within a few hours the plants can be sold fresh in urban markets, or processed and packed and ready for sale to the increasing numbers of supermarkets.

This review has clearly shown the reliance of sustainable FAM production on local access and availability in the necessary quantities of required nutrients, which in many urban contexts have been provided by urban wastewater. However, as these wastewater-based systems have evolved alongside urbanization, they have suffered increasingly from industrial contamination of the wastewater itself, leading to lower productivities but also increasing the consumer health concerns of younger, better-informed urban populations. The evidence clearly shows that FAM production, while having to move further away from cities, has also been intensifying and is less reliant on wastewater and more reliant on inorganic fertilizer inputs.

While it is clear that particular FAM species lend themselves towards mass production to provide employment and incomes for thousands of often lower-income individuals, and a nutritious and relative cheap food for millions of urban dwellers, it is perhaps less clear how the production systems will survive, modify and develop in the future. Whether they will be able to continue to safely use and recycle urban wastewater in “protected” peri-urban locations close to urban markets without continually being threatened with eviction from property developers is unclear. It is likely that producers will move outwards to the ever-distancing urban peripheries, where some are already intensifying production and relying on bought inorganic fertilizers and chemical sprays to raise productivities. These questions are relevant and should be asked, because despite records of FAM consumption going back to over 2 000 years, it is only in the last 30 or 40 years that commercial production and farming at scale of FAMs have been taking place in South and Southeast Asia for a few key species. Thus, these FAMs are a relatively new and young food production system and associated value chain, which are only likely to evolve and develop in the future. It is hoped that research institutes, development organizations and the private sector will see their potential and look to identify which of the other not yet mass-cultivated species will be the best candidates for future scaling up and commercial production.

In conclusion, there is considerable future potential for edible freshwater aquatic plant production systems in tropical and temperate developing countries where wastewater is freely available, and this production can be both financially and environmentally sustainable. However, for these types of nutrient recycling, wastewater treatment food-production systems to spread out from their accepted cultural heartlands of Southeast Asia, a range of stakeholders, including urban planners, occupational health and food safety researchers, aquaculturalists, agriculturalists, existing aquatic plant growers, market chain specialists and others, need to come together to discuss, design and produce safe, sustainable integrated workable models with associated budgeted plans that can be taken up by potential and new uptake cities and peri-urban areas.

REFERENCES

Anh, V.T., van der Hoek, W., Ersbøll, A.K., Thuong, N.V., Tuan, N.D., Cam, P.D. & Dalsgaard, A. 2007. Dermatitis among farmers engaged in peri-urban aquatic food production in Hanoi, Vietnam. *Tropical Medicine and International Health*, Volume 12, Issue December: 59–65.

Austin, D.F. 2007. Water spinach (*Ipomoea aquatica,* Convolvulaceae): a food gone wild. *Ethnobotany Research & Applications*, 5: 123–146. Accessed 16 November 2016.
(also available at http://scholarspace.manoa.hawaii.edu/bitstream/10125/226/6/I1547-3465-05-123.pdf).

Basketter, D.A., Briatico-Vangosa, G., Kaestner, G.W., Lally, C. & Bontinck W.J. 2006. Nickel, cobalt and chromium in consumer products: a role in allergic contact dermatitis? *Contact Dermatitis*, 28 (1): 15–25. First published in January 1993. Version of record online: 11 April 2006.
DOI: 10.1111/j.1600-0536.1993.tb03318.x.

Biswas, K.P. 1927. Flora of the salt lakes, Calcutta. *Journal of Department of Science*, 8: 1–48.

Boyd, C.E. 1968. Fresh – Water plants: a potential source of protein. Econ. Bot 22:359-368.

Cai, Q.Y., Mo, C.H., Zeng, Q.Y., Wu, Q.T., Ferard, J.F. & Ladislao, B.A. 2008. Potential of *Ipomoea aquatica* cultivars in phytoremediation of soils contaminated with di-*n*-butyl phthalate. Environmental and Experimental Botany, 62(3): 205–211.

Chen, Y., Zhou, R., Lin, X., Wu, K., Qian, X. & Huang, S. 2008. ISSR analysis of genetic diversity in sacred lotus cultivars. *Aquatic Botany*, 89(3): 311–316.

Cohen, J., Mirotchnick, N. & Leung, B. 2007. Thousands introduced annually: the aquarium pathway for non-indigenous plants to the St Lawrence Seaway. *Frontiers in Ecology and the Environment*, 5(10): 528–532. DOI: 10.1890/060137.

Cook, C.D.K., Gut, B.J., Rix, E.M., Schneller, J. & Seitz, M. 1974. *Water plants of the world. A manual for the identification of the genera of freshwater macrophytes*. The Hague. P. 561.

Dalsgaard, A., Klank, L.T., Vuong, T.A., Phung Dac Cam, P.D., Marcussen, H., Jorgensen, K., Holm, P.E., Brocca, D., Simmons, R., Lan, T.P.L. & Mara, D. 2006. *Food safety of aquatic plants and fish raised in wastewater-fed ponds*. EC INCO Dev FP project publication. Contract number ICA4-CT2002-10020. Project homepage: www.papussa.org. Accessed June 2016.

Dasgupta, R. 1973. Contribution of botany of a portion of salt lakes, West Bengal. *Bulletin of the Indian Museum,* 1, 36–43.

East Kolkata Wetland Management Authority (EKWMA). 2011. *Conservation and management plans of east Kolkata wetlands, India.* Report submitted to the Ministry of Environment and Forests, Government of India.

Edie, H.H. & Ho, B.W.C. 1969. *Ipomoea aquatica* as a vegetable crop in Hong Kong. *Economic Botany*, 23: 32. doi: 10.1007/BF02862969.

Edwards, P. 1980. *Food potential of aquatic macrophytes*. ICLARM Studies and Reviews, 551 pp. International Center for Living Aquatic Resources Management, Manila, Philippines.

Edwards, P. & Pullin, R.S.V. 1990. *Wastewater-fed aquaculture*. Proceedings of the International Seminar on Wastewater Recycling and Reuse for Aquaculture. Kolkata, 6–9 December.

Egbert, A.W. 2010. *Promotion of indigenous vegetables in Asia. Conservation and use of selected crops in Indonesia, the Philippines and Taiwan*. ISHS Acta Horticulturae 918: XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): III International Symposium on Plant Genetic Resources.

Gilbert, K. 1984. *A review of the aquatic plant (water spinach).* Report prepared by the Bureau of Aquatic Plant Research and Control, Florida Department of Natural Resources. USA, USDA.

Ghosh, D. 2005. Ecology and traditional wetland practice, Kolkata: *Worldview*.

Herklots, G.A.C. 1972. *Vegetables in Southeast Asia*. New York, Hafner Press.

Ikakkar, M., Mohan & Ram, H.Y. 1986. Regeneration of whole plants from tissue cultures of the tropical aquatic legume, *Neptunia oleracea. Journal of Plant Physiology*, 126(1): 83–91.

Iqbal, S. 1999. Duckweed aquaculture: potentials, possibilities and limitations for combined wastewater treatment and animal feed production in developing countries. SANDEC Report No. 6/99 91 pp. Department of Water and Sanitation in Developing Countries. Swiss Federal Institute for Environmental Science and Technology, EAWAG, Duebendorf, Switzerland.

Ji, H. 304 C.E. *Nan-fang ts'ao mu chuang* 南方草木状 *Nanfang caomu Zhuang* [Plants of the southern regions].

Korkut, A.Y., Gunes, A., Kop, A.C., Handan, A., Ozlem, G., Mehmet, A.O., Ozkul, B.K., Edis, S., Cuneyt, C., Semra, F., Kursat, S. & Sahin, G.C. 2016. Preliminary study for utilisation of some invasive aquatic plants as raw material for aquaculture feeds. *Fresenius Environmental Bulletin,* 25 (11): 4915–4920. 6 pp.

Khamwan, K., Akaracharanya, A., Chareonpornwatra, S. & Shinmyo, A. 2005. Genetic transformation of water spinach (*Ipomoea aquatica*). *Plant Biotechnology*, 20(4): 335–338.

Kong, Q.D. 2005. *The aquatic vegetable cultivars and resources of China*. Wuhan, China, Hubei Science and Technology Press. pp. 3, 61, 101, 149, 175, 219, 248, 269, 293, 303, 313, 339.

Lang, T. 2000. Food policy for the 21st century: can it be both radical and reasonable? In: *For hunger proof cities: sustainable urban food system*s. Edited by K. Mustafa. IDRC, Canada.

Lee, C.L., Wang, T.C., Hsu, C.H. & Chiou, A.A. 1998. Heavy metal sorption by aquatic plants in Taiwan. *Bulletin Environ. Contam. Toxicol*., 61: 497–504. New York, Springer-Verlag.

Lee, C.L., Wang, T.C., Lin, C.K. & Mok, H.K. 1999. Heavy metals removal by a promising locally available aquatic plant, *Najas graminea* Del., in Taiwan. Chemical process industries and environmental management. *Selected Proceedings of the International Specialized Conference on Chemical Process Industries and Environmental Management Water Science and Technology,* 39 (10–11): 177–181.

Lee, S.L. 2002. The Chinese Mariner Zheng He [Cheng Ho]. Available at www.chinapage.com/history/zhenghe2.html. Accessed January 2017.

Li, M., Wu, Y.J., Yu, Z.L., Sheng, G.P. & Yu, H.Q. 2007. Nitrogen removal from eutrophic water by floating-bed-grown water spinach (*Ipomoea aquatica* Forsk.) with ion implantation. Water Research, 41(14): 3152–3158.

Li, L., Teixera da Sliva, J. & Cao, B. 2007. Aquatic vegetable production and research in China. Asian and Australian Journal of Plant Science and Biotechnology, 1(2): 37–42.

Liao, S.W. & Chang, W.L. 2004. Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan. *J. Aquatic Plant Management*, 42.

Little, E.C.S. & Henson, I.E. 1967. The water content of some important tropical water weeds. *Pesticides Artic. News Summary*, 13: 223–227.

Mandal, R.N., Datta, A.K., Sarangi, N. & Mukhopadhyay, P.K. 2011. Diversity of aquatic macrophytes as food and feed components to herbivorous fish – a review. *Indian Journal of Fisheries*, 57(3): 65–73. India, Australia: Central Marine Fisheries Research Institute (on behalf of Indian Council of Agriculture, 2011).

Mandal, R.N., Saha, G.S., Kalita, P. & Mukhopadhyay, P.K. 2008. *Ipomoea aquatica* – an aquaculture friendly macrophyte. *Aquaculture Asia Magazine*, April 2008.

Marcussen, H., Dalsgaard, A. & Holm, P.E. 2009. Element concentrations in water spinach (*Ipomoea aquatica* Forssk.), fish and sediment from a wetland production system that receives wastewater from Phnom Penh. *Cambodia Journal of Environmental Science and Health, Part A Toxic/Hazardous Substances and Environmental Engineering*, 44 (1): Abstract.

McGarry, M.G. & Tongkasame, C. 1971. Water reclamation and algae harvesting. *Journal of Water Pollution Control Fed.,* 43: 824–835.

Mitchell, D.S. 1974. *Aquatic vegetation: its use and control*. Paris, UNESCO. 135 pp.

Northcott, D.S. 1982. *The role of aquatic macrophytes in the availability of food for young fish*. Dissertation/thesis.

Padilla, D.K. & Williams, S.L. 2004. Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. *Frontiers in ecology and the environment*, 2, (3): 131–138. DOI: 10.1890/1540-9295(2004)002[0131: BBWAAO] 2.0. CO;2.

Parkinson, R. & Quirke, S. 1995. *Papyrus – the Egyptian bookshelf*. University of Texas, Austin, Texas, USA. ISBN 0292765630.

Purnomohadi, N. 1999. *Urban agriculture as an alternative strategy to face the economic crisis: a case study*. Jakarta RUAF publication.

Rahman, M.M., Yakupitiyage, A. & Ranamukhaarachchi, L. 2006. Fertiliser requirements of morning glory for its higher production in the Asian region. Asia-Pacific Journal of Rural Development, X VI (2).

Reddy, K.R. & DeBusk, T.A. 1987. State-of-the-art utilization of aquatic plants in water pollution control. *Water Science and Technology*, 19(10): 61–79.

Reilly, A. & Kaferstein, F. 1997. Food safety hazards and the application of the principles of the hazard analysis and critical control point (HACCP) system for their control in aquaculture production. *Aquaculture Research*, 28 (10): 735–752.

Sheridan, G.E.C., Claxton, J.R., Clarkson, J.M. & Blakesley, D. 2001. Genetic diversity within commercial populations of watercress (*Rorippa nasturtium-aquaticum*), and between allied Brassicaceae inferred from RAPD-PCR. *Euphytica*, 122: 319.

Strauss, M. 1997. Health (pathogen) considerations regarding the use of human waste in aquaculture. *Environmental Research Forum*, 5/6: 83–98.

Tiwari, N.C. & Chandra, V. 1985. Water spinach. Its varieties and cultivation 1985. National Botanic Research Institute, Lucknow 226 001, India. *Indian Horticulture*, 30(2): 23–24.

Van der Hoek, W., Vuong, T.A., Cam, P.D., Chan, V. & Dalsgaard, A. 2005. *Skin diseases among people using urban wastewater in Phnom Penh*. Urban Agriculture 2005. RUAF Foundation, ETC Netherlands. EC PAPUSSA project. Contract number: ICA4-CT2002-10020.

Van Hoeck, A., Horemans, N., Monsieurs, P., Cao, H.X., Vandenhove, H. & Blust, R. 2015. The first draft genome of the aquatic model plant *Lemna minor* opens the route for future stress physiology research and biotechnological applications. *Biotechnology for Biofuels*, 8: 188.

Wang, G-Y. 1991. *Book of component parts in food*. Beijing, People's Medical Publishing House. pp. 10–16.

Wang, Q. & Zhang, X. 2004. *Illustrations of lotus cultivars in China*. Beijing, China Forestry Press.

Westphal, E. 1992. *Ipomoea aquatica* Forssk. In: L. Mannetje & R. Jones, eds. *Plant resources of Southeast Asia*, pp. 164–166. No. 4. Forages. Wageningen, Netherlands, Pudoc Scientific Publishers.

Zhou, X. 2016 Cultivation of aquatic macrophytes falls between aquaculture and horticulture. FAO Aquaculture Newsletter, 55 (September 2016): 6–7. Rome.

Yuri T., Yamamoto Y.T., Rajbhandari, N., Lin, X., Nishimura, Y. & Stomp, A.M. 2001 Genetic transformation of duckweed *Lemna gibba* and *Lemna minor. Vitro Cellular & Developmental Biology – Plant,* 37(3): 349–353.

Zeng, C., Cheng, Y., Lucas, J.S. & Southgate, P.C. 2012. *Aquaculture – farming aquatic animals and plants. Second edition.* Wiley-Blackwell, eds: J.S. Lucas and P.C. Southgate. Chapter 22: Other Decapod Crustaceans, p. 514.

Zhang, Q., Achal, V., Xu, Y. & Xiang, W.N. 2014. Aquaculture wastewater quality improvement by water spinach (*Ipomoea aquatica Forsskal*) floating bed and ecological benefit assessment in ecological agriculture district. *Aquacultural Engineering*, 60: 48–55. http://dx.doi.org/10.1016/j.aquaeng.2014.04.002.

Zhao, Y.W. 1999. *Chinese aquatic vegetables*. Beijing, Agricultural Press. pp. 18, 81, 128.