Chinampas: An Urban Farming Model of the Aztecs and a Potential Solution for Modern Megalopolis

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Summary. Urban horticulture is not as new as many people think. Throughout history, different techniques have been used to ensure sustainable urban agricultural production. A good example of this is the chinampa system, which was developed during the time of the Aztecs in the region of Lake Xochimilco, south of Mexico City. A chinampa is a raised field on a small artificial island on a freshwater lake surrounded by canals and ditches. Farmers use local vegetation and mud to construct chinampas. Fences made of a native willow [bonpland willow (*Salix bonplandiana*)] protect the chinampa from wind, pests, and erosion. The dominating crops are vegetables and ornamentals. The canal water that rises through capillarity to the crops reduces the need for additional irrigation. A considerable portion of the fertility in the soils is system-immanent and generated in the aquatic components of the chinampa. Complex rotations and associations allow up to seven harvests per year. Chinampas also provide ecosystem services, particularly greenhouse gas sequestration and biodiversity diversification, and they offer high recreational potential. Recently, research and community initiatives have been performed to try to recover the productive potential of chinampas and align this sustainable system with the needs of the 21st century. In other parts of the world, some with a history of raised field agriculture, similar efforts are being made. The chinampa model could help supply food and ecosystem services in large cities on or near swamplands, large rivers, or lakes.

Chinampas, from the Nahuatl word *chinamitl* (hedge close to the reed), comprise a short stretch of land in the lakes in the southern Valley of Mexico City, where horticulture is practiced (Real Academia Española, 2018). They are also commonly called floating gardens (Ortiz et al., 2015). Chinampas describe both the region and type of intensive pre-Columbian agriculture performed in shallow lakes or marshes (Morehart and Frederick, 2014; Ramos-Bello et al., 2001; Torres et al., 1994). Chinampas are considered raised field (RF) systems, which are a type of agriculture consisting of elevated, narrow platforms used as fields surrounded by water canals connected to ditches. These fields are constructed by digging the canals and mounding the obtained earth on the platforms (Lhomme and Vacher, 2002).

The chinampa system is still practiced in suburban and inner city agriculture (Leon-Porfilla, 1992). It is one of the most intensive and productive production systems ever developed (Altieri and Koohafkan, 2004), and it is highly sustainable. Traditional chinampas are biodiverse; they can be kept in almost continuous cultivation, their soils are renewable, and they create a microenvironment that protects crops from frosts (Morehart and Frederick, 2014). In addition to their economic and environmental contributions, chinampas also provide cultural benefits to southern Mexico City (Merlín-Uribe et al., 2013). The role of the chinampas as a recreational resource is becoming increasingly important because the combination of tourism and agriculture has provided the impetus for a revitalization of pre-Hispanic traditions (Losada et al., 1998).

Similar RF systems were developed in other parts of the New World, but they disappeared during the colonial period; only chinampas survived (Renard et al., 2012). The chinampas of today are situated at an altitude of 2240 m near the lake region of Mexico City, mainly Lake Xochimilco, which is 23 km south of the downtown area. Xochimilco is a remnant of a formerly extensive wetland region formed by five lakes that has undergone anthropogenic alterations over the past 2000 years. Other regions near where chinampas were created, such as historical Xaltocan, have disappeared (Morehart, 2011; Narchi, 2013; Torres et al., 1994).

History

The area in the south of Mexico City has been cropped since 1500 BCE (Narchi, 2013). During the late Aztec period (1325–1521), extensive irrigation networks with floodwater systems and canals were created, which enabled the construction of the chinampas. Their development was linked to high regional population density and the growth of sizable local urban communities. Forced labor imposed by the governing elite to produce surpluses was a further trigger of agricultural intensification. The RF agriculture provided pre-Columbian farmers with better drainage, soil aeration, moisture retention during the dry season, high and long-term fertility, and high productivity per area and input (Renard et al., 2012; Torres et al., 1994).

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1	meq/100 g	$cmol \cdot kg^{-1}$	1
1.6093	mile(s)	km	0.6214
2.5900	mile²	km²	0.3861
1	mmho/cm	$dS \cdot m^{-1}$	1
62.5000	oz/lb	$g \cdot kg^{-1}$	0.0160

After the conquest, new crops were established, especially vegetables with a high tolerance for moisture such as lettuce (*Lactuca sativa*) or cabbage (*Brassica oleracea* var. *capitata*). The introduced livestock provided manure for fertilization. In contrast, the destruction of the Aztec political system involved the deterioration of the hydraulic control of the lake area. The second part of the 20th century was characterized by an explosion of the population of Mexico City, especially southern Mexico City. The consequences were less area for chinampas and a decrease in available freshwater. In the Xochimilco region, the chinampa area under cultivation decreased by more than 60% during the second half of the 20th century (Torres et al., 1994). Nevertheless, the system maintains high yields with relatively low inputs. Due to the introduction of conventional production techniques in the context of the Green Revolution around 1970, the chinampas of today are significantly altered compared to the Aztec ones (Renard et al., 2012).

The Aztecs in the Valley of Mexico used RF agriculture to exploit the swamplands bordering lakes. Similar historical arrangements were built in other regions (Altieri and Koohafkan, 2004). Systems in Tlaxcala, Mexico (Crews and Gliessman, 1991), the ancient raised gardens near Lake Titicaca (Erickson, 1992), and RF in southern China and Oceania (Renard et al., 2012) show close similarities with the chinampas. There are also analogies with RF in other parts of Latin America, Asia, Oceania, and Africa (Table 1). Less similar RF systems existed in the Netherlands, Denmark, Russia (Groenman and van Geel, 2017), France (Hortillonnages d'Amiens, 2018), and Bangladesh (Food and Agriculture Organization of the United Nations, 2018).

Chinampas today

Threatened by the quick growth of Mexico City and its suburbs, chinampas have disappeared from most of the urban landscape (Altieri and Koohafkan, 2004). Between 1989 and 2006, urban land increased from 46.7% to 57.2% of the total area in Xochimilco (not including illegal housing), and the space for chinampas decreased from 7.4% to 2.5%. Around 1990, the local government promoted the use of greenhouses due to their independence of precipitation. Consequently, the greenhouse area increased from 0.02% to 2.3% (Merlín-Uribe et al., 2013). Urbanization has caused environmental problems such as forest degradation, erosion, floods, land sinking, pollution of soil and water, reduced water retention and infiltration, and a loss of biodiversity. Farmers now deal with increasing pest populations and changes in the regional climate (Torres et al., 2000). Negative crop responses to environmental degradation include reduced flowering and fruiting, crop size reduction, and lower yields (Torres et al., 1994). Another serious threat is that the water supply, which needs to sustain the city's growing need for potable water, is decreasing (Losada et al., 1998). In 1950, the local government began supplying treated sewage water for the chinampas because many canals annually run dry. The polluted water caused soil degradation and habitat alteration. The water hyacinth (*Eichhornia crassipes*) currently prospers in the chinampa canals, thus making navigation difficult and inhibiting the growth of endemic flora (Torres et al., 1994).

Chinampa soils sequester large quantities of carbon (Renard et al., 2012) and are becoming a relevant strategy in Mexico City's efforts to reduce greenhouse gas (GHG) emissions. However, due to their humidity and high organic matter (OM) content, chinampa soils are characterized by considerable aerobic microbial activity and, consequently, high oxygen consumption. These conditions favor GHG emissions. A study performed in Xochimilco indicated that emissions of carbon dioxide were generally low, but that nitrous oxide contributed 90% and methane contributed 9% to GHG emissions. It was shown that frequent irrigation increases GHG emissions as denitrification is stimulated and anaerobic microsites are created (Ortiz et al., 2015).

Dimension and construction

Most RF systems are grouped in parallel series to form ladder- and checkerboard-like arrangements, bordered by ditches or embankments. The chinampas near Xochimilco regularly have a rectangular design. The length of the individual fields varies from 8 to 100 m, and the width varies from 2 to 25 m. The desired capillary effect determines the optimal dimensions: if the soil water is deficient during certain periods, then narrow fields are more convenient, and vice versa (Martínez, 2004; Renard et al., 2012). The Aztecs built their platforms to a height of 50 to 70 cm (Armillas, 1971). If the surface of a chinampa protrudes the water level by 45 to 65 cm, then shallow-rooting crops can be subirrigated. For deeper rooting crops, or in soils with a high capillary rise, a minimum height of 88 cm is preferable (Crossley, 2004).

The first step in the construction of a chinampa is locating a firm floor in a shallow canal area. Chinampas are constructed with mud scraped from the surrounding swamps or lakes (Altieri and Koohafkan, 2004). The corners of a field are delimited by solid posts. Around each field, a fence made of *ahuejotes* (bonpland willow) is built. The use of this local willow species is common because it grows quickly and effectively fixes the borders of the mounds. Additionally, *ahuejotes* provide shade, create a protective barrier against wind and pests, and serve as trellises for vine crops. After the planting, the willow is interwoven with reeds and branches of other plants. The result is the *chinamil* (a solid fence) that is continuously fortified with floating mud and plant material. When the *chinamil* is stable and the raised mud reaches a height of 50 cm, the top layer must dry for several weeks. Later, more mud, compost, or other organic materials are added (Martínez, 2004).

Soils

Chinampa soils are cumullic anthrosols. Clay textures are most common. Gray tones dominate when soils are dry, and black tones dominate when soils are wet. The soil density diminishes with depth, mainly because of higher OM content, which results in high aggregation and low compaction. Bulk densities are less than 1, and the porosity reaches values of 61% to 90%. Well-aerated and waterlogged soil compartments are present and vary in distribution. The soils show an alkaline pH of 8.3 to 8.7 in the surface, but they tend to be acidic in deeper layers, where the

Table 1. Evidence of historical raised bed garden systems or raised-field agriculture similar to the chinampas.

Region	Countries	Reference
South America	Peru, Bolivia (particularly near Lake Titicaca and in the Llanos de Mojos in Bolivia)	Boixadera et al., 2003
		Bruno, 2014
		Groenman and van Geel, 2017
	Colombia	Mckey et al., 2014
	Venezuela, Ecuador, Chile	Renard et al., 2012
Mesoamerica	Maya lowlands: Yucatan Peninsula, Tabasco, Belize, Guatemala	Gliessman, 1991
		Mckey et al., 2014
		Turner and Harrison, 1981
	Tlaxcala and Veracruz, Mexico	Renard et al., 2012
Africa	West Africa, particularly Senegal	Denevan and Turner, 1974
		Iriarte et al., 2010
	Nigeria, Uganda, Kenya, Tanzania, Zambia	Denevan and Turner, 1974
Asia	China	Yanying et al., 2014
		Altieri and Koohafkan, 2004
	Central Asia	Groenman and van Geel, 2017
	Burma, Malaysia, India, Vietnam, Philippines	Denevan and Turner, 1974
	Thailand	Altieri and Koohafkan, 2004
	Bangladesh	Climate Action Network Southeast Asia, 2017
	Indonesia	Renard et al., 2012
Oceania	New Caledonia, Fiji, Papua New Guinea	Denevan and Turner, 1974

OM content is high (Ramos-Bello et al., 2001; Renard et al., 2012). Chinampa soils are generally rich in OM due to the applied lake sediments and plant residues (Ortiz et al., 2015). The subsoil is highly stratified; it contains fibric, almost wholly organic, peaty horizons, diatomite units of varying thickness, and a thin, widespread layer of reworked volcanic ash (Crossley, 2004).

The total nitrogen content ranges from 5.92 to 6.17 g·kg^{-1} (Ortiz et al., 2015). Different from other production systems, most layers of a chinampa soil are inundated for considerable periods. Waterlogging usually enhances the availability of phosphorus, making it more soluble and more diffusible. In contrast, the nitrogen availability is negatively affected. Nitrogen accumulates in the OM deposited in anaerobic conditions, and when this OM is transported to aerobic conditions, it is rapidly mineralized to nitrate (Renard et al., 2012). Nevertheless, the nutrient content and availability of an average chinampa soil are favorable for most crops; the main limitation is salinity. Chinampa soils are sodic-saline in the surface layers, and sodic, saline, and regular in deeper areas (Ramos-Bello et al., 2001). The electric conductivity ranges from 2.79 to 6.64 dS·m^{-1} (Ortiz et al., 2015). The cation exchange capacity and concentration of calcium ions (Ca^{2+}) are more than 60 and 90 cmol·kg^{-1}, respectively. Because of the alkaline pH and high OM and clay content, the heavy metal ion activity in solution is low because these ions are widely absorbed, fixed, or precipitated. Therefore, concentrations of heavy metals (most frequently, lead and nickel) usually do not exceed the permitted limits (Ramos-Bello et al., 2001).

Drainage system and irrigation

Traditional chinampas required the construction of complex drainage ditches and the implementation of a flood control apparatus such as a dike and sluice gates (Morehart and Frederick, 2014). Between each chinampa field, small ditches 1 to 2 m wide were built that connected through wide navigation channels. These canals allowed the filtering of water at the rhizosphere level of the crops; they were used for transport, irrigation, and to create water reservoirs as well as fish weirs (Martínez, 2004; Renard et al., 2012).

Most RF require two "built-in" mechanisms to provide and store water for the crops: high soil OM content provides water retention, and capillarity conducts water from the canals to the crops in an "integrated" sub-irrigation system (Renard et al., 2012). Only very particular soil and plant properties allow natural sub-irrigation. The width and height of the wetland fields as well as the soil type are the most critical variables. A functioning sub-irrigation system counts with a) a planting platform high enough to allow root growth; b) a subsoil composed primarily of fine sand and coarse silt to produce a capillary fringe high enough to be within the crops' rhizosphere; and c) a crop root zone that is less than 85 cm above the groundwater but not too profoundly reaching into the capillary fringe. In saline soils, the top of the capillary fringe should be more than 30 cm below the surface. The capillary fringe is commonly interspersed with *ahuejote* roots, and sub-irrigation is essential for supplying moisture to the willows and the crops (Crossley, 2004).

Today, sub-irrigation is a minor factor in the overall decision-making process of the chinampa farmers, who commonly use mechanic irrigation techniques and, therefore, do not prioritize the maintenance of their fields at the appropriate height to take advantage of capillarity. Consequently, numerous chinampas are so low that waterlogging is a problem, and others exceed the maximum height to enable sub-irrigation. Sub-irrigation reduces the need for irrigation, but it cannot replace it. It is relevant when the onset of the rainy season is delayed or during dry years (Crossley, 2004). During the dry season, from November to May, channel water is also used to irrigate the crops (Chavarría et al., 2010). In traditional systems, canal water is scooped and splashed on the chinampa using poles and buckets. The farmer stands on the chinampa or in a canoe (Parsons, 1991). A standard tool is the *zoquimatl*, which is a ladle-like tool with a long handle. Currently, mechanized irrigation using buckets and hoses is most common (Crossley, 2004).

The surrounding lakes have provided enough freshwater for the ancient chinampas (Morehart and Frederick, 2014), but both quantity and quality of the supplied water have decreased. The water used today, which predominantly comes from a treatment plant, is partially contaminated with sodium and heavy metals. As it reaches the canals, it receives additional pollutants from household waste water, feces, and garbage due to the tourist industry (Ramos-Bello et al., 2001).

Fertilization and pest and disease management

Fertilization in the chinampas centers on the recycling of material produced within the very system. The essential nutrient source is the OM generated in its aquatic components. Farmers transfer vegetation and sediments from the bottom of the canals to the field surface, which is both a fertilization and canal maintenance measure. Under dry soil conditions, most algae, bacteria, and macrophytes die; however, when the soil remoisturizes, their populations recover immediately, and aerobic bacteria quickly mineralize the nutrients stored in the dead organisms. Algae and macrophytes exhibit "luxury consumption" of nitrogen and phosphorous, assimilating these nutrients in excess and storing them for use under nutrient-deficient conditions. Furthermore, nitrogen-fixing bacteria and cyanobacteria increase the N-reserves of a chinampa system (Renard et al., 2012). The actinorhizal association between nitrogen-fixing bacteria (*Frankia* sp.) and certain alders (*Alnus* sp.) is a further nitrogen supply (Crews and Gliessman, 1991). A significant source of OM is the water hyacinth, which is capable of producing up to 900 $kg \cdot ha^{-1}$ dry matter daily (Altieri and Koohafkan, 2004). As additional fertilization measures, chinampa farmers apply dry manure, synthetic fertilizers, crop residues, kitchen waste, ash, charcoal, and, occasionally, human excrement. The use of crop residues as mulching materials suppresses weeds (Renard et al., 2012; Torres et al., 2000).

Traditional chinampas are characterized by a high degree of biodiversity in time and space, which helps to prevent pests (Torres et al., 1994). Additionally, chinampa soils contain several fungal species that limit the proliferation of pathogens (Renard et al., 2012). Conventional farmers also use synthetic pesticides.

Agrobiodiversity

Currently, chinampa farmers produce flowers, maize (*Zea mays*), legumes such as bush bean (*Phaseolus vulgaris*) and fava bean (*Vicia fava*), amaranth (*Amaranthus cruentus*), and at least 40 different vegetables such as tomato (*Solanum lycopersicum*), pepper (*Capsicum annuum*), lettuce, radish (*Raphanus raphanistrum* ssp. *sativus*), seepweed (*Suaeda pulvinata*), and purslane (*Portulaca oleracea*). On some chinampas, free-range animals are kept between the crops. Chickens are most common, but ducks, swine, cattle, sheep, and draught animals can also be found. Most animals are kept in small corrals and feed on the excess produce or waste from the chinampas. Their manure is incorporated into the platforms (Altieri and Koohafkan, 2004; Canabal, 1997; Clauzel, 2009; Crossley, 2004; Losada et al., 1998; Ramos-Bello et al., 2001; Torres et al., 2000).

Vegetable and ornamental production predominate, but maize cropping, which was formerly common, has become rare. Commercial floriculture (mainly monocropping in greenhouses) prevails because it provides the highest gross returns and works in salty and infertile soils. In contrast, vegetable production is more traditional. Frequently, horticultural farmers combine cash crops with subsistent production. Most vegetables are produced in polycropping arrangements (Torres et al., 1994) and complex rotations of up to seven crops per season (Parsons, 1991). Even conventional production allows three rotations per year and up to six harvests (Canabal, 1997; Merlín-Uribe et al., 2013).

Contemporary adaptations of the chinampa system

There have been efforts to establish "modern" chinampa-like production systems in numerous countries (Table 2). The scope of these projects varies from small organic farms to large urban development projects. The first effort to revitalize chinampas started in Mexico in 1975. A former research entity of the Mexican government, the INIREB (Instituto Nacional de Investigaciones sobre Recursos Bióticos), encouraged the construction of RF in swampy regions of the Mexican states Veracruz and Tabasco. The INIREB even hired producers from Xochimilco to guide the development of ≈100 RF. Among other crops, maize, rice (*Oryza sativa*), bush bean, alfalfa (*Medicago sativa*), radish, lettuce, cabbage, squash (*Cucurbita* sp.), and watermelon (*Citrullus lanatus*) were produced at two project sites. One technical mistake during project implementation was the incorrect use of dredges to construct the chinampas. These vehicles inverted the soil profile and brought infertile clay to the top and OM downward. The project in Veracruz failed from the beginning. One reason was the top-down approach of its managers who designed and implemented the project without considering the alleged beneficiaries, the local farmers. In contrast, the functionality of the chinampas in Tabasco improved over time. After a quick retreat of the officials, the project continued thanks to research and local initiatives. There is evidence of its persistence until at least the early 2000s (Altieri and Koohafkan, 2004; Burton, 2013; Chapin, 1988).

In the 1980s, a similar (combined community development and research) project was performed near Lake Titicaca, another historical RF farming region. Researchers from the University of Illinois rebuilt ancient RF in an area of 10 km^2. Similar to the breakdown in Mexico, numerous farms were soon abandoned. However, by the 1990s, some smaller farms were still operating. The status quo of the project is uncertain. Comparable research was performed in the swampy plains of eastern Bolivia, the Llanos de Mojos (Smith, 2012). Today, in Latin America, several small organic farms are implementing the chinampa model. For example, in the Mexican state of Guanajuato, a farm produces maize and legumes in a traditional chinampa enriched with permaculture crop management (Laado, 2013).

Chinampa-like production systems have an increasing role in certain Asian countries, where they serve as a strategy to enhance both food security in poor regions and the reduction of GHG emissions. So-called floating

Table 2. Contemporary efforts of re-interpretation of chinampas.

Site	Project nature	Production system	Reference
Mexico	Research and community development (concluded)	Traditional chinampa	Chapin, 1988
	Productive	"Improved" chinampa	Laado, 2013
Peru and Bolivia	Research (concluded)	Traditional Andean raised fields	Erickson, 1992; Smith, 2012
Bangladesh	Development aid	Small floating islands built using water hyacinth	Climate Action Network Southeast Asia, 2017
	Development aid	Small floating islands on rafts	Deltsidis, 2016
Indonesia	Productive	Chinampa-like transformed former rice field	Denton, 2015
Myanmar	Productive	Chinampa-like, tomato production	Mae, 2016
Congo, Zambia	Productive	Unspecified	Comptour et al., 2018; Mckey et al., 2014;
Florida	Research	Diverse floating hydroponic models	Sweat et al., 2003
Illinois	Recreation	Unspecified	Urban Rivers, 2018
Poland	Urban horticulture	Unspecified (planning stage)	City of Szczecin, 2018

islands (different from chinampas because they are not fixed on the canal ground) are a common technical implementation. In Bangladesh, a project by a nongovernmental organization called Practical Action adopted the country's traditional floating gardens to provide food during periods of shortages. The RF are built using the water hyacinth as a boundary. They are 8 m long and 1 m wide. Afterward, they are covered with soil and cow manure to produce different vegetables. The initiative started in 2005 and today, despite the withdrawal of financial support, most of the project areas are still functional. The Government of Bangladesh adopted the concept, and in 2013, it approved a large-scale project to promote floating gardening for climate change adaptation (Climate Action Network Southeast Asia, 2017). A further project in Bangladesh, funded by the University of California Davis and Tufts University, consists of floating islands placed in household fishponds to allow small-scale fish farmers to grow horticultural crops and produce seedlings. The islands are constructed from locally available materials and comprise a raft containing a soilless medium of coir and vermicompost. Flotation is provided by second-hand plastic containers attached to the bottom of the raft that can be transplanted to ground beds when the floodwater recedes (Deltsidis, 2016, 2017). At an organic farm in Bali, Indonesia, a former paddy rice terrace was transformed into a chinampa-like system (Denton, 2015). Furthermore, traditional *Sorjan* production still exists in Indonesia (Renard et al., 2012). This system consists of RF where dryland crops are grown and rice is cropped in the lowered sinks (Domingo and Hagerman, 1982). The *Sorjan* system is also used in the Philippines (Philippine Rice Research Institute, 2016).

In North America and Europe, floating gardens on rivers are becoming popular measures to increase urban biodiversity and function as recreational spots. Commonly, horticulture has a minor role. Most of the respective projects are still in the planning stage. In this regard, the city government of Szczecin, Poland, is currently developing a large-scale urban horticulture project that involves floating gardens on its main river and canals (City of Szczecin, 2018). The city government of Chicago, IL, cooperates with local initiatives, companies, and universities in the development of a park of floating gardens on the Chicago River. The focus is on recreation and re-naturalization of the river. The project is expected to conclude in 2020 (Urban Rivers, 2018). The University of Florida experiments with floating hydroponics and promotes their distribution among local horticultural producers (Sweat et al., 2003).

Outlook

Despite versatile efforts to revitalize and reinterpret chinampas, the implementation of the production system is widely limited to small-scale research and development projects. In Mexico, its origin, even with ambitious local initiatives, the outlook is alarming. A projection for the year 2057 assumes that in Xochimilco, without a concerted effort from the involved players (particularly farmers and local government), most current chinampa land will be converted to housing. Therefore, the persistence of chinampas strongly depends on the economic priorities and agricultural criteria of farmers and political interventions. Along with production, restored chinampas would provide a series of ecosystem services to Mexico City. This includes water filtration, regulation of water levels, microclimate regulation, increased biodiversity, and carbon capture and storage. Finally, RF systems increase the recreational value of a region and its economic vibrancy (Merlín-Uribe et al., 2013; Torres et al., 1994).

Mexico City could benefit from restored chinampas and similar systems, and all cities close to freshwater swampland or an adaptable lake or river might benefit also. Regions that could benefit from RF production include the Mississippi River Delta, the Hudson River Delta, extensive parts of Florida, the Great Lakes Region in the United States and Canada, the Pantanal region (Brazil, Bolivia, and Paraguay), the eastern and western Congolese swamp forests, the African Great Lakes region, eastern South Africa, Shanghai and the Yellow River Delta in China, the Kutch District and parts of the state of Kerela in India, the

Padma River Delta and (almost all) southern Bangladesh and neighboring India, the Yangon Metropolitan area in Myanmar, extensive parts of Sumatra (Indonesia), the Mindanao River in the Philippines, the Rhone River Delta in France, Hamburg in Germany, the Mersey Delta in England, the Gulf of Finland (Finland, Estonia, Russia), and the Darwin Area and Western District Lakes near Melbourne in Australia.

The benefits of creating chinampas are not limited to big cities but also could aid smaller rural communities, especially in tropical wetlands. There, drainage of wetlands for cattle farming or paddy rice monocropping are the most common agricultural adaptations of the land, resulting in adverse environmental consequences. Furthermore, RF prevent crops from floods and offer an alternative to the clearing of tropical forest for slash-and-burn agriculture. Finally, chinampas could help reduce GHG emissions and maintain tropical wetlands and their soils (Renard et al., 2012).

In conclusion, RF such as chinampas, if correctly managed, produce high yields with relatively low inputs. They also provide ecosystem services (especially GHG sequestration and increase of agrobiodiversity) and offer both recreational and socio-economic benefits to the world's megalopolis and small communities in the tropics. One limitation to their larger-scaled implementation has been high labor costs, especially for the traditional manual construction. The labor requirement could be reduced using earth-moving machines, but care must be taken to avoid compaction and inversion of the soils (Chapin, 1988; Renard et al., 2012).

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