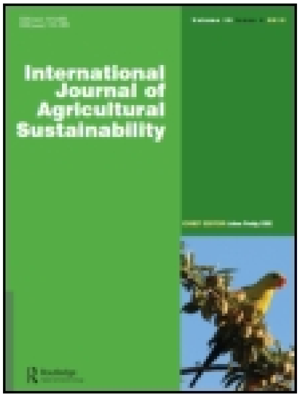

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Environmental and socio-economic sustainability of chinampas (raised beds) in Xochimilco, Mexico City

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Environmental and socio-economic sustainability of *chinampas* (raised beds) in Xochimilco, Mexico City

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The *chinampas* (raised beds) of Xochimilco, Mexico City, are highly productive, traditional wetland agricultural systems, which were able to feed most of the population in pre-hispanic times. There is a strong trend to substitute chinampas with plastic greenhouses for flower production, which creates negative impacts in the landscape, environment and culture. This study compares the environmental and socio-economic sustainability of chinampas and greenhouses, at both the farm and regional levels, using the MESMIS framework. Even though the results show that greenhouses are more profitable, the contribution of chinampas to ecosystem services cannot be substituted by greenhouses, as tree cover is lost, canals are filled and food is not provided. Greenhouses had a higher diversity, but also a higher agrochemical use and are heavily dependent on external inputs and subsidies. Chinampas have shifted from staple crops to commercial horticulture in order to remain a technically viable and economically feasible option for local farmers. However, compensation mechanisms for the provision of ecosystem services are urgently needed if this ancient system is to be maintained. The framework allowed the integration of indicators at both farm and regional scales, combining on-farm surveys with GIS techniques, which could assist in ecosystem service valuation.

Keywords: Chinampas; greenhouses; MESMIS framework; sustainability evaluation; traditional agriculture

Introduction

Traditional agricultural systems are of scientific interest as they satisfy the basic needs of small-scale farmers under marginal conditions, with a low use of external inputs of industrial origin (Altieri 2002). Several studies relate the indigenous techniques of natural resource management with processes and functions which maintain the stability of agroecosystems, thus contributing to sustainable production processes (Altieri 2004, Abbona *et al*. 2007, Garcia-Frapolli *et al*. 2007, Holthaus 2008). Agrobiodiversity is one of the main attributes, as it encourages soil conservation

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and fertility, food security, pest control and the supply of products to the market (Jackson *et al*. 2007, Love and Spaner 2007). Traditional agricultural systems and the landscapes that they form have a cultural value as sources of knowledge based on the co-evolution of farmers and ecosystems, as part of the cultural heritage (Berkes *et al*. 2000) and as an important component of life quality through the pleasure and spiritual relaxation generated (Council of Europe 2000). Some of these systems involve ingenious, time-tested combinations of techniques and practices, which support both food security and environmental diversity, and are now recognized by the FAO Globally Important Agricultural Heritage Systems initiative. Relevant examples making a highly productive, intensive use of water include the *waru-waru* raised beds in the Andes and the rice–fish association in South East Asia (Lu and Li 2006, Koohafkan and Altieri 2011).

This is the case of the agricultural landscapes of the peri-urban zone of Xochimilco, in Mexico City, where traditional chinampas subsist under significant threat from urban and industrial land use changes (Ezcurra 1991, Stephan-Otto 2006).Chinampas are small, strip-shaped islands built with sediment from the lake bottom, branches and decaying vegetation, creating a network of canals (Torres-Lima *et al*. 1994). The canals are part of the irrigation system and have an average depth of 1.5 m (Contreras *et al*. 2009). Chinampas are bordered by *ahuejotes* (*Salix bomplandiana*, a native willow), which perform multiple functions, including live fences, wind and insect barriers and holding soil within the plots.

This pre-hispanic crop system produced a wide variety of crops, based on integrated nutrient management from lake sediment, aquatic plants, crop and livestock residues; and on integrated water management including irrigation, waste decomposition and fishing. Along with the crops, several non-domesticated plants with medicinal, food or forage use were tolerated or encouraged (Jiménez-Osornio and Gómez-Pompa 1991). Chinampas were most important between the XIV and XVI centuries, being able to produce most of the food consumed in Tenochtitlan (now Mexico City), with a population of around 250,000 people at the time (Rojas 1983). The management of chinampas can be classified as multipurpose, given the diversity of uses (agriculture, housing, livestock keeping, fishing and wildlife habitat) and cultivated products (food, forage, medicinal and ornamental) (Jiménez-Osornio *et al*. 1990, Soriano 1999).

The landscape of chinampas is therefore composed by its agro-forestry elements and the canals that serve as a means of transport for people and goods. As a result of their aesthetic value and cultural importance, chinampas were declared part of a World Heritage Site by UNESCO in 1987 (Clauzel 2009), a protected natural area by the Mexican Government in 1992 and a Ramsar Site (Convention on Wetlands of International Importance) in 2004 because of their provision of ecosystem services. These include underground aquifer recharge, local and regional water flow regulation and maintenance of biodiversity, including numerous endemic and migratory species (Aranda 2004).

Strong land use change pressures are currently affecting the existence of chinampas, including demographic pressure and the introduction of industrialized systems (Clauzel 2009). In the last two decades, the use of plastic greenhouses for flower and horticultural production has been promoted, causing the abandonment and transformation of chinampas. In 2006, the area of chinampas in production in Xochimilco was estimated at 262 ha, with an annual loss rate of 31 ha, compared with 244 ha of greenhouses, with an annual growth rate of 14 ha (Merlín-Uribe *et al*. 2012). These changes involve the loss of the lacustrine environment, which integrates water, trees and wetlands. From the point of view of ecosystem services, this could mean the change in provision of cultural services, regulation, provision and support.

One of the most important political and economic arguments behind land use change is that greenhouses are more productive and efficient in economic and energy use terms. It is therefore very relevant to evaluate in a comparative way the productivity and efficiency of both systems, as well as their environmental impact. Sustainability evaluation has focused mainly on environmental and technical aspects, leaving socio-economic aspects behind, along with the multifunctional role of agriculture (Binder *et al*. 2010). A multi-dimension, multi-scale sustainability assessment is therefore required. The objective of this study was to evaluate the environmental and socio-economic sustainability of chinampas and greenhouses in Xochimilco, Mexico, by integrating farm and regional indicators.

Methodology

Study area

Xochimilco is located 18 km south from the centre of Mexico City and encompasses 12,200 ha of urban area, tourist areas, wetlands, secondary forest and different agricultural systems (Wigle 2010). The Xochimilco wetland system is composed of 207 km of canals connecting eight small lakes and two flood plain areas (Figure 1). This aquatic ecosystem is part of the remains of the original five-lake system, occupying approximately 920 km^2 of the Mexican Central Basin (Zambrano *et al.* 2009).

Long-term, intensive development has produced a mosaic of completely urbanized areas (mostly in the northern zone) along with rural and agricultural areas (in the central and southern zones). There have been attempts at ecological engineering, such as the creation in 1989 of the Xochimilco Ecological Park, at the northern edge. Water at this park comes from sewage treatment plants and then passes through 200 ha of very shallow artificial wetland (<0.5 m deep), before feeding the chinampa canals and the adjacent crop land. Owing to the shallow conditions, 140 species of migratory birds, such as the Pelican (*Pelecanus erythrorhynchus*) arrive during the winter in the Park (Stephan-Otto 2006).Threatened aquatic endemic species include the axolotl (*Ambystoma mexicanum*) and crayfish (*Cambarellus montezumae*) (Zambrano *et al*. 2009). Most agricultural activity can be divided into chinampas, intensive agriculture (greenhouses), and rain fed agriculture in the areas outside the canal network. Other activities, such as tour

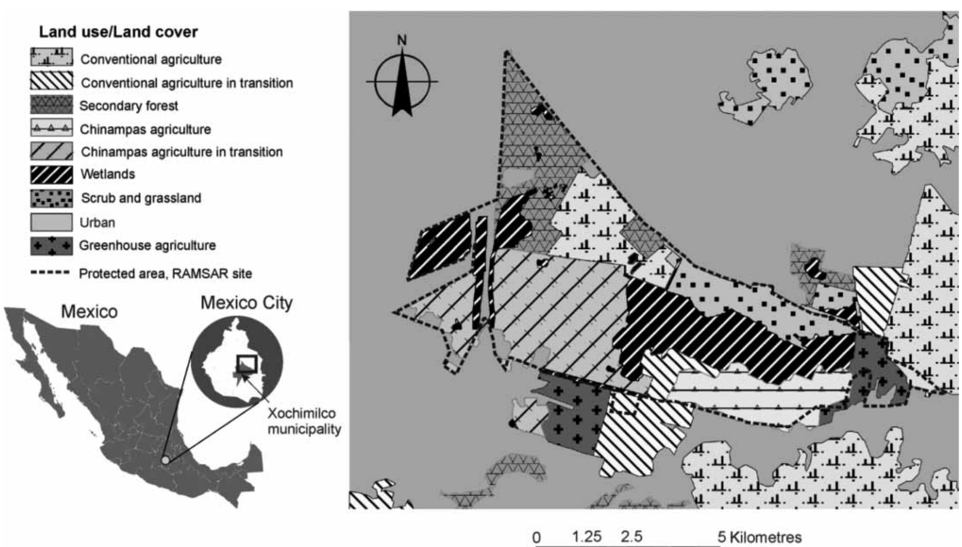

Figure 1. Location of the study area.

boats, receive around two million visitors per year (UNESCO 2006). Two neighbouring communities were chosen for this study: San Gregorio Atlapulco, representative of chinampa agriculture, and San Luis Tlaxialtemalco, where most greenhouses can be found.

Chinampa and greenhouse systems

Chinampa plots are an average 1,400 m^2 in size and are privately owned. Production is centred on horticultural crops, mainly lettuce (*Lactuca sativa*), *verdolaga* (*Portulaca oleracea)*, *arágula* (*Eruca sativa*) and coriander (*Coriandrum sativum*), which are sold at the Xochimilco market. Sediment from the canals and aquatic plants, mainly water hyacinth (*Eichhornia crassipes*), along with cattle manure are the main nutrient sources for crops, as they are rich in organic matter (Quiroz-Flores *et al*. 2008). A combination of traditional technology and mechanized tools is used. The pre-hispanic *chapín* technique, in which a layer of canal sediment is placed on the chinampa and shaped into a grid, serving as a germination bed, is still used. Several crops a year are harvested, as the production cycle averages 3–4 months.

Greenhouses were introduced in the area in the 1990s after the sinking and flooding of chinampas, mainly in San Luis Tlaxialtemalco, where local authorities financed them to compensate chinampa owners. In some of these sites, *ahuejotes* have been cut and the canals filled with construction debris to counteract the constant sinking, which can be attributed to underground water abstraction (González-Morán 1999). Greenhouses have an average size of 600 m^2, and production is oriented to ornamental plants sold in pots, mainly *nochebuena* (*Euphorbia pulcherrima*), *malvón* (*Pelargonium hortorum*), *petunia* (*Petunia spp.*) and *begonia* (*Begonia spp.*), which are grown in a mixture of up to four substrates of external origin. Production cycles also last 3–4 months, allowing several crops all year round.

Chapines have been substituted by plastic germination trays, and the use of agrochemicals is high, as pests are frequent and crops require high-nutrient availability. The technology is mainly mechanized and the main energy source is electricity. Production is market oriented, and some growers are also owners or tenants of stalls in the local flower market, which attracts costumers from all over Mexico City (Figure 2).

Evaluation of sustainability

The framework for the evaluation of management systems using indicators (MESMIS, for its Spanish acronym) was used for this study because of its holistic and interdisciplinary approach, which allows the comparison between reference and alternative resource management systems. In addition to environmental indicators, it also considers economic and social ones (López-Ridaura *et al*. 2002). MESMIS has been recognized as a system-based framework, flexible enough to be applied in a diverse range of contexts (Van Cauwenbergh *et al*. 2007). The framework is adapted to small-scale farming systems, and has been applied in over 60 diverse case studies, mainly in Mexico and Latin America. The MESMIS programme is also actively engaged in training practitioners and developing interactive learning tools (Astier *et al*. 2012, http://mesmis.gira.org.mx/mesmis-interactive).

Within MESMIS, the operational structure of the evaluation process is cyclical. Several phases are considered to guide and implement the process, including defining the vision, context and objectives of the system; establishing a framework to define the dimensions, attributes and criteria, in order to derive indicators with their evaluation units and reference or ideal values; and finally communicating results, which will in turn provide feedback to management decisions.

The framework also proposes a multi-scale, multidimensional approach, which allows evaluating processes and integrating information on the interaction of the systems in such a way

Figure 2. Changes in the chinampa landscape. Clockwise from top left: A typical chinampa landscape. Greenhouses among filled canals substituting chinampas. Chinampa agriculture is now partially mechanized, and largely dedicated to cash crop monoculture. Intensive pot flower production in greenhouses.

that the effect of the social, economic and environmental processes at different scales is identified (Binder *et al*. 2010). Sustainability is defined as 'the process by which material and spiritual needs of human population would be met, without degrading or even improving the socio-environmental conditions that sustain them' (Masera *et al*. 1999). Specifically, sustainable agro ecosystems are those that meet the following attributes:

- A high level of *productivity* by means of an efficient and synergic use of natural and socio-economic resources.
- *Stability, resilience and reliability*, referring to the presence and effectiveness of the negative feedback processes that allow the maintenance of a state of dynamic balance at a constant productivity level.
- *Adaptability* to cope with changing socio-environmental conditions.
- *Self-reliance*, implying enough independence and self-sufficiency to maintain performance in the occurrence of external changes.
- *Equity* in the distribution of costs and benefits among the different stakeholders (López-Ridaura *et al*. 2005).

An important premise of MESMIS is that sustainability cannot be measured *per se*, but rather evaluated through the comparison of two or more systems. Furthermore, sustainability evaluations are system, space and time specific (López-Ridaura *et al*. 2002).

According to Astier and González (2008), a robust, non-exhaustive group of criteria and indicators of sustainability must be chosen. Indicators should be able to reflect changes in resource management practices, be adapted to the capacities and resources of the evaluation team, be clear and easy to transmit and serve as instruments for decision makers at different agroecosystem scales. Table 1 shows how sustainability attributes were derived into criteria and indicators following these principles and considered relevant for the case study.

Farm scale indicators

The information to measure indicators was obtained from two surveys. An agroecological one, including 124 questions on 11 subjects of natural resource management, was applied to 50 farmers per system, selected through stratified sampling (De Vaus 2002). Afterwards, a socioeconomic survey was applied to four farmers per system, previously identified as key informants. In this case, a direct sampling method was used, since a higher data precision was required, and because of the reluctance of many farmers to provide economic data and information related to the use of agrochemicals. To analyse agrochemical use an independence χ^2 analysis was carried out. The toxicity of pesticides used was assessed using the official Pesticide Catalogue (CICOPLAFEST 2004).

The determination of physico-chemical parameters of water bodies next to the plots was done through field measurements. Forty-eight samples of water from the canals adjacent to both chinampas and greenhouses were taken. The measured variables included temperature, conductivity, total dissolved solids, salinity, dissolved oxygen and pH. Faecal coliforms (colony forming unit, CFU) were determined by Solís *et al*. (2006) in areas with the same management during the same season (drought). The critical, minimum and optimum values were determined using the local values for drinking, treated and sewage water. In the case of coliforms, the maximum value for irrigation water has been established at 1,000 CFU/100 mL by the official norm NOM-003-ECOL-1197 (DOF 1997). Statistically significant differences in the physico-chemical parameters of water were obtained through a Mann–Whitney test with an alpha threshold of 0.05. Relative values were then calculated through the reference interval method described by Galván-Miyoshi

Table 1. Derivation of criteria and indicators of sustainability for chinampa and greenhouse systems in Xochimilco, Mexico.

Attribute	Criterion	Indicator	Source	Scale
Productivity	Efficiency	Net margin	Survey	Farm
		Benefit:cost	Survey	Farm
		Initial investment cost	Survey	Farm
Stability, resilience and reliability	Resource conservation	Cultivated species	Survey	Farm
		Canal conservation	GIS	Region
		Forest conservation	GIS	Region
		Land use change	GIS	Region
	Environmental impact	Pesticide applications per season	Survey	Farm
		Synthetic fertilizer use	Survey	Farm
		Water quality index	Field sampling	Farm
Adaptability	Change and innovation capacity	Organized farmers	Survey	Farm
		Trained farmers	Survey	Farm
Self-reliance	Self-sufficiency of production	Reliance on subsidies and credits	Data base	Region
		Family labour	Survey	Farm
Equity	Family equity	Gender equity in subsidies	Survey	Farm
	Community equity	Equity in income distribution	Survey	Farm
		Participation in decision making	Survey	Farm

(2008). The water quality index was obtained through a simple average of the relative values of conductivity, dissolved oxygen and total dissolved solids, as suggested by Esty *et al*. (2005), plus faecal coliforms.

The Gini index is generally used to calculate equity in income distribution in a given population (Silber and Weber 2008). The index was calculated with the income data from the socio-economic survey, using the statistical software 'R', with the Ineq package programmed by Zeileis (2007).

Regional scale indicators

As canals and *ahuejotes* are icons of the chinampa environment, the presence and density of these elements were used as indicators of conservation. The presence of trees is also recognized as a provider of ecosystem services (MEA 2005). A quick bird multi-spectrum high-resolution satellite image (2-m spatial resolution) provided by CORENA (Mexico City Natural Resources Commission), taken in January 2007, ortho rectified and geo referenced, was used to identify those canals still in use. Visible trees, which are over 1.5 m in diameter and therefore over 3 years old, were counted. A network of 1108 quadrants of 1859 m^2 was created using ArcGIS 9.0 to calculate the density per quadrant and the mean density per management system. The same procedure was used to measure the canals in lineal metres and the quadrant mean per management system. The statistical analysis for the quantification of trees and canals consisted in two-tailed Mann–Whitney tests ($P < 0.05$). Land use change was estimated by comparing the above-mentioned Quickbird image with a Landsat 5 TM 30 m multispectral satellite image taken in 1989, and validating the data through random field observations and interviews with local inhabitants.

A detailed analysis of land use changes in the area is presented in a separate study (Merlín-Uribe *et al*. 2012).

In order to evaluate the reliance on subsidies and credits, the database of the Rural Sector Information System (SISER) of the Mexican Ministry of Agriculture was used (SAGARPA 2009), which integrates agricultural and economic information for each farm. The SISER database contains information on the government subsidies to farmers. These were classified by support programme (chinampas or greenhouses), population (number of supported men and women) and productive chain (horticulture or flower production). A total of 318 entries from 5 budget years was analysed, all of them consisting in financing for the purchase of machinery and inputs. From this information, the number of supported projects, number of total beneficiaries and the total amount of support per year were derived.

Analysis and integration of indicators

The determination of relative values of indicators was done through paired comparisons, distance to optimum values and reference intervals (Galván-Miyoshi 2008). The relative values were then expressed in percentage with respect to the optimum values, a higher percentage meaning a better performance or higher sustainability level in management strategies. Relative values were then plotted against optimum values in a radial or 'amoeba' graph (Ten Brink *et al.* 1991, Galván-Miyoshi 2008).

Results and discussion

Productivity

Table 3 summarizes the obtained values for each indicator, along with reference ('ideal') values and their sources. Net margin was considerably higher for greenhouses, averaging 80,950 USD per season per hectare, compared with 14,166 USD for chinampas. This was directly related to the higher price of ornamentals, as well as the fact that most greenhouse growers sell their produce directly in the local market. It is important to note that greenhouses are commonly managed by an average of two partners, as opposed to individual farmers in the case of chinampas. Net margin was therefore divided by two in order to obtain a comparable indicator value. Surveyed farms in both systems range in size from 500 to 8000 m^2, with smaller ones making a highly intensive use of the available land. This might not necessarily scale up into higher margins with an increase in available area.

The benefit: cost indicator showed that in chinampas, economic resources were used in a slightly more efficient way, with a ratio of 2.26, while in greenhouses this was 2.03. Flower production has considerably higher production costs due to the use of substrates and agrochemicals. This is also an indirect measure of external input dependence; however, the lower dependence in chinampas is relative, as farmers are integrating an increasingly higher amount of inputs to their productive processes.

The indicator initial investment per m^2 assessed the ability of farmers to start a productive cycle assuming they do not have inputs, tools or machinery. Farmers state that one of their main difficulties is finding the necessary amount to purchase basic inputs. It is assumed that the lower this is, the higher is the self-reliance capacity. In this case, chinampa farmers required an average of USD 9.66 per m^2 to start growing lettuce, including the most expensive tools such as rotovators, water pumps, canoes and oars. For greenhouses, the amount was estimated at USD 30.61 per m^2, including the most common tools and basic inputs.

In terms of production costs, petrol represents 36.3% for chinampa owners, making them highly dependent. In contrast, this is only 14.3% for greenhouse growers, since their main energy source is electricity. Chinampa owners pay the full cost of energy, while greenhouse owners are informally connected to the grid and therefore do not pay for electricity, which greatly favours their production costs (Table 2).

Stability, resilience and reliability

The number of cultivated species was higher in greenhouses, with 36 species compared to only 12 in chinampas. This is considerably down from the 51 cultivated species reported by Jiménez-Osornio and Gómez-Pompa (1991). Staple crops found by these authors (maize, beans and squash) are less common, and intercropping practices are no longer seen. Commercial seed varieties have also replaced local seed selection practices in most cases. The higher diversity in greenhouses does not mean there is a functional relation between crops. However, it represents an advantage in terms of higher resilience to price or market changes.

Table 2. Sustainability indicators evaluated in chinampa and greenhouse systems.

Indicator	Chinampas	Greenhouses	Optimum	Source/criteria
Net margin (USD/season/ha)	14,166 (±4545)	40,475 (±36477)	40,475	Maximum in greenhouses
Benefit:cost	2.26 (±0.76)	2.03 (±0.53)	4	Local maximum
Initial investment cost (USD/m^2)	9.66 (±6.01)	30.61 (±14.73)	9.66	Minimum in chinampas
Canal conservation (m/ha)	92 (±41.9)a	24 (±31.3)b	116	Local maximum
Forest conservation (no. trees/ha)	17 (±9.9)a	13 (±12)b	52	Maximum found
Cultivated species (no.)	12	36	51	Historical value†
Land use change (% between 1989 and 2006)	−67	11550	0	Ideal value
Pesticide applications per season (no.)	2.8 (±1.6)b	8.5 (±9.1)a	1	Maximum recommended
Synthetic fertilizer use (kg N/season/ha)	351	390	120	Optimum recommended§
Water quality (index)	30.5	69.6	100	Treated/sewage water, official norm
Organized farmers (%)	24	14	100	Ideal value
Trained farmers (%)	58	74	100	Ideal value
Reliance on subsidies and credits (% of farmers)	28	35	10	Personal appreciation
Family labour (% of farmers)	54	48	54	Local maximum
Gender equity (% of women receiving subsidies)	43	47	50	Ideal value
Equity in income distribution (Gini index)	12	57	1	Ideal value
Participation in decision making (% of farmers)	78	68	100	Ideal value

Different letters across rows indicate significant differences according to Mann–Whitney ($P < 0.05$) or χ^2 tests.
† Jiménez-Osornio and Gómez-Pompa (1991).
§ Castaños (1993).

Agricultural Heritage Systems (AHS) have an added value which is much wider than the immediate economic return (Koohafkan 2009). In terms of the maintenance of natural resources on which production is based, the chinampa system showed higher values in the conservation of forest cover and canals. The GIS analysis showed an average of 17 trees per quadrant for chinampas and 13 for greenhouses. In the case of canals, 92 m per quadrant were measured for chinampas, compared to only 24 for greenhouses. In both cases the differences were statistically significant ($P<0.05$). In many AHS sites agroforestry systems are part of a multifunctional working landscape (Harvey *et al*. 2008, Koohafkan and Altieri 2011). The benefits from the conservation of trees in traditional Mexican agricultural systems, such as pest regulation, nutrient cycling and multiple human uses, have been reported since Altieri and Trujillo (1987). Abundant tree cover serves as a buffer for remaining natural areas (Wallace *et al*. 2005) and contributes to the maintenance of important regional ecosystem services (Soto-Pinto *et al*. 2002, Harvey *et al*. 2008) as well as to other cultural and aesthetic services intrinsic to AHS (Koohafkan 2009).

Land use change for chinampas was estimated at −527 ha between 1989 and 2006, while greenhouses increased from 2 to 244 ha in the same period. It is important to note that a significant proportion of the lost area in chinampas (230 ha) has been reclassified as transitional, implying partial urbanization and/or abandonment of agriculture (Merlín-Uribe *et al*. 2012).

Most greenhouse farmers (94%) used chemical pesticides, compared with 68% of chinampa owners, of which 6% combines them with other methods. A quarter (26%) of chinampa owners uses organic methods to control pests and diseases. The higher use of pesticides was confirmed with a χ^2 independence analysis, indicating a dependent relation between pesticide use and greenhouses ($P< 0.001$). Average number of applications per season was 2.8 for chinampas, compared with 8.5 for greenhouses, which was statistically significant ($P < 0.001$). Out of the five pesticides used in greenhouses, two of them (carbamate and fenthion) are highly toxic for the environment and extremely toxic for humans. In the case of chinampas, there are also five products reported, of which two are extremely toxic for the environment (methyl parathion and metamidophos) and four are highly toxic for humans (the above mentioned plus fenthion and endosulfan). Farmers were generally not keen to talk about this subject; hence no doses could be registered. Highly and extremely toxic pesticide use is banned under the management plan of the protected area and the control and surveillance measures of CORENA, which has informed farmers about the dangers of excessive pesticide use. However, farmers keep using them routinely, even if the crops are not affected by pests, usually following advice from agronomists and agrochemical salesmen.

Synthetic fertilizer is used by only 30% of chinampa farmers, compared with 96% of greenhouse growers. The χ^2 analysis showed a dependent relation between fertilizer use and greenhouses ($P < 0.001$). However, those chinampa farmers using fertilizers have similar rates to greenhouse growers (1.4 vs. 1.6 tonnes N/ha/year), well above common recommendations. Chinampa farmers are skilled for maximum and effective use of local resources. Their systems rely heavily on recycling of nutrients and materials, and are therefore less dependent on off-farm inputs (Koohafkan and Altieri 2011). As reported in other comparative studies, chinampas still use less agrochemicals than agro-industrial systems (Lu and Li 2006, Gaspar *et al*. 2009, Xie *et al*. 2011). Halwart and Gupta (2004), in a compilation of rice–fish system studies also concluded that the use of agrochemicals is considerably lower and the returns higher compared with monocultures.

Aquatic plants are used as a fertilizer by 44% of chinampa farmers and only 8% in greenhouses. The use of water hyacinth gives two advantages over greenhouses, as it improves macro- and micronutrient availability, therefore reducing dependence on synthetic fertilizers, as shown by Chukwuka and Omotayo (2008), while improving the aquatic environment, as their excess can reduce dissolved oxygen and block sunlight.

Local water quality in the canals showed significant differences in three of the six measured parameters (Table 3). There were no differences in temperature, dissolved oxygen and pH; however, conductivity, total dissolved solids and salinity differ significantly, in a very similar way to the data of Zambrano *et al*. (2009). There were more solids in the chinampa area, which can be due to the presence of soil from the erosion of the edges, manure and organic matter from the cropping activity. In greenhouses, erosion and runoff are limited by the null use of soil as a crop bed, and the introduced debris, which limits the dissolution in water of the soil. Solís *et al*. (2006) found significant differences in the coliform counts in canals, exceeding the norm. Some ornamental crops, like *nochebuena*, are highly sensitive to low water quality, and some farmers are now using drinking water to grow them. Fishing is no longer practised next to the greenhouses, due to the small size and depth of canals. In the case of chinampas, fish are practically no longer consumed locally and rather sold at the main Xochimilco market as a non-local product, due to concerns of the local population about potential microbial contamination. In this sense, the closeness to urban settlements could be an important factor affecting water quality.

Adaptability

In terms of the organization for agricultural activities, both groups mentioned being little organized, with only 24% of chinampa owners and 14% of greenhouse growers belonging to a farmers group. This status gave them in some cases better conditions for product marketing and access to government subsidies.

More greenhouse growers received training in agriculture-related skills than chinampa owners (74% against 58%). The main subjects for both groups were fertilizer management and pest and disease management, with chinampa owners also receiving training in reforestation and greenhouse growers on pesticide management. The source of training was mainly official; however, greenhouse growers received twice as many private courses, while chinampa owners reported acquiring most of their knowledge through traditional and oral sources.

Self-reliance

In terms of external dependence, chinampa owners require nine different inputs including tools and fuel, while greenhouse owners need 13 different inputs including the plastic covers, tools and electricity. In the case of greenhouses most external inputs are plastic, such as bags, pots and trays. Some of the substrates, such as peat moss and oak forest soil, are brought from nearby and far-away woodlands.

Table 3. Water quality parameters in canals adjacent to chinampas and greenhouses.

	Chinampas	Greenhouses	Drinking	Treated	Sewage
Temperature (°C)	18.7 (±1.1)	18.1 (±1.3)	17.7	21.6	19.1
Conductivity (mS/cm)	0.84 (±0.09)a	0.62 (±0.04)b	0.46	0.62	0.96
TDS (g/L)	0.61 (±0.03)a	0.46 (±0.03)b	0.35	0.44	0.70
Salinity (ppm)	0.47 (±0.02)a	0.38 (±0.04)b	0.26	0.34	0.54
Dissolved O^2 (mg/L)	1.67 (±1.11)	1.37 (±0.75)	2.82	2.57	0.68
pH	7.53 (±0.51)	7.53 (±0.11)	7.82	7.39	7.59
Coliforms (CFU/100 mL)	2000	500	240	1000	n/a

Different letters across rows indicate significant differences according to Mann–Whitney test (<0.05).
TDS, total dissolved solids; CFU, colony forming units.
Coliform values taken from Solís *et al*. (2006)

Both systems tend to increase their dependence on external inputs, especially for lettuce and flower cultivation. There are other less dependent crops, such as *verdolaga*, coriander, *epazote* (*Chenopodium ambrosioides*) and some flowers germinated with the *chapín* technique, such as *gazania* (*Gazania rigens*) and *mercadela* (*Calendula oficinalis*). However, environmental, soil and economic conditions have influenced the increasing use of these inputs in the search for higher and more constant returns.

Reliance on subsidies and credits showed the self-dependence of farmers given the difference in investment amounts. According to the SISER database, chinampa owners received 94 subsidies between 2003 and 2007, while greenhouse owners received 224 in the same period. The average amount of support per project was 2,154 USD per project in the case of chinampas, compared with 2,455 for greenhouses. Only 28% of applications from chinampas were approved, compared with 35% for greenhouses. It is then clear that greenhouses are receiving considerably more government support, which is especially important given their high investment costs.

According to the local authorities, government support is aimed at promoting profitable agriculture as a means of preserving conservation land, rather than reducing poverty (Mr Ignacio Ruiz López, Director of Rural Development, personal communication). In these programmes, the farmer contributes with around 45% of the cost of the project, with the rest financed by the government, either as a contribution or a credit. Support is given when applications are clearly presented, generally backed by a paid consultant. Another requirement is to form part of a group, so the responsibility for paying back falls within several growers. Chinampa owners perceive that greenhouse farmers receive more support thanks to a corruption network, or because of having a status of ‘big growers’. However, some greenhouse growers share the same perception and believe that the same groups are always favoured. These tend to be the most skilled ones, those who have learned how to better navigate the administrative system, or those who normally pay back the credits in time.

Equity

Family labour was present in 54% of chinampas and 48% of flower growers. This is in average one family member, which nevertheless does not receive a salary in 55% of chinampas and 56% of greenhouses employing them. Equity level was also evaluated through participation in decision making within the community. Seventy-eight per cent of chinampa owners reported taking part in decision making, mainly related to cleaning and maintenance tasks, compared with 68% among greenhouse owners.

Greenhouses were better evaluated in terms of gender equity, mainly due to the presence of women as retailers in the local flower market. It was also common to see women working in greenhouses, carrying out tasks such as pruning, pot filling and cleaning. In contrast, few women carry out agricultural work in chinampas, as the tasks are physically more demanding, except for crops such as *verdolaga* and coriander. Neira (2004) studied the role of women autonomy in greenhouses in San Luis Tlaxialtemalco, and concluded that even though the income of greenhouse growers’ wives is not greater than that of non-agricultural workers, they do have a higher decision-making capacity and freedom of movement, mainly because of the type of tasks in flower marketing and their age.

Equity in income distribution was evaluated through the Gini index, which was 0.12 for chinampas and 0.57 for greenhouses. This can be attributed to a variety of factors such as management efficiency, farm size, sale conditions and amount of investment. In this case inequity could be due to the differentiated use of technology and capitalization between farmers. Both situations are characteristic of a more industrialized agriculture, immersed in a capital accumulation system.

Conclusions and recommendations

The final integration of indicators shows that chinampas had higher values in 10 of 17 indicators (Figure 3). Chinampas were more sustainable in terms of stability, resilience and reliability; self-reliance and equity, while greenhouses were more productive in terms of higher margins, but with a lower efficiency. Both systems had a similar level of adaptability.

The evaluated systems showed the interaction patterns, or trade-offs, commonly seen in other sustainability evaluations (Astier *et al*. 2011). Productivity is generally opposed to stability, resilience and self-reliance, due to the high dependence on external inputs, which allows for higher yields and in some cases higher profitability. This economic advantage is achieved at a cost of less self-reliance, which is critical for a sustainable system (Figure 4).

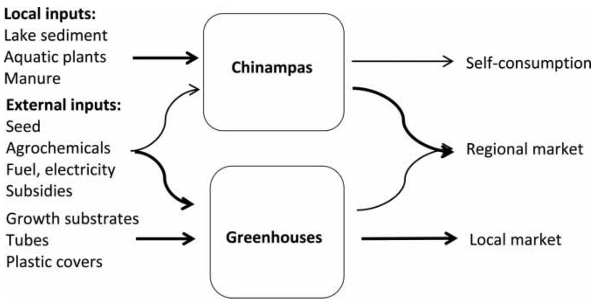

Figure 3. Inputs and outputs in chinampa and greenhouse systems in Xochimilco, Mexico. The width of the arrows indicates the importance of the flow.

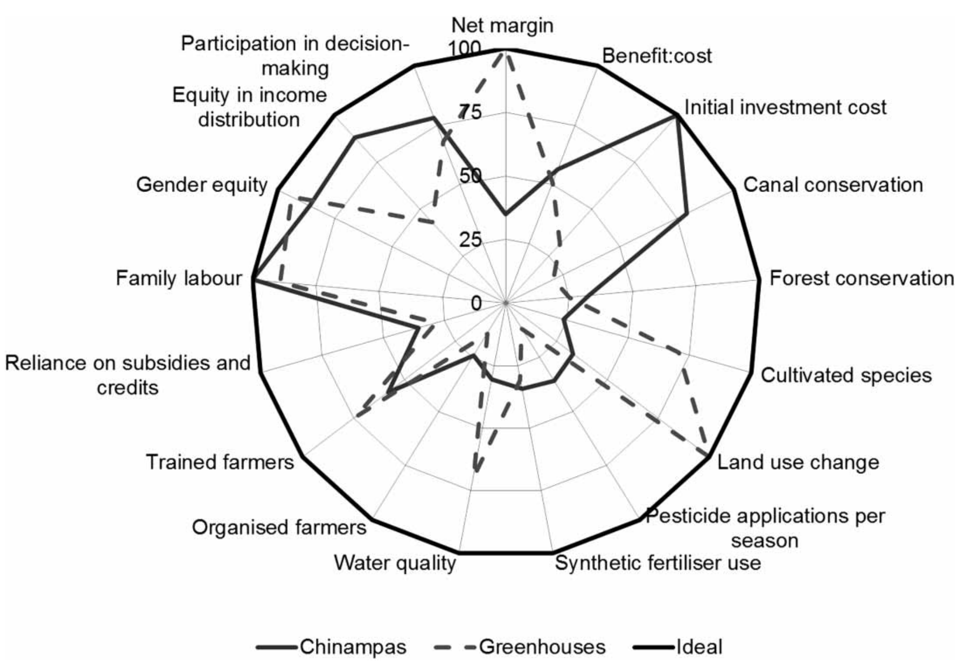

Figure 4. Amoeba graph for the evaluated indicators.

Even though there is a large investment in greenhouses, and margins are considerably higher, the benefit–cost relation is slightly better for chinampas, with lower investment, lower dependence on external inputs and higher reliance on traditional knowledge of production techniques. The higher profitability of greenhouses can be explained by a combination of factors, such as the higher value of the produce, its direct sale at the local market, high external input use, higher government subsidies and low-energy costs due to free electricity.

While the priority in greenhouses is to achieve higher benefits in a shorter term, chinampas have a stronger functional relation between agricultural practices and the maintenance of forest cover and canals, both closely related to ecosystem service provision. Mexico City is a heavily polluted metropolitan area, with a limited availability of green areas; hence, maintaining the canals and forest cover in chinampas is highly valuable, if the services of sequestering carbon, water cycle regulation and wildlife habitat provision are considered. Measuring such services could be carried out using GIS methods like the ones used in this study, as suggested by Swinton *et al*. (2006).

However, chinampas also have functions and properties which are difficult to quantify because of their intangible nature, namely their aesthetic and recreational values. In the case of cultural services, related to the landscape and maintenance of ecosystem-mediated culture, chinampas have an enormous value. This agricultural system is a tangible heritage for archaeological and historic reasons, which cannot be replaced with intensive greenhouse agriculture. Several methods to assign values to ecosystem services that lack markets, such as contingent and hedonic valuations, have been discussed by Swinton *et al*. (2007).

Chinampa owners do not receive any benefits from UNESCO designation, as Jiménez-Osornio and Gómez-Pompa (1991) already observed. Unlike other AHS, chinampas are in great risk of extinction due to land use change. Therefore, strong incentives based on the above-mentioned valuations are therefore needed if these systems are to be preserved. In the case of greenhouses, it has been noticed that canal filling does not prevent further sinking, as water extraction continues in the region. Hence, other management alternatives with a lower environmental impact need to be explored.

Agrochemical use and toxicity is considerably higher in greenhouses, as well as external use substrates, suggesting a higher environmental impact, which nevertheless needs to be assessed. Even though water quality in chinampas was negatively influenced by dissolved solids and the use of manure, this impact could be compensated by the ecosystem services provided by the canals and forest cover. Future water quality evaluations should take into account variables such as nitrate levels and pesticide residues.

External input dependence is a feature of high-tech systems, such as greenhouses. It was clear that high yields were obtained, thanks to the high investment, which makes growers highly dependent on external economic inputs, and less self-reliant. The lower organization capacity is due to the limited availability of farmers to participate in organized groups and intervene in decision making within the community.

A relevant finding in the greenhouse system is the role of women in agriculture, shifting from housewives and cooks for the chinampa workers to flower sellers in the local market. This change represents an advantage as not many women in the chinampa system have the opportunity to develop beyond the household realm. This is directly related to the availability of spaces for product sale; hence, the local market in San Luis Tlaxialtemalco has an essential role in the sustainability of the greenhouse system, as it promotes gender equity, improves sale conditions, widens marketing options and promotes the diversity of cultivated species.

In terms of equity, despite almost 20 years of greenhouse agriculture, both communities are still classified as very highly marginal (CODEPLAT 2003a, 2003b), which shows the low impact of this system in the welfare level of the community.

The choice of measured indicators is a reflection of the interdisciplinary nature of the evaluation team, and its degree of reliability is highly dependent on the quality of the information provided by farmers. Variation among farms was high, and for some indicators only limited data were available. It was not possible to obtain values for some key variables, such as pesticide doses. As a punctual representation of a cyclic process, indicator measurement requires confirmation and improvement of data-recording processes through several years, in order to take into account long-term environmental and socioeconomic variations. Reference values are also subject to interpretation and in several cases were difficult to obtain, as there are few data available from previous studies or comparable systems. This can also be addressed through further evaluation cycles, which could provide insights into trends for comparison.

It was possible to integrate farm-level indicators with regional scale ones, using readily available data and GIS techniques. Some of the regional indicators reflect the impact of policies towards the studied systems, as in the distribution of subsidies per system and gender.

As Moctezuma-Malagón *et al*. (2008) stress, sustainability indicators must be clearly understood and applied by those involved in policy and management design, such as farmers, agronomists and local authorities. Most of the indicators chosen in this study could be easily understood by local farmers, and then used to improve management strategies. Nevertheless, future evaluation cycles should involve all stakeholders in a participatory way.

The evolution of the chinampa system in the light of previous studies is evident, rapidly shifting from an almost self-sufficient intercropping of staple crops integrated with fishing, to a more intensive, market-oriented monoculture system, while maintaining some of its key features, such as the forest and water components, along with some traditional cultivation techniques. Chinampas have transformed but remain as a technically feasible and economically viable alternative for local farmers and their families. Land use change due to increasing urban pressure and policies promoting industrial agriculture are probably the most significant threats to their sustainability.

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References

Abbona, E.A., *et al.*, 2007. Ecological sustainability evaluation of traditional management in different vineyard systems in Berisso, Argentina. *Agriculture, ecosystems and environment*, 119 (3–4), 335–345.

Altieri, M.A., 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agriculture, ecosystems and environment*, 93 (1–3), 1–24.

Altieri, M.A., 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in ecology and the environment*, 2 (1), 35–42.

Altieri, M.A. and Trujillo, J., 1987. The agroecology of corn production in Tlaxcala, Mexico. *Human ecology*, 15 (2), 189–220.

Aranda, S.M., 2004. Ficha informativa de los humedales de Ramsar. Sistem alacustre 'Ejidos de Xochimilco y San Gregorio Atlapulco'. México. Secretaría de Medio Ambiente, Gobierno del Distrito Federal. Available from: http://www.wetlands.org/RSIS/_COP9Directory/Directory/ris/4MX050sp.pdf [Accessed 15 December 2011].

Astier, M. and González, C., 2008. Formulación de indicadores socioambientales para evaluaciones de sustentabilidad de SMRN complejos. *In*: M. Astier, O. Masera and Y. Galvan-Miyoshi, eds. *Evaluación de sustentabilidad. Un enfoque dinámico y multidimensional*. Valencia, Spain: SEAE, CIGA, ECOSUR, CIECO, UNAM, GIRA, Mundiprensa, Fundación … Instituto de Agricultura Ecológica y Sustentable, 119–138.

Astier, M., *et al.*, 2011. Sustainability indicators, trends and trade-offs in peasant agroecosystems: analysing fifteen case studies from Latin America. *International journal of agricultural sustainability*, 9 (3), 409–422.

Astier, M., *et al.*, 2012. Assessing the sustainability of small farmer natural resource management systems. A critical analysis of the MESMIS program (1995–2010). *Ecology and society*, 17 (3), 25.

Berkes, F., Colding, J., and Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological applications*, 10 (5), 1251–1262.

Binder, C.R., Feola, G., and Steinberger, J.K., 2010. Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. *Environmental impact assessment review*, 30 (2), 71–81.

Castaños, C.M., 1993. *Horticultura: Manejo simplificado*. Mexico: Universidad Autonoma Chapingo.

Chukwuka, K.S. and Omotayo, O.E., 2008. Effects of Tithonia green manure and water hyacinth compost application on nutrient depleted soil in South-Western Nigeria. *International journal of soil science*, 3 (2), 69–74.

CICOPLAFEST (Comisión Intersecretarial para el Control del Proceso y Uso de Plaguicidas, Fertilizantes y Sustancias tóxicas), 2004, *Catálogo de plaguicidas*. México. Secretaría de Salud, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Secretaría del Medio Ambiente y Recursos Naturales.

Clauzel, C., 2009. Between urban pressure and heritage: which place for agriculture in the Chinampas of Xochimilco (Mexico)? *Cahiers agricultures*, 18, 323–328.

CODEPLAT (Coordinación de Planeación para el Desarrollo Territorial, Gobierno del Distrito Federal), 2003a, *Sistema de Información del Desarrollo Social. Unidad Territorial San Gregorio Atlapulco*. Available from: http://www.sideso.df.gob.mx/documentos/ut/XOC_13–053–1_C.pdf [Accessed 9 February 2012].

CODEPLAT (Coordinación de Planeación para el Desarrollo Territorial, Gobierno del Distrito Federal), 2003b, *Sistema de Información del Desarrollo Social. Unidad Territorial San Luis Tlaxialtemalco*. Available from: http://www.sideso.df.gob.mx/documentos/ut/XOC_13–043-1_C.pdf [Accessed 9 February 2012]

Contreras, V., *et al.*, 2009. Recent decline and potential distribution in the last remnant area of the microendemic Mexican axolotl (*Ambystoma mexicanum*). *Biological conservation*, 142 (12), 2881–2885.

Council of Europe, 2000. *European landscape convention*. Florence, European Treaty Series 176. Available from: http://conventions.coe.int/Treaty/en/Treaties/Html/176.htm [Accessed 15 February 2009].

De Vaus, D.A., 2002. *Surveys in social research*. Sydney: Routledge.

DOF (DiarioOficial de la Federación), 1997, *14 de agosto. Norma Oficial Mexicana NOM-003-ECOL-1997*. Mexico: Gobierno del Distrito Federal, 1–7.

Esty, D.C., *et al.*, 2005. *2005 Environmental sustainability index: benchmarking national environmental stewardship*. New Haven: Yale Center for Environmental Law and Policy.

Ezcurra, E., 1991. *Del as chinampas a la megalópolis: el medio ambiente en la Cuenca de México*. 2nd ed. Mexico: SEP.

Galván-Miyoshi, Y., 2008. Integración de indicadores en la evaluación de sustentabilidad: de los índices agregados a la representación multicriterio. *In*: M. Astier, O. Masera, and Y. Galván-Miyoshi, eds. *Evaluación de sustentabilidad. Un enfoque dinámico y multidimensional*. Valencia, Spain: SEAE, CIGA, ECOSUR, CIECO, UNAM, GIRA, Mundiprensa, Fundación Instituto de Agricultura Ecológica y Sustentable, 95–107.

Garcia-Frapolli, E., *et al.*, 2007. Biodiversity conservation, traditional agriculture and ecotourism: land cover/land use change projections for a natural protected area in the northeastern Yucatan Peninsula, Mexico. *Landscape and urban planning*, 83 (2–3), 137–153.

Gaspar, P., *et al.*, 2009. Sustainability in Spanish extensive farms (Dehesas): an economic and management indicator-based evaluation. *Rangeland ecology and management*, 62 (2), 153–162.

González-Morán, T., 1999. The Basin of Mexico and its metropolitan area: water abstraction and related environmental problems. *Journal of South American earth sciences*, 12 (6), 607–613.

Halwart, M. and Gupta, M.V., eds., 2004. *Culture of fish in rice fields*, World Fish Center Contributions, 1718. Rome: FAO/World Fish Centre.

Harvey, C.A., *et al.*, 2008. Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican Hotspot. *Conservation biology*, 22 (1), 8–15.
Holthaus, G.H., 2008. *Learning native wisdom: what traditional cultures teach us about subsistence, sustainability, and spirituality.* Lexington: The University Press of Kentucky.
Jackson, L.E., Pascual, U., and Hodgkin, T., 2007. Utilizing and conserving agro biodiversity in agricultural landscapes. *Agriculture, ecosystems and environment*, 121 (3), 196–210.
Jiménez-Osornio, J., *et al.*, 1990. Pasado, Presente y Futuro de las Chinampas. *In*: A. Gomez-Pompa and T. Kathleen, eds. *Reportes de Sostenibilidad Maya No. 1*. Riverside: University of California, 5–16.
Jiménez-Osornio, J.J. and Gómez-Pompa, A., 1991. Human role in shaping of the flora in a wetland community, the chinampa. *Landscape and urban planning*, 20 (1–3), 47–51.
Koohafkan, P., 2009. Conservation and adaptative management of Globally Important Agricultural Heritage Systems (GIAHS). *Resources science*, 31 (1), 4–9.
Koohafkan, P. and Altieri, M.A., 2011. *Globally important agricultural heritage systems. A legacy for the future*. Rome: Food and Agriculture Organization of the United Nations.
López-Ridaura, S., Masera, O., and Astier, M., 2002. Evaluating the sustainability of complex socio-environmental systems. The MESMIS framework. *Ecological indicators*, 2 (1–2), 135–148.
López-Ridaura, S., *et al.*, 2005. Multiscale methodological framework to derive criteria and indicators for sustainability evaluation of peasant natural resource management systems. *Environment, development and sustainability*, 7 (1), 51–69.
Love, B. and Spaner, D., 2007. Agrobiodiversity: its value, measurement, and conservation in the context of sustainable agriculture. *Journal of sustainable agriculture*, 31 (2), 53–82.
Lu, J. and Li, X., 2006. Review of rice-fish farming systems in China – one of the Globally Important Ingenious Heritage Agricultural Systems (GIAHS). *Aquaculture*, 260 (1–4), 106–113.
Masera, O., Astier, M., and López-Ridaura, S., 1999. *Sustentabilidad y manejo de recursosnaturales: el marco de evaluación MESMIS*. México: Mundi-Prensa, GIRA, UNAM, Instituto de Ecología.
MEA (Millennium Ecosystem Assessment), 2005. *Cultivated systems. ecosystems and human well-being: current state and trends assessment*. Washington, DC: MEA, Island Press, 745–794.
Merlín-Uribe, Y., *et al.*, 2012. Urban expansion into a protected natural area in Mexico City: alternative management scenarios. *Journal of environmental planning and management*. doi: 10.1080/09640568.2012.683686.
Moctezuma-Malagón, A., *et al.*, 2008. A methodology for evaluating the sustainability of inland wetland systems. *Aquaculture international*, 16 (6), 525–537.
Neira, F., 2004. Participación laboral y autonomía femenina en un contexto de agricultura urbana. *Estudios demográficos y urbanos*, 20 (3), 533–567.
Quiroz-Flores, A., Miranda-Arce, M.G., and Lot-Helgueras, A., 2008. Estudio comparativo de algunas variables fisicoquímicas del agua en canales secundarios de Xochimilco con y sin *Eichhornia crassipes* (martius) Solms-Laubach. *Polibotánica*, 25, 127–133.
Rojas, T., 1983. *La Agricultura chinampera: Compilaciónhistórica*, Colección Cuadernos Universitarios. Serie Agronomía No. 7. Mexico: Universidad Autónoma de Chapingo.
SAGARPA (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) y Gobiernos Estatales, 2009. *Sistema de Información del Sector Rural (SISER)*. Aggregated Database. Mexico. Available from: http://www.siser-alianzacontigo.gob.mx/ [Accessed 9 February 2009].
Silber, J. and Weber, M., 2008. The generalized Gini index and the measurement of income mobility. *Economics bulletin*, 4 (9), 1–7.
Solís, C., *et al.*, 2006. Irrigation water quality in southern México City based on bacterial and heavy metal analyses. *Nuclear instruments and methods in physics research*, *B*, 249 (1–2), 592–595.
Soriano, R., 1999. *The chinampa system as a model of sustainable agriculture*.Thesis (PhD). Wye College, University of London.
Soto-Pinto, L., Perfecto, I., and Caballero-Nieto, J., 2002. Shade over coffee: its effects on berry borer, leafrust and spontaneous herbs in Chiapas, Mexico. *Agroforestry systems*, 55 (1), 37–45.
Stephan-Otto, E., 2006. *Xochimilco hoy: una realidad insustentable*. Mexico: Universidad Nacional Autonoma de México.
Swinton, S.M., *et al.*, 2006. Ecosystem services from agriculture: looking beyond the usual suspects. *American journal of agricultural economics*, 88 (5), 1160–1166.
Swinton, S.M., *et al.*, 2007. Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. *Ecological economics*, 64 (2), 245–252.
Ten Brink, B.J.E., Hosper, S.H., and Colin, F., 1991. A quantitative method for description and assessment of ecosystems: the AMOEBA-approach. *Marine pollution bulletin*, 23, 265–270.

Torres-Lima, P., Canabal-Cristiani, B., and Burela-Rueda, G., 1994. Urban sustainable agriculture: the paradox of the chinampa system in Mexico City. *Agriculture and human values*, 11 (1), 37–46.

UNESCO, 2006. *Xochimilco: Un Proceso de gestión participativa*. Mexico: UNESCO.

Van Cauwenbergh, N., *et al.*, 2007. SAFE – a hierarchical framework for assessing the sustainability of agricultural systems. *Agriculture, ecosystems and environment*, 120 (2–4), 229–242.

Wallace, G.N., Barborak, J., and MacFarland, C.G., 2005. Land-use planning and regulation in and around protected areas: a study of best practices and capacity building needs in Mexico and Central America. *Natureza y Conservacao*, 3, 147–167.

Wigle, J., 2010. The 'Xochimilcomodel' for managing irregular settlements in conservation land in Mexico City. *Cities*, 27 (5), 337–347.

Xie, J., *et al.*, 2011. Ecological mechanisms underlying the sustainability of the agricultural heritage rice–fish coculture system. *PNAS*, 108 (50), E1381–E1387.

Zambrano, L., *et al.*, 2009. Spatial heterogeneity of water quality in a highly degraded tropical freshwater ecosystem. *Environmental management*, 43 (2), 249–263.

Zeileis, A., 2007. *The ineq Package: Measuring inequality, concentration and poverty.* The Comprehensive 'R' Archive Network. Available from: http://cran.r-project.org/web/packages/ineq/index.html [Accessed 15 June 2008].