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Integrating Agroecological Food Production, Ecological Restoration, Peasants' Wellbeing, and Agri-Food Biocultural Heritage in Xochimilco, Mexico City

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Abstract: *Chinampería*, a jeopardized precolonial agricultural practice, persists in the Xochimilco wetland, Mexico City. Agroecological *chinampa* production is a recognized UNESCO World Heritage Site, and contributes to the sustainability of both the urban wetland and the city. The '*chinampa*-refuge' model (CRM) is a transdisciplinary effort to strengthen traditional agroecological practices and ecological restoration. Through an inter/transdisciplinary research framework, we addressed the model's role in the sustainability of this socio-ecosystem concerning four significant drivers of the wetland's transformation. The CRM has improved water quality locally, increased the suitable habitat for native aquatic biodiversity, and supported traditional agroecological practices, thus improving the quality and safety of food products. However, there are clear challenges regarding production and commercialization, some of which may be addressed through the strengthening of the social organization and collective action. However, other challenges are beyond the reach of *chinampa* producers' efforts and the CRM, but are decisive in changing the degradation trends. In order to address these challenges, urgent and participatory government actions are needed based on the recognition of the causes of wetland degradation and the role of traditional *chinampa* production in its sustainability.

Keywords: peri-urban agriculture; small-scale agriculture; urban sustainability; food sovereignty; water quality

1. Introduction

Cities are complex territories, nodes of accelerated fluxes of capital, people, information, matter, and energy [1] that strongly influence the environmental dynamics of close and distant territories [2–4]. In the context of global environmental change, cities' sustainability constitutes a growing concern, as they are expected to host 68% of the world population by 2050 [5]. Complex interwoven processes that involve hydrological dynamics and water access, agri-food systems, and the maintenance of biodiversity are essential for the wellbeing of urban people and the future of cities. This is particularly challenging for the Global South, where most urban growth will occur [6].

More than 20 million people inhabit the Metropolitan Area of Mexico City, located at the bottom of an endorheic basin, originally occupied by a system of wetlands, where the precolonial city of Tenochtitlan was constructed. The Colonial period brought about the destruction of the pre-Hispanic hydraulic system. From then on, lakes were drained and desiccated to prevent flooding, and most of the rivers descending into the basin were piped [7,8]. Groundwater extraction has been increased for decades in order to meet a large part of the city's water needs, causing subsidence, which affects the infrastructure, complicates city wastewater drainage, and increases flood risks [9]. Given these hydrological transformations, existing remnant wetlands are strategic for hydrological regulation.

There is ample evidence of the socioecological importance of the Xochimilco wetland, where a unique ancient production system persists: the *chinampa* system, also called *chinampería.* The wetland and its associated traditional agricultural practices provide numerous socio-environmental benefits: they maintain the adequate ecological conditions of the wetland, sustain producers' livelihoods, improve urban access to high-quality food products, and contribute to climate and water regulation, and to the conservation of biodiversity and biocultural heritage [10,11]. Currently, the wetland supports around 180 plant species and more than 200 species of vertebrates, including various migratory birds and seven endemic species, such as the axolotl (*Ambystoma mexicanum*) [12].

However, the *chinampas* system and the wetland suffer from long-term and ongoing degradation. Xochimilco's springs, which sustained the wetland, were diverted to feed the city's water needs in the 19th Century [8]. This decision reduced the water table levels and led to the desiccation of the canals. Water scarcity led to groundwater extraction from wells, which aggravated subsidence, leading to the decision to divert treated water from a wastewater treatment plant toward the wetland in the 1950s. Currently, the combined effects of treated wastewater and the discharges of irregular settlements; the transformation of agricultural practices, which entail agrochemical use; and poorly regulated touristic activities have reduced the water quality, negatively affecting *chinampería*, biodiversity, the ecosystem, and human health [13,14]. Urban growth and economic diversification have turned Xochimilco into a mosaic of different land uses; agricultural abandonment and the loss of the *chinampa* system would lead to complete urbanization and the loss of the wetland [15].

Xochimilco's ecological and cultural importance led to its recognition as part of the local system of protected areas of Mexico City and as a RAMSAR site. It has also been declared a World Heritage Site by UNESCO, and is considered a Globally Important Agricultural Heritage System by the FAO [16–18]. However, the results of strategies to conserve the wetland and its agricultural system have been limited [19]. Factors underlying Xochimilco's degradation, including those perceived by local actors, have been extensively studied [20]. By recognizing the importance of maintaining the productive capacity of the system, and of sustaining the ecological processes of the wetland, for its identity and multifunctionality, Jiménez et al. [21] propose a set of drivers that have historically and recurrently influenced the system: (1) water quantity and quality, (2) existing markets for *chinampa* products, (3) the sociocultural value of *chinampa* agriculture, (4) social organization in favor of traditional agriculture, and (5) the local effects of global and regional forces (such as policies and climate change).

Sixteen years ago, one of our research groups (Laboratorio de Restauración Ecológica at Instituto de Biología, UNAM) created the "*chinampa*-refuge" model (CRM) to strengthen traditional agroecological practices and the ecological restoration of water canals surrounding *chinampas* [12,22]. This model promotes transdisciplinary work with *chinampa* producers to maintain traditional agroecological practices and establish rustic filters in the canals to exclude invasive exotic fish species, which harm other species' habitats and the structure of *chinampas*. Thus, the original food web is restored, improving the water quality of the specific site, as well as the ecological functionality of the system [12]. However, there is still insufficient knowledge regarding the contribution of the CRM to other dimensions of socioecosystem sustainability and the challenges this sustainability faces for its long-term viability.

In this study, using an inter/transdisciplinary approach, we analyzed the contribution and challenges of the "*chinampa*-refuge model" (CRM) in shaping some drivers proposed by Jiménez et al. [21], as follows: (1) water quality and its relation to the ecological restoration of the water canals surrounding *chinampas*, the improvement of the ecological conditions necessary for production and biodiversity, and the safety of *chinampa* products; (2) the existing markets for *chinampa* products, by analyzing the challenges involved in traditional agroecological production directed to markets and their commercialization, as well as the comparative quality of these products based on their sensorial attributes; and (3) social organization in favor of traditional agriculture, by analyzing the social organization for commercialization, as it is critical for the profitability of agroecological *chinampa* production. Finally, we discuss the limitations of the CRM model in light of driver (4): the local effects of global and regional forces. Understanding the contributions and limitations of the CRM regarding these drivers of change is key for designing strategies to improve its viability in the long term. In doing so, we aim to strengthen traditional agroecological production, producers' wellbeing, and the food sovereignty of the city, as well as to protect the sociocultural value of *chinampa* agriculture and improve the ecological conditions of the wetland.

Xochimilco and the Chinampa System

The Xochimilco wetland is located in the southern part of Mexico City, at 19°15′11″ North and 99°19′15″ West (Figure 1). In the 1960s, urban growth reached the wetland, fueled by immigration induced by rural poverty and the industrialization of the country [23]. Irregular settlements began to grow into former *chinampa* areas and as they lacked infrastructure and services, directed their sewage directly to the wetland. These settlements also meant land use change and increased urbanization. The national and international recognition of the social and ecological importance of the wetland and its agricultural system, through the various decrees mentioned above [18], provoked a slight decrease in urbanization [21].

Today, the Xochimilco wetland comprises a mosaic of land uses and economic activities [15], and is highly threatened by diverse processes which are leading to its degradation. The disarticulation of the pre-Hispanic hydrological system in the colonial period, the diversion of Xochimico's spring water to meet the city's needs at the end of the Nineteenth Century, and the decision to derive treated wastewater to replenish the wetland were among the most critical interventions that transformed the wetland [21]. Previous studies [24–26] have shown that the counts of fecal coliform bacteria in the water used for production in *chinamapas* are higher than those established as adequate for the reuse of treated wastewater for irrigation [27] and for the discharge of raw wastewater into national water bodies [28].

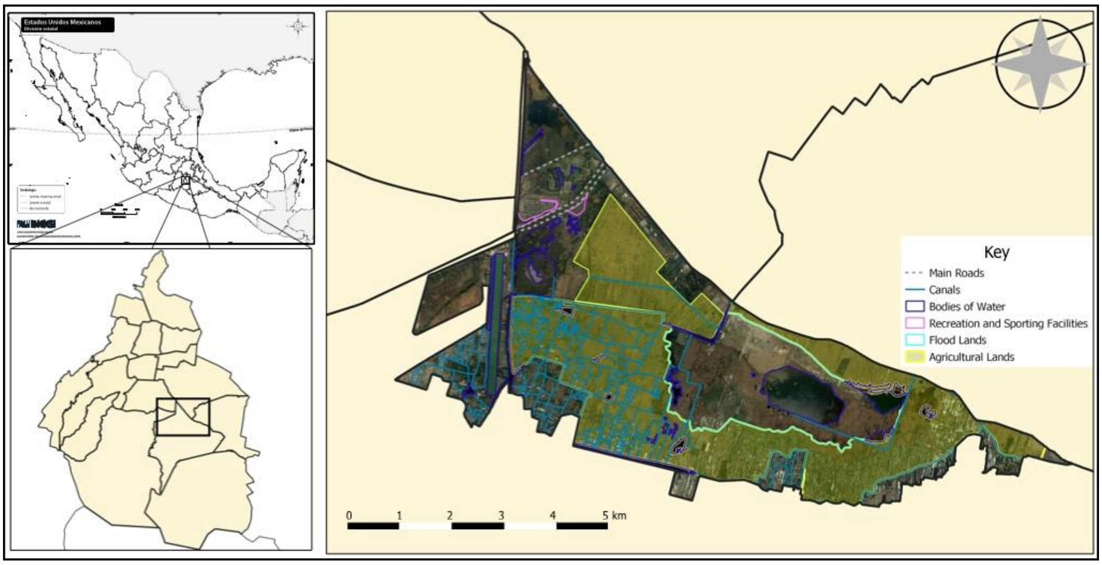

Figure 1. Location and main spatial characteristics of the local natural protected area of the Xochimilco wetland, Mexico City, Mexico. Map developed by Gabriel Soulá, based on Google Satellite Images and [29–31].

The *chinampa* system is made up of agricultural islands (*chinampas*) on the wetland surface. *Chinampas* are structured and maintained in place by Bonpland willow trees (*Salix bonplandiana)*, using high-fertility sediments obtained from the bottom of the wetland. Historically, irrigation water was obtained through capillarity [32], as each *chinampa* is surrounded by water canals (Figure 2), but at present, water is pumped from adjacent canals. This agricultural system is one of the most diverse and productive systems in the world [33]. The creation of this cultivation technique by *chinampa* producers allowed the sustainable provision of food for one of the most important urban centers in Mesoamerica [34].

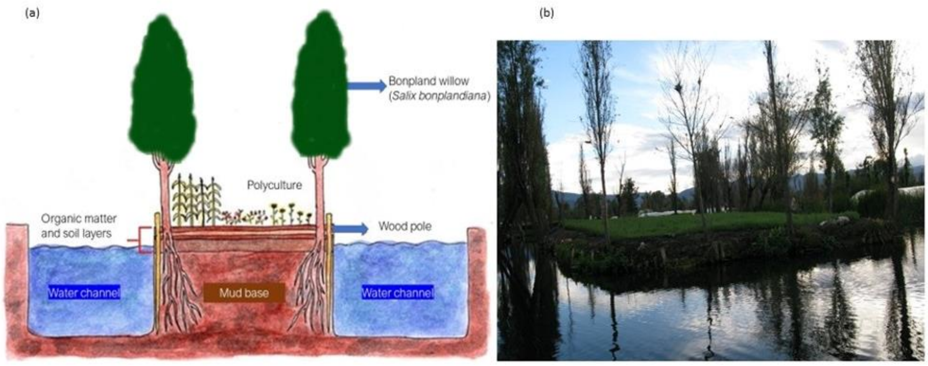

Figure 2. (**a**) Schematic transverse view of a *chinampa*. The drawings were produced by Adela Madariaga and Ilana Villanueva. (**b**) *Chinampa* overview, Xochimilco, Mexico City, Mexico. Photograph: MM-H.

The expansion of greenhouses with high agrochemical inputs, irregular settlements, and the proliferation of other *chinampa* uses, such as football fields, threatens the remaining *chinampa* system. The quality of its products is affected by the intensive groundwater extraction, water contamination derived from the inefficiency of the wastewater treatment plant, irregular settlements' sewage, and poor solid-waste management. Production and commercialization challenges are also significant [35–37]. Some of these processes are associated with governmental indifference, corruption, and the absence of sustainability criteria in urban planning [36,38]. Agricultural abandonment derived from the difficulties faced by producers, including young people's disinterest in agriculture, has led to the loss of 31 ha of *chinampas* annually [12,15,21]. Finally, the economic viability of agroecological *chinampería* faces the challenge of its disadvantageous insertion into the city's agri-food system, which is dominated by large-scale transnational and national companies, as well as intermediaries and monopolies [39].

Despite the multiple pressures, the system has survived for more than 700 years [21]. Among the current elements of resistance to pressures are the cultural farmer identity, the sense of pride in being a *chinampa* producer, the sense of place and the values attached to it, and the wellbeing associated with agricultural livelihoods, as well as the fact that a market demand for *chinampa* products still exists [21,37,40].

2. Materials and Methods

The project was constructed through collective discussion among four research groups that worked from various interdisciplinary perspectives from different institutions. This process involved building a common framework to articulate the different aspects of the system addressed by each research group. The project design also involved some of the main concerns of *chinampa* producers, gathered throughout the 16 years for which the Restoration Ecology research group worked with producers, and from initial meetings for project discussions with them. In some discussion groups, local governmental agents were also included; these interactions also led some of us—M.I.R., L.Z., A.C.E.-G., M.B.P.U., and F.F.—to participate in the design of the new local norm that regulates agroecological production in conservation areas of Mexico City. The SARS-CoV-2 pandemic and the sanitary measures implemented in Mexico City halted fieldwork and meetings; thus, many of the research and interaction activities, when possible, were conducted virtually. Following the main drivers of the system transformation proposed by Jiménez et al. [21], we addressed the contribution of the CMR as follows.

2.1. Water Quality

This driver relates water quality to the ecological restoration of the water canals surrounding *chinampas*, the ecological conditions necessary for production and biodiversity, and *chinampa* products' safety. Environmental health influences the quality of agricultural products, particularly lettuces, which are depicted as a horticultural representative product. For the 2021 dry and rainy seasons, we performed bacteriological analyses of water and lettuce in ten *chinampas* of two different groups: (1) *chinampas* working with the CRM model (with refuges) and (2) *chinampas* not working with the CRM model (without refuge). For each *chinampa*, irrigation water and ten randomly selected lettuces were collected.

In the case of water, 1 L samples were collected in triplicate in previously washed and sterile polypropylene flasks. These were transported to the lab, and were refrigerated at 4 °C. From each sample, 100 mL water was analyzed following the membrane filtration method, using a nitrocellulose 0.45-µm membrane [41]; we placed the residue in a bacteriological culture medium m FC (BIOXON) and incubated it at 44 °C for 48 h. The colony counts were reported as CFU/100 mL.

The lettuces were cut entirely and transported in individual bags to the lab. From each lettuce, 25 g was placed in a sterile bag with 100 mL sterile PBS solution 1X. The bags were sealed and subjected to orbital agitation for 30 min. Subsequently, the solution was recovered in sterile propylene tubes with a strainer, in order to avoid vegetable residues [42]. The samples were processed following the membrane filtration method described previously. We performed heavy metal determination, such as As, Cu, Cr, Hg, Pb, and Zn, which have previously been found to accumulate in the sediments of the wetland [43]. The quality and safety of water and products are relevant for access to markets for *chinampa* production, and are also influenced by traditional agroecological techniques.

The quality of the canals as refuges was evaluated regarding their ability to function as habitats hosting native species. This was assessed through qualitative information obtained from each producer. We used the water transparency and the number of plants and insect species in new refuges (installed within a year), and old ones (of more than two years old), as assessment criteria.

2.2. Existing Markets for Chinampa Products

For this driver, we first addressed the challenges of traditional agroecological production for the market in the context of Xochimilco. We also examined the commercialization challenges associated with the asymmetrical insertion of agroecological *chinampa* producers in the city's agri-food system. We explored the perspectives of CRM producers through semi-structured interviews and one discussion group. The interviews were transcribed, and textual analysis was developed using Atlas.ti software.

On the other hand, considering the asymmetric insertion of *chinampa* products in the Mexico City agri-food market, we compared their quality based on sensory attributes. In order to assess the quality of CRM *chinampa* products, the most important *chinampa* products for *chinamperos* were discussed and selected with them in a meeting. Twelve products were selected collectively with CRM *chinampa* producers: lettuce, spinach, collard, chili, beet, carrot, *romeritos*, *lengua de vaca*, purslane, maize, broccoli, and cauliflower. The sensorial attributes of these products were compared to those of conventional examples. This procedure involved forming and training a panel of 30 judges: current and graduated students of gastronomy from the Universidad del Claustro de Sor Juana. A set of sensorial descriptors was decided by consensus for each product. The judges scored the *chinampa* and conventional products without knowing the origin of the products being tested. Mean scores were assigned to the *chinampa* and conventional products. Profiles for the 12 products are being developed and compared with their conventional counterparts. SARS-CoV-2 restrictions particularly limited this part of the investigation and, as a result, information is still under analysis. We only present here the sensory analysis results for five products as preliminary results.

2.3. Social Organization in Favor of Traditional Agriculture

We explored the social organization around commercialization through semi-structured interviews applied to people involved in the commercialization activities of agroecological *chinampa* products. These interviews allowed us an understanding of the different commercialization relationships involved in the production–commercialization interface. The interviews were transcribed and codified in Atlas.ti software. The codification and analysis were based on the characterization of the social relations involved in the commercialization and the potential of network formation.

3. Results

3.1. Water Quality

Figure 3 shows the temporal variation between the dry and rainy seasons of fecal coliforms (FC), as indicator bacteria, in water samples taken from non-CRM and CRM canals, and in lettuce produced by non-CRM and CRM *chinampas* in Xochimilco. The bacterial densities obtained in the water per 100 mL were integrated with those found in lettuce per 100 g in order to present the bacterial loads of the irrigation water and the product together. The red line represents the maximum permissible limit established by the NOM-EM-034-FITO-2000 regulation for FC in water reused for vegetables (2000 colony-forming units per 100 mL; CFU/100 mL).

Figure 4 shows the temporal variation between the dry and rainy seasons of *Escherichia coli* (*E. coli*), as a potential bacterial pathogen, in water samples taken from the non-CRM and CRM canals, and from lettuce produced by non-CRM and CRM *chinampas* in Xochimilco. There is no permissible limit stipulated in the Mexican normativity for *E. coli*.

In general, the density of bacteria in surface water is highly variable. The specific results of water from the agroecological *chinampa* indicate that the microbiological quality of the reused treated wastewater, evaluated specifically by the count of fecal coliform bacteria and *Escherichia coli*, did not exceed 10^3 CFU/100 mL. The bacteriological counts registered in lettuce did not exceed 10^3 CFU/100 g, which means that they maintain an adequate order of magnitude for irrigation and consumption with disinfection. This also means that agroecological *chinampas* decrease the concentrations of bacteria in treated wastewater for reuse [27] and in vegetables that are consumed raw [44]. These results show the differences between water and lettuce obtained from agroecological *chinampas* and those from sites without these agroecological practices. The bacterial counts recorded in lettuces from agroecological *chinampas* can be easily reduced domestically by washing and disinfecting with commercial products (hypochlorite, colloidal silver, among others) [45].

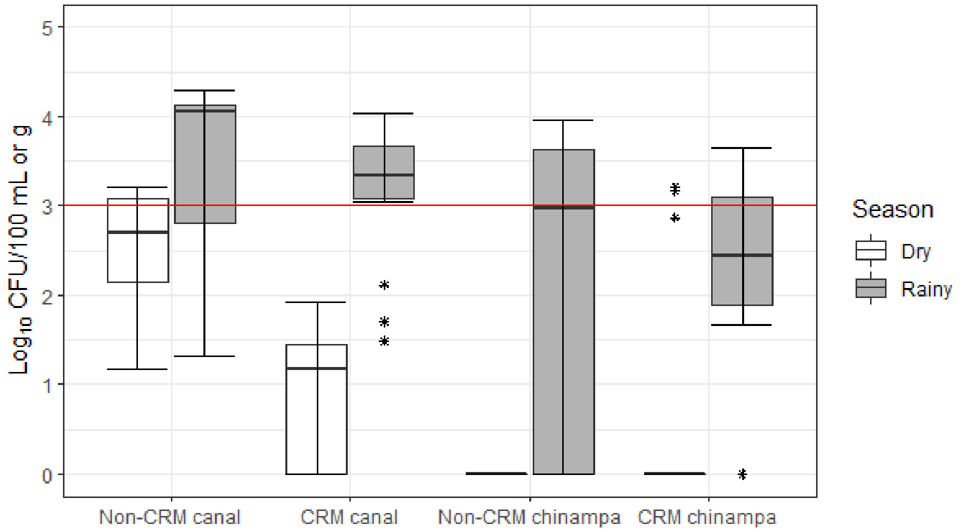

Figure 3. Temporal variation of fecal coliforms (FC) in water from non-CRM and CRM canals, and in lettuce from non-CRM and CRM *chinampas* sampled in Xochimilco. The red line depicts the maximum permissible limit established by the Mexican regulation. *: outlier data.

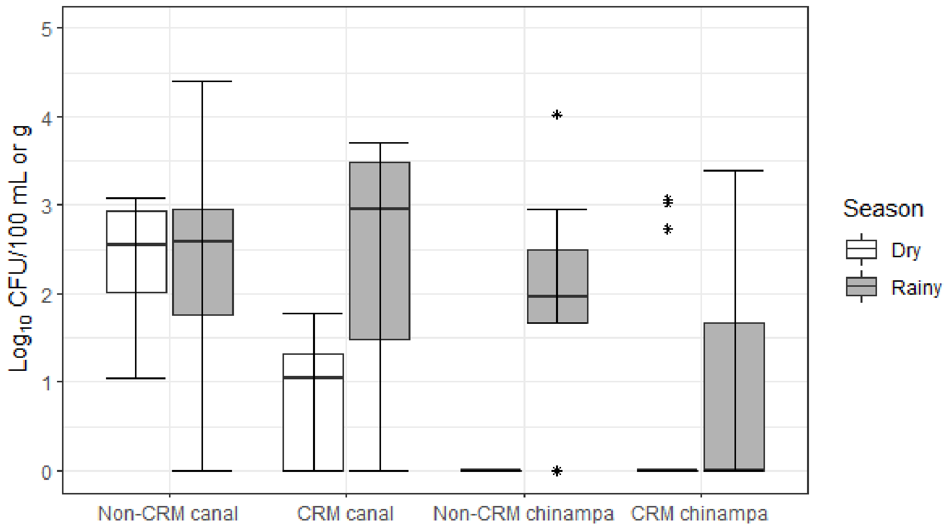

Figure 4. Temporal variation of *Escherichia coli* (*E. coli*) in water from non-CRM and CRM canals, and in lettuce sampled from non-CRM and CRM *chinampas*. *: outlier data.

The heavy metals analyzed are present in lettuce, highlighting mercury registered in 8/10 *chinampas* in concentrations >0.01 mg/kg, chromium detected in 5/10 *chinampas* in concentrations >0.5 mg/kg, and copper recorded in 8/10 *chinampas* in concentrations >0.2 mg/kg [46]. The results correspond to composite samples; as such, it is essential to carry out a broader sampling in order to identify hot spots of heavy metals, and to evaluate the origin of their presence in particular products. Once the sites of concern can be identified, specific practices could be proposed for the management of affected *chinampas*. This is a topic of environmental and health relevance that requires further research, including the evaluation of heavy metal accumulation in the vegetables of diverse origins that are consumed in the city.

Water quality is a crucial element for the ecological restoration of canals to sustain native biodiversity and recover the ecological dynamics of the wetland. The project started with five *chinamperos* belonging to a single collective organization. With them, 11 refuges were created in five *chinampas*, where 17 biofilters were installed, covering a combined length of 1283 m of canals. After five years, the number of *chinamperos* increased up to 23, belonging to five different collective organizations; the refuges installed grew to 48 in 36 *chinampas*, and the number of biofilters installed reached 67, covering 5782 m of canals. The refuges also proved to be free of exotic fish, and the few carps and tilapia that can enter them can be easily controlled and eradicated. Therefore, the habitat for the axolotl and other species increased 4.5 times in five years.

During this time, we have proven that the canals converted to refuges are qualitatively better habitats for native biodiversity than those which are not converted into refuges. For example, water transparency, a crucial variable for ecological dynamics within aquatic systems [47], changes dramatically as refuges evolve. The Secchi disk values outside the refuges were around 30 cm. These values are reduced in young refuges to 21.6 cm due to labor within the canals, such as sediment removal to increase the canal's depth and constant interventions to establish aquatic plants. However, months later, the water transparency increases up to 72.6 cm, which means that light can reach the bottom of the canal, allowing rooted plants to survive and triggering new food web dynamics within the water [48]. This increase in water transparency promotes a suitable environment for aquatic plants that increased to up to 5.5 species in old refuges, compared with 1.9 species in young refuges. Plant coverage also increased and, therefore, invertebrates' diversity and abundance also increased. Inside old refuges, *chinamperos* have detected about 7.6 morphospecies—taxonomic species based wholly on morphological differences from related species—compared with 0.9 species in new refuges. In old refuges, it is common to find small native fish and axolotl, both adults and eggs.

3.2. Existing Markets for Chinampa Products

The agroecological productive processes in a wetland are much more complex than in firm land. Transportation through water canals of both agricultural inputs and production, as well as the implementation of traditional agroecological practices, requires a larger investment of time and labor. In addition, the restoration and maintenance of water canals as refuges (Figure 5) also requires the investment of time and work.

(a) (b)

Figure 5. (**a**) *Chinamperos* transporting agroecological inputs. Photograph: MBP-U. (**b**) Rustic filters established in a water canal between *chinampas.* Photograph: MM-H.

CRM producers simultaneously maintain and recover traditional practices, and have reduced the use of herbicides, synthetic fertilizers, and pesticides. Pest control is achieved by agricultural diversification and biological control. The agricultural diversification within *chinampas* is high. This diversity combines traditional food products, such as maize, chili, or zucchini, with those demanded by the market, including "gourmet" foods. Combining the production of all of the *chinamperos* interviewed, we documented 68 different cultivars; these include aromatic herbs, bulbs, cereals, flowers (with some of them being edibles, and included in traditional cuisine, but with low market demand), green vegetables, legumes, and *quelites*—edible herbs that grow spontaneously but are favored and cared for. The most diverse cultivars were lettuce (with 18 varieties), followed by tomatoes (8), cabbage, maize, spinach, and radish (5), beets, chilies, and coriander (4). Half of the *chinamperos* interviewed keep the seeds for use in the following sowing cycle; therefore, 30.4% of the cultivars and 22.7% of the documented varieties are maintained in situ through this practice. Seed interchange between producers is also common.

The main agro-productive challenges in production, according to *chinamperos*, include low water quality, a spatial heterogeneity of soil nutrients that leads to differential soil management needs, saltpeter in soils, and the desiccation of canals. As stated by one producer: "Specifically, in the chinampa zone, the problem is water quality and saltpeter in the soil". Diversified *chinampas* also imply that the periods from sowing to harvest differ among products, such that they are juxtaposed throughout the year. Different cultivars are in distinct phases of the cycle at a given time of the year, and require diverse forms of attention. Diversification also imposes restrictions on commercialization, particularly when large quantities of a single product are required at specific times. High production costs, particularly for seeds and the gasoline needed to pump water from the canals for irrigation, are also important. Producing in a wetland also implies that inputs and production must be transported by boats and canoes, increasing the costs and labor invested, including for the maintenance of the navigation conditions of the canals.

The commercialization routes are variable. The production may be sold directly to consumers in "green" or conventional markets, intermediaries, or through commercialization networks. Some producers also direct their production to the *Central de Abastos*, the largest-scale market that centralizes and monopolizes agri-food commercialization in Mexico City. On average, 11.3% of all production is directed for subsistence (Figure 6).

Most of the production is directed to conventional markets and itinerant street markets (*tianguis*). Noticeably, most of the production directed to "green" or alternative markets comes predominantly from one producer who owns a large *chinampa* surface. Furthermore, intermediaries purchase a high proportion of the production.

A central issue for the commercialization of agroecological products is that the food system of Mexico City is dominated by conventional products; most marketing spaces do not differentiate among the products' characteristics, nor do they consider the products' origin and the agricultural practices involved, as stated by various interviewees:

> *The main problems are the lack of knowledge of people about the project and about the cultural and alimentary value of products, as well as the competence of chain grocery stores.*

> *One of the main problems is to obtain a competitive price; as part of what is agroecological, is the social part,* [that means] *paying a fair price to the producer; and for many people, I think there is still much misinformation about the value of these products compared to those of a standard supermarket* [. . .]

> *It is impossible to compete with the prices of the Central de Abastos when they sell 1 kilo of tomatoes for 10 pesos and we sell them for 46 pesos; then there is a huge difference, but we guarantee that it comes from the chinampa, from a producer that has certain characteristics, while the other one, they do not know where it comes from, and very likely has pesticides, it is cheaper, why? Because there is very much product.*

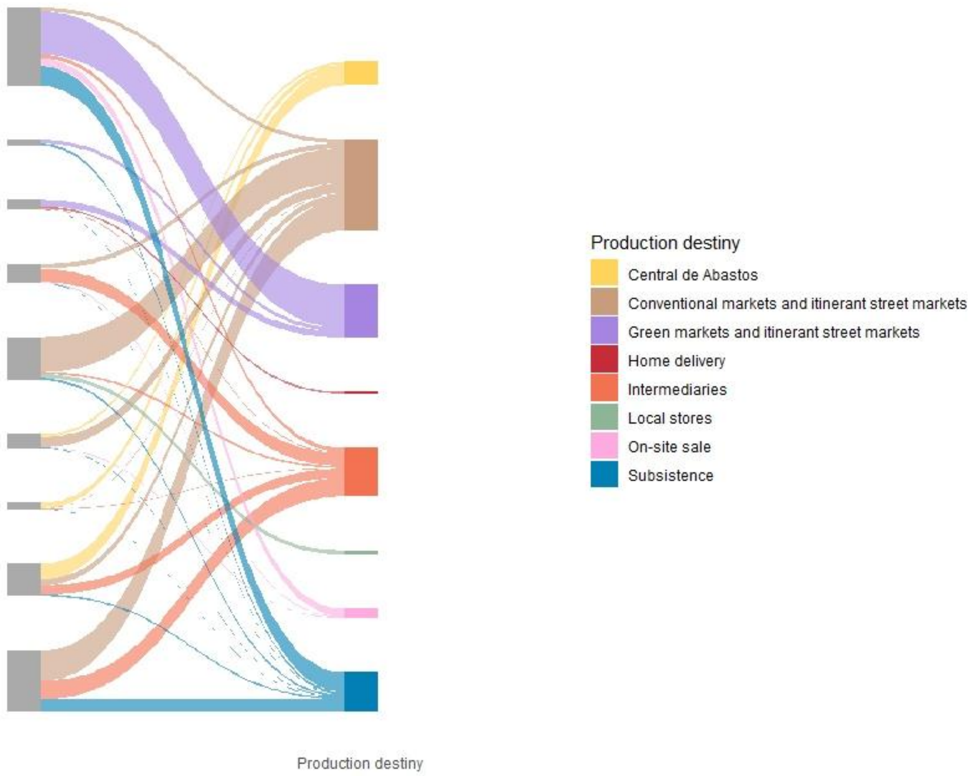

Figure 6. The representation of the production destiny of *chinampa* products. The width of the gray rectangles (**left**) represents the size of the *chinampas* owned by each producer. The width of the production destiny (**right**) represents the proportion of production directed to each alternative. Elaboration: Leonardo Calzada.

Access to green and gourmet markets is limited by the costs involved, including transport and fees, and by the high competition in them. Green and gourmet markets are scarce in the city, reflecting the low demand for local agroecological production. The commercialization advantages and disadvantages also vary for each product. Another challenge to commercialization in green and gourmet markets is the prejudice of consumers against Xochimilco products due to the low water quality, as stated by a producer:

> [. . .] *When we sell, they don't trust a lot in the products of Xochimilco, I mean, there is this common idea that the Xochimilco products are dirty, that the water of Xochimilco is dirty* [. . .] *they have asked me if we irrigate them with sewage.*

The challenges to obtaining fair prices are many. A significant limitation is that, for producers, it is quite difficult to calculate a fair price. For them, the systematization of information about their own production is complex, given the changing spatial configuration of cultivars and sowed surfaces in the three to five productive cycles per year. They also struggle to calculate and assign an economic value to the time and labor invested in the various activities involved in the production and commercialization processes. The varying and informal measurement units used by different routes of commercialization compound these difficulties. An extreme example was narrated by one of our interviewees:

> *In* [name of a virtual store], *when I had to assign my prices, as a producer, I do not have so much experience in the commercialization, but in production. As a producer, they tell me 'Assign your prices', thus I calculate that producing a lettuce cost me 6 pesos* [. . .] *and then I begin to see the prices assigned by the rest of the fellows, and I think they were in 18 pesos at minimum* [. . .] *I said to myself 'I don't know if I am wrong or what'*

Access to gourmet and alternative markets and the possibility of obtaining fair prices also depend on the quality of the products, as perceived by consumers. Figure 7 depicts the comparison of the sensorial attributes between CRM and conventional products. All of the products showed a larger percentage of attributes that were superior or equal to their conventional counterparts, except for spinach.

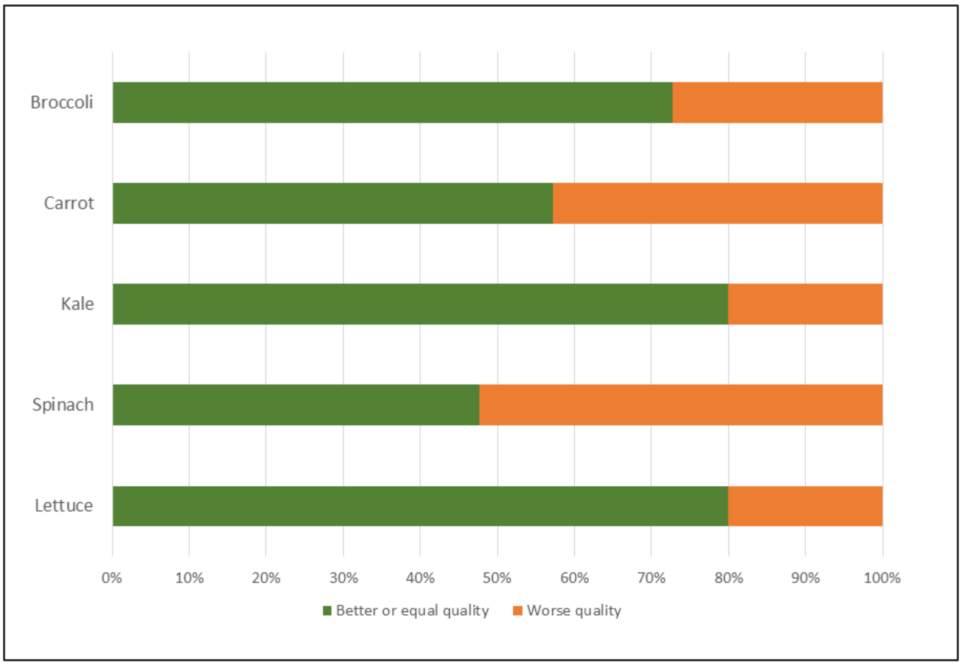

Figure 7. The percentage of better or equal sensorial attributes of CRM products, as compared to conventional products.

3.3. Social Organization in Favor of Traditional Agriculture

Commercialization strategies are diverse. A producer may commercialize products by him/herself; sometimes, various family members are involved, or some producers group together to commercialize. Some others, alone or in small groups, are attached to commercialization networks.

We registered 40 different organizations involved in the commercialization of agroecological *chinampa* production. These organizations vary in their structure, objectives, and forms of articulation with producers. Some organizations are centered on the economic profits derived from accessing elite green, alternative and gourmet markets, where consumers, although they are more aware of the characteristics of food, are more concerned about health issues [39] than sociocultural and ecological ones. Therefore, organic products are preferred. However, certified organic production is not an alternative for Xochimilco producers:

> *We don't have the conditions to be organic, nor will we have them, because we are chinamperos. Given the quality of land, water, and air... even if you don't use chemicals, the neighbor does, and then they reach you.*

> *I have always said that our certification is our own work. I have seen fellows who are certified, but their way of working does not support them* [. . .] *the certification is your own work and showing that* [the product] *is clean.*

Another possibility of access to alternative food markets is selling to gourmet restaurants. Engaging with these spaces has the advantage that people recognize the product's quality and the ecological and sociocultural values behind the production. However, the timing, quantities, and uniformity of the products demanded constitute limitations for this kind of commercialization, although there are producers who are already commercializing through these channels.

One of the most promising avenues for sound commercialization which might sustain traditional agroecological *chinampa* production is the articulation and creation of alternative agri-food networks that seek to strengthen the relationship between producers and consumers, by integrating all kinds of values (human and ecosystem health, social justice, and solidary economy). Some of these networks are committed to forms of resistance vis a vis the dominant industrial agri-food system. As stated by interviewees involved in such networks:

> *We are a cooperative of distribution of goods and services; we seek to work from the solidary economy, agroecology, and food sovereignty; we seek the common good for all participants of the process, from the producer to the consumer.*

An advantage of these networks is that they are more adapted to the conditions and necessities of Xochimilco producers, are more flexible, and promote local organization, cooperation, and the protection of agro-biodiversity:

> *We do not seek to work with certified producers. It is not something the organization looks for* [. . .] *that is why we are articulated with the Committee of Participative System of Guarantee* [. . .] *We look for projects that promote agroecological processes, integrating all components of agroecology, not only the use of traditional practices or free of agrochemicals but also those that encourage organization processes, seed conservation, and community and territory building"*

> *In the past, in chinampas there were beans. We want to encourage beans to be sown again, because* [Xochimico producers] *are closer than other producers; also, maize, which is now scarce. Producers preferred other trendy products, like kale* [...] *How do we recuperate things that have disappeared and must be brought from afar?*

4. Discussion

The Xochimilco wetland and its unique agricultural system bring about numerous ecological, sociocultural, and economic benefits to the city [10,11,13,19]. Institutional efforts to preserve the wetland have not only had limited effects but have, in many cases, been counterproductive, partly as a result of inadequate perspectives and the absence of coherent projects designed to address the root causes of the complex dynamic of the wetland [20,36]. Simple examples are the subsidies that the local government continues the grant for greenhouse agricultural development, which entail the intensive use of agrochemicals that further water pollution, or the prioritizing of chaotic touristic activities, which also affect the ecological conditions of the wetland [20]. This situation is compounded by the indifference and corruption of local authorities, which are linked to the ongoing growth of informal settlements and the creation of clientele networks, which erode the possibilities of collective action [36,40].

The historical violence exerted over the wetland, its biodiversity, and the livelihoods of *chinampa* producers through the dispossession of water from their springs and their territory, as well as the lack of governmental commitment to reverse these circumstances, have left *chinampa* producers with a sense of betrayal and loss [19,40]. Current degradation trends continue, and losing the *chinampa* system would likely lead to the loss of the wetland to urbanization. The magnitude of the consequences is incommensurable, encompassing the loss of cultural heritage, sustainable food production, livelihoods, traditional ecological knowledge, biodiversity, the wellbeing of local people, a unique biocultural landscape, specific socio-natural relations, and identities.

This notwithstanding, the *chinampa* system has shown remarkable resilience, surviving for more than 700 years, showing *chinamperos'* adaptation ability and creativity [21]. The people of Xochimilco have resisted anti-peasant agrarian policies, unfair competition, and a lack of recognition of their traditional ecological knowledge [19]. A strong agrarian identity, the sense of pride and autonomy, and a sense of place are part of the reasons not to abandon *chinampa* production [37,40]. However, the rate of *chinampa* abandonment calls for a real commitment that stems from the recognition of its importance.

The system has undergone significant changes throughout its history, leading to new states. The main drivers for such changes were proposed by Jiménez et al. [21] as a subject of public policies. However, the CRM project is meant to become a driver for the restoration of the socioecological dynamics of the wetland, allowing both biodiversity and agricultural producers to thrive. Unlike other projects and policies, the CRM is envisaged as an integral transdisciplinary effort to change the current trends of both the wetland and the *chinampa* system. Therefore, evaluating its contribution and the challenges it faces vis a vis the major driving forces of change involved in this socioecosystem is central to the development of strategies to address its viability. In the following sections, we discuss the role of the CRM concerning each one of these key drivers.

4.1. Water Quality

The most critical challenge for *chinampa* producers is water quality. Our results show that the presence of fecal coliforms is reduced in the water of CRM canals and in lettuces from CRM *chinampas*, in both the dry and rainy seasons, except for the presence of *E. coli* in the water in the rainy season. This may be the result of the reduced water circulation in the CRM canals produced by rustic filters combined with the suspension of the lakebed soil. The Mexican regulation in force for the reuse of treated wastewater [27] points out that the number of indicator bacteria must be $<10^3$ CFU/100 mL. According to Mexico City's regulation for agroecological production [49], the water used for cultivation must comply with the provisions of the NOM-003-SEMARNAT-1997 [27]. Therefore, the water around CRM *chinampas* meets the bacterial parameters of both regulations. For lettuces, indicator bacteria were found in an acceptable concentration, as indicated in current regulations [44]. Interestingly, during the dry season, bacteria were not detectable in the lettuce. It would be important to investigate the role of solar radiation in preventing the bacterial presence in these vegetables during the dry season.

However, the heavy metals in products such as lettuce exceed the concentrations allowed for mercury, chromium, and copper [46]. These contaminants probably cannot be controlled by *chinamperos*, as they are not linked to their production practices, and their origin is unknown. Thus, the intervention of the corresponding authorities is necessary to monitor and specify vulnerable products, based on specific analyses, in order to implement mitigation actions. In the near future, a central goal must be the expansion of the study of heavy metals in lettuce produced in *chinampas*, establishing the methods to reduce their presence. Considering our results, it seems that this condition has prevailed at least since 2014 [43,50]. Research on urban agriculture has described similar problems regarding the presence of heavy metals in soil and agricultural products [51–53], and a possible source to be considered is the atmospheric deposition of metals [52].

For the *chinampa* production, it would be necessary to know which products accumulate higher concentrations of heavy metals, and which specific metals they accumulate. This would be a point of departure for proposing—in conjunction with *chinampa* producers, local environmental, health and urban–rural development authorities, and interested organizations—strategies for a transition to producing vegetables that accumulate lower heavy metal concentrations. Furthermore, preparation practices to diminish these contaminants could be developed.

This prevailing condition in the peri-urban area may favor a transition to working on solutions, involving all interested parties, including governmental institutions. Recently (11 March 2022), an update of NOM-001-SEMARNAT [28] came into effect. This regulation implies the requirement of toxicity tests for water quality determination. It is necessary to emphasize that, in facing such a complex problem, neither producers nor authorities can approach a solution independently. A transdisciplinary approach would be necessary, involving academia, *chinampa* producers, social organizations, and authorities in the co-production of technological solutions and adequate management proposals. This is particularly relevant considering that this is not an isolated problem; rather, it is part of a broader and more complex metropolitan system that needs to adapt to new prevailing conditions, and Xochimilco is part of it.

In addition to the generally improved bacteriological safety of water and products derived from the implementation of the CRM, the model has proven valuable in restoring adequate environmental conditions in water canals so that they become suitable habitats for native biodiversity [12]. Two years after the restoration of the canals, they attain the restoration of the habitat to sustain native biodiversity. During this period, contaminants, sediments, and salts are reduced within the canals. From that moment on, the canal can maintain the habitat of the canals as they were before the disturbance. The CRM contributes by improving water quality and expanding habitats suitable for native biodiversity. The CRM has the potential to make a larger contribution to socioecosystem health if more *chinamperos* and abandoned *chinampas* are incorporated and the project increases in scale. However, it is crucial to consider that the water problem in Xochimilco is multidimensional and operates at a broader spatial and political scale. A decided intervention of governmental institutions to construct a coherent, participatory, and integral program to address the water quality of Xochimilco is urgently required.

4.2. Existing Markets for Chinampa Products

Agroecological production in *chinampas* is challenging under prevalent conditions. However, this situation is compounded by the disadvantageous insertion of producers into the agri-food system of Mexico City. The system is dominated by large-scale transnational companies, large-scale monopolies, intermediaries, and hoarders [39]. A large part of CRM production is still directed toward conventional markets. Producers must face unfair competition, low product prices, and insufficient governmental support.

Alternative/green commercialization spaces are the ideal niche for CRM *chinampa* production. These spaces have different profiles: some are articulated to elite healthy "gourmet" food discourses, where organic food is preferred [39]. As our results show, others promote solidarity in consumption and the formation of producer–consumer networks, recognize diverse production values, and even view their work as a form of resistance to the dominant agri-food system. Commercialization networks closely follow these diverse profiles; therefore, how and with whom producers are related for commercialization purposes are vital regarding how their products and production practices are valued.

Generally, agroecological *chinampas* produce vegetables of higher quality than conventional production; however, a better articulation with alternative markets is necessary in order to increase profitability and producers' income. This is a key factor in preventing *chinampa* abandonment, with all the losses this entails [21,37,40]. However, this articulation faces challenges, like the costs of fees and transportation and the fact that these spaces are scant, highly competitive, and—for some producers—inaccessible. There is also a reluctance to consume Xochimilco products based on a generalized idea of their lack of safety. In this sense, sensibilization campaigns for consumers, strengthening the relationship between producers and consumers, and developing flexible markets are necessary, considering that *chinampa* production cannot meet organic standards.

The incorporation of producers and abandoned *chinampas* into agroecological production is necessary, as well as the expansion of market opportunities. However, scaling production without constructing robust organization processes involves several risks, such as losing control over the production process and the concentration of benefits outside the *chinampa* by more powerful actors. There is even the risk of outside agents renting or purchasing *chinampas* to produce agroecological products, which leads to questions over the reproduction of agroecological practices devoid of historical and cultural roots and disarticulated from *chinampa* livelihoods and meanings. We consider this central to making *chinampería* viable for *chinamperos*, but this goal may also face the additional challenge of a lack of involvement of local young people in agricultural activities.

Creating accessible and flexible alternative markets with the collaboration of local governmental institutions, other interested organizations, and collectives is necessary. Strong communication efforts are also essential in order to strengthen the recognition of the ecological, sociocultural, and economic role of traditional agroecological production in the *chinampa* system by society as a whole. Additionally, this recognition could take the form, as suggested by Torres-Lima et al. [35], of governmental interventions such as minimum income payment for urban agroecological producers under high pressures; a payment for environmental services for the conservation and natural restoration of the wetland, and the integrity of *chinampas*; and financing for hydraulic and agricultural irrigation, agroproductive rehabilitation, infrastructure, and equipment. On the other hand, governmental institutions should disincentivize the growth of other economic activities that negatively affect the ecological conditions of the wetland, which is also vital for the maintenance of agroecological production and biodiversity. Furthermore, although it would be of high political complexity, halting the expansion of irregular settlements and negotiating strategies for managing sewage and solid wastes in those areas has become necessary for the improvement of production and articulation to alternative markets.

4.3. Social Organization in Favor of Traditional Agriculture

The CRM project seeks to promote local agroecological production. This, in turn, can potentially improve short commercialization chains, thus reducing the environmental and economic impact of the city's agri-food system [54,55] and promoting the food sovereignty of Xochimilco and the city [56,57]. Articulating with alternative markets is still incipient, and requires strong local social organization.

Commercialization and articulation in markets mainly involve individuals and family groups, who may or may not be linked to agri-food networks. The prevalence of individualism and the limitations for collective action in this context have been previously documented [40]. This atomization increases the vulnerability of producers of intermediaries and the inability to negotiate transaction conditions and resist other processes that affect them. Power asymmetries between *chinampa* producers and other actors could be reduced by strengthening the producers' organization, leading to increased negotiation and resistance abilities. Even stronger collectives might be formed by integrating producers and consumers, as Torres-Lima et al. [35] suggest, to encourage the flow of goods and services, and to pressure adequate governmental measures for the improvement of production conditions, such as water quality, fair prices, and the opening of spaces of commercialization.

4.4. Local Effects of Global and Regional Forces

The CRM—along with the committed work of *chinampa* producers—has contributed to the improvement of the overall water quality where it has been implemented. Once the heavy metal concentration decreases, the CRM *chinampas* produce high-quality products, and the canals surrounding them become suitable habitats for hosting native biodiversity. Recognizing the value of *chinampa* producers, their knowledge, and their practices has played an important role in their involvement in the project, where their identity and pride as agricultural producers come into play.

Despite the contribution of the CRM, many of the challenges described in this study limit the conservation of the wetland and the expansion and improvement of agroecological *chinampa* production. Some of these are issues that need attention and the work of *chinampa* producers in collaboration with collectives, commercialization networks, academics, and local governmental institutions; in particular, producers' cohesion and organization, as well as strengthening their financial and negotiation abilities. Furthermore, the continuing effort of constructing and enhancing commercialization and collaboration networks is central. These processes may reduce the current asymmetries that characterize their relations with more powerful external actors, and may improve their insertion into existing economic structures.

Other challenges, however, are clearly beyond the scope of the CRM and of the productive practices and actions of *chinampa* producers. These challenges include water quality (encompassing the presence of heavy metals), the ongoing encroachment of irregular settlements, the chaotic development of tourism and other economic activities, and an agri-food system characterized by dominating industrial production, hoarding, low prices for producers, and the accumulation of benefits in few hands. These issues are related to multiple forces operating at broader sociopolitical and economic scales, and as such, are a subject of public policy.

Urgent governmental actions are necessary; these should be based on recognizing the root causes of Xochimilco degradation and the central role of agroecological *chinampa* production in its viability into the future. Improving water quality, halting formal and informal settlement growth, developing strategies to manage sewage and solid wastes from these settlements, disincentivizing economic activities that negatively affect ecological conditions (particularly water quality), supporting agroecological practices, facilitating commercialization, and supporting information campaigns are among the actions required from local governmental institutions. Furthermore, dealing with institutional corruption and clientelism is necessary, as they have been prevalent and have had critical pernicious effects [20,36,37,58].

5. Conclusions

This study addresses the contribution of the CRM to the sustainability of the Xochimilco wetland in relation to some of the main drivers of the transformation of the socioecosystem proposed by Jiménez et al. [21], and the challenges that remain to be solved. The CRM has improved water quality in the canals and extended the suitable habitat of aquatic native biodiversity. Furthermore, the CRM supported and spatially expanded traditional agroecological practices, thus enhancing food product quality. However, research regarding water safety use for irrigation must be deepened. Regarding production, access to markets, and social organization, in 16 years of work with *chinampa* producers, the CRM has supported producers in solving productive problems and improving practices; furthermore, processes of discussion, negotiation, and reflection have been developed, increasing the possibility of collective action. However, clear challenges regarding production, commercialization, and organization strongly limit the model's viability as a strategy to restore the conditions for thriving biotic and human communities. The actions needed in order to face these challenges include strengthening the local social organization, developing financial and negotiation abilities, building networks for production and commercialization, and reaching out and articulating with other agricultural organizations. These actions would increase the possibility of developing collective action and reducing asymmetries vis a vis more powerful actors, thus achieving a less disadvantageous articulation with markets. Some of these challenges can be addressed through the work of *chinampa* producers in collaboration with other committed social actors, such as academia, non-governmental organizations, and solidary networks.

In this study, we also detected some of the main challenges that are clearly out of the reach of *chinampa* producers' actions and practices, and of the CRM. Such challenges are multidimensional and depend on forces operating at broader sociopolitical and economic scales, and are therefore subject to transformation via public policy. Nevertheless, attention should be paid to the inability of various governmental management and conservation projects to change the wetland's socioecological degradation tendencies. Among the main challenges and constraints that must urgently be addressed are water quality (including the accumulation of heavy metals), formal and informal settlement growth, the lack of strategies to manage sewage and solid wastes from these settlements, and the current support of economic activities that negatively affect ecological conditions, particularly water quality.

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