PERSPECTIVE

Adapting Wetland Restoration Practices in Urban Areas: Perspectives from Xochimilco in Mexico City

Luis Zambrano, Miguel Ignacio Rivas, Carlos Uriel-Sumano, Ruben Rojas-Villaseñor, Maya Rubio, Horacio Mena, Diana Laura Vázquez-Mendoza and Armando Tovar-Garza

ABSTRACT

Restoration in urban areas must be approached based on socio-ecosystem dynamics and should include different disciplines to achieve a successful long-term program. These dynamics may generate positive feedback loops that contribute to ecosystem resilience. Understanding the feedback loops is necessary to increase the opportunities for restoration practices to push the system toward stable states where local people benefit from the restoration programs. To highlight the significance of a multi-disciplinary approach, we present the progression of a long-term restoration project in an urban wetland: Xochimilco, a highly perturbed system at the south of Mexico City that still provides several ecosystem services. It hosts a high biodiversity of plants and animals, including *Ambystoma mexicanum* (the Axolotl), a neotenic salamander strongly tied to Mexican culture and a species used in many physiological and genetic research studies. We described an ecosystem depletion feedback loop, starting from the polluted water that lowers crops quality, eventually leading to agricultural abandonment. This opens the area to urban settlements which further pollute the water through sewage. To disrupt this negative feedback loop, we developed the "Chinampa-Refuge" project centered on agriculture production within the wetland and using the axolotl as a flagship species. The restoration process relies upon the establishment of aquatic refuges to increase water quality, a change which benefits native species as well as the crops. This benefit to farmers should make the creation of the refuges more attractive. That, in turn, should increase the number of refuges, and the water quality of the system.

Keywords: axolotl, feedback loop, socio-ecosystem, water quality

Restoration Recap

- Restoration in cities must draw from theory in ecology, as well as sociology and economics.
- Restoration projects must identify variables in feedback loops which redirect the system toward sustainable practices for conservation through economic activities and social interactions.
- Flagship species and traditional land use activities can be critical components in the creation of new feedback loops for restoration.

Most restoration plans and research are based on ecological theory, but as a part of developing sustainable practices other disciplines, such as economics and sociology, are increasingly involved (Biswas et al. 2009). These disciplines help maximize economic benefits and strengthen human interactions with nature (Giddings et al. 2002). These complex multi-directional relationships generate interactions among each variable of the socio-ecosystem dynamics in the restoration actions (Jellinek et al. 2019).

Adopting a socio-ecosystem approach to restoration is particularly necessary in urban areas with highly perturbed systems in which the remnant green spaces provide essential benefits for the citizens (Gregory McPherson 1992, Swanwick et al. 2003). Restoration in cities is particularly challenging since the intense interaction with the human population requires fast, well communicated, and

Color version of this article is available through online subscription at: http://er.uwpress.org

Ecological Restoration Vol. 38, No. 2, 2020
ISSN 1522-4740 E-ISSN 1543-4079

accurate responses (Cilliers 2010). When social and economic interactions are not adequately coupled in a project, any restoration program can collapse, even if built upon a robust ecological method.

Restoration based on a socio-ecosystem approach aspires to do more than recompose nature. It should reconnect urban people with their environment (Millard 2010). This scheme should consider ecological information to implement actions, and evaluate which of these actions mesh with historical and cultural ties to local nature (Cilliers 2010). The coupling of human social and ecosystem dynamics at different scales generates a third complex system that must be understood at a larger scale, which includes all the relevant factors such as social, economic, and ecological elements. Since there is limited research about the socio-economic benefits of restoration in Africa and Latin America (Browne et al. 2018), it is essential to share perspectives on projects within these ecosystems and cultures.

Feedback Loops in Ecological Restoration

As with many systems with multiple variables, the socio-ecosystem presents positive feedback loops (Swanstrom 2008), which are dynamics driving them to stable states (Thomas 1978). Identifying dynamics of feedback loops in ecological restoration activities can be useful since their task is to understand which critical variables have produced the ecological perturbances in need of restoration (Naveh 2005, Mayer and Rietkerk 2006). Once these variables are identified, intervention in the system is plausible by replacing one feedback loop with a new one that places the restoration process on track (Scheffer 1998). These feedback loops are the base of the resilience capacities of the system targeted for restoration (Sundkvist et al. 2005, Swanstrom 2008, Sterk et al. 2017).

Based on these ideas, any restoration process would present benefits to the overall ecosystem only if a critical number of actions occur to shift the system from one feedback loop to the other. This task is difficult in urban societies since the resilience of the socio-ecosystem varies along the urban development process (Elmqvist et al. 2019), giving short time windows for the implementation of successful ecological restoration programs. Waiting for the best timing, plus the time consumed by the restoration project, does not help in urban societies that frequently expect rapid results in restoration campaigns and do not see restoration as a long-term process (Handel 2016).

The second set of difficulties for implementation of restoration projects based on feedback loops is the need for complete understanding of the whole socio-ecosystem in the long term, which varies from place to place. The lack of knowledge of the particularities of the system may drive programs to failure. For example, many integrated conservation and development projects (ICDPs) have had difficulties linking conservation activities to local development in rural areas in the last three decades (Alpert 1996). Some of these projects fail, partly because the design incompletely understands the variables since it is external from the country and the local culture (Chambers et al. 2019). Practitioner should be aware of this risk, and a careful step-by-step program is needed to continually evaluate advances and ascertain the results of each new idea. This can be achieved by adopting a participatory (Cilliers, 2010) and adaptative management approaches, using at least the five principles for collective success in socioecological restoration: backbone support organizations, common agenda, shared measurement, communication, and mutually reinforcing activities (Naiman 2013).

Project Site: Xochimilco

In evaluating these couplings in socio-ecosystem dynamics, we report on a restoration program in an urban wetland (Xochimilco) in Mexico City. The restoration program started 15 years ago. Our initial project design drew only upon ecological theory. To improve success, we subsequently adapted this design to include human social and cultural dynamics. The program aimed to restore this urban wetland area, as well as reduce the probability of future urbanization (VonBertrab and Zambrano 2010). Restoration of the wetland is important because its disappearance may increase the average temperature of the urban area, reduce the number of species in the basin, and increase the waterflood vulnerability of the city (Zambrano et al. 2018).

Wetland History

Mexico City was founded in a five lake system by the pre-Columbian cluster of indigenous cultures (von Humboldt 2014). The dominant culture was the "Mexica," the keystone of the Aztec civilization (Rojas Rabiela 2004). In pre-Columbian times, human settlement started on a peninsula at the central part of the lakes, leaving the food production to the southern area of the lakes (Xochimilco). The agricultural activity in this region used the sediments of the lake to create rectangular islands within the lakeshore to grow plants for food (Feinman and Rabiela 1997). The islands are called "chinampas," and their farmers are called "chinamperos." The proliferation of this agricultural technique generated a large number of islands surrounded by 1–10 m wide canals (Morehart 2012, Gonzalez Pozo et al. 2016). Different sized canals created a maze of waterways that provide water to rinse the crops, sediment to fertilize the soil, and transportation infrastructure for boats used by chinamperos to move and sell their products.

Ecologically, the creation of chinampas has augmented the amount of shore area, increasing the number of habitats for different riparian and aquatic organisms. Species such as *Salix bomplandeana* (willow) helped to stabilize the chinampas edge, and native aquatic plants such as *Zannichlelia*

Figure 1. Representation of the deity Xolotl. Picture obtained from wikimedia.com.

palustris, Ninpahea mexicana, N. gracilis, Typha dominguensis and *T. latifolia* (Lot-Helgueras and Novelo 2004) provide habitat for macroinvertebrates such as crayfish (*Cambarellus montezumae*), fishes (*Chirostoma humboldtianum, Girardinchthys vivipaurs*), reptiles (*Thamnophis eques, Diadophis punctutus, Barisa imbricata*) or amphibians (*Rana tlaloci and Ambystoma mexicanum*) (Rojas Rabiela 2004). These plants and animals are the habitat and food of more than 100 species of aquatic birds, like *Pelicanus erythoronrhynchos, Phalacrocorax brasilanus, Fulca americana, Ardea alba, Recurvirostra americana* (Ayala-Perez et al. 2013). As a consequence, instead of reducing the biodiversity of the region, food production in the chinampas simultaneously increased native species populations (Voss et al. 2015). This Aztec city in pre-Columbian times grew based on the close relationship between "Mexicas" and the riparian and aquatic species from the wetland. Possibly, the most crucial interaction between civilization and nature was the axolotl, *A. mexicanum,* that was considered to be the representation of one of the most important Aztec gods, Xolotl (Figure 1; Bartra 2011).

After the Spanish conquest, the way of managing the wetland in the valley was modified. Pre-Columbians controlled the water in storms thorough overflows with dams and regulatory canals and wetlands, while colonial management drained the valley with extensive sewage infrastructure (Candiani 2014). Over the following centuries, a slow but steady drying-out process of the five lakes took place (Vitz 2019). The area now is mainly covered by urban settlements of Mexico City, leaving a few small wetlands. Despite the reduction, the wetlands still have significant capacity for food production and hosting aquatic biodiversity (González and Torres 2014). One of the last remnants is Xochimilco (Figure 2), which occupies only 2% of the original five lake system (Zambrano et al. 2009). This remnant was preserved because it lies at the lowest altitude of the city, which makes it vulnerable to floods, and because it still produced food for the city (Figure 3).

Wetland Perturbation

In the last 60 years, this remnant wetland suffered from deep urbanization pressure and changes in the hydraulic regime (Sosa-Rodriguez 2010). Trends in the global food production market during the Green Revolution focused on maximizing agricultural yield (Conway and Barbier 2013). This program encouraged the homogenization of production to make plant fertilization more efficient, reduce plagues, and promote cropping. Traditionally, local farmers used to produce "milpa," which is multi-species planting (corn, zucchini, and beans) within the same area. Industrialization allowed the cultivation of a single crop, reducing plant heterogeneity and the possibilities of local feedback interactions between ecosystems and agriculture (Nyström et al. 2019). Consequently, there has been an abandonment of agriculture production in the chinampas, and many of them are unproductive or used for other activities such as tourism or football fields (Merlín-Uribe et al. 2013a). The few productive chinampa*s* that still function use pesticides and fertilizers that lixiviate to the water, killing most of the invertebrates and damaging food web systems (Zambrano et al. 2010a). Consequently, native species populations are failing, and the most iconic of them, the axolotl, is categorized as Critically Endangered in the wild (Contreras et al. 2009).

Ecologically-Centered Restoration Project Design

There have been many attempts to restore this wetland, but most have focused on creating infrastructure to attract tourism. None of these early attempts considered the ecosystem dynamics with the native species. Our approach differed from previous ones, creating a restoration program based on the understanding of the axolotl survival threats and using it as a flagship species (Zambrano et al. 2014). This salamander is notorious as an essential key for Mexican culture. Internationally, it is a highly valued species because of its biological attributes such as neoteny, tissues, and organs regeneration capacities and large DNA (Voss et al. 2015, Smith et al. 2018). This species helped to evaluate the problems of the whole wetland. Biologically, the axolotl threats stem from three factors. 1) Exotic fish introduction—Carp (*Cyprinus carpio*) and Tilapia (*Tilapia nilotica*) overpopulate Xochimilco canals after being

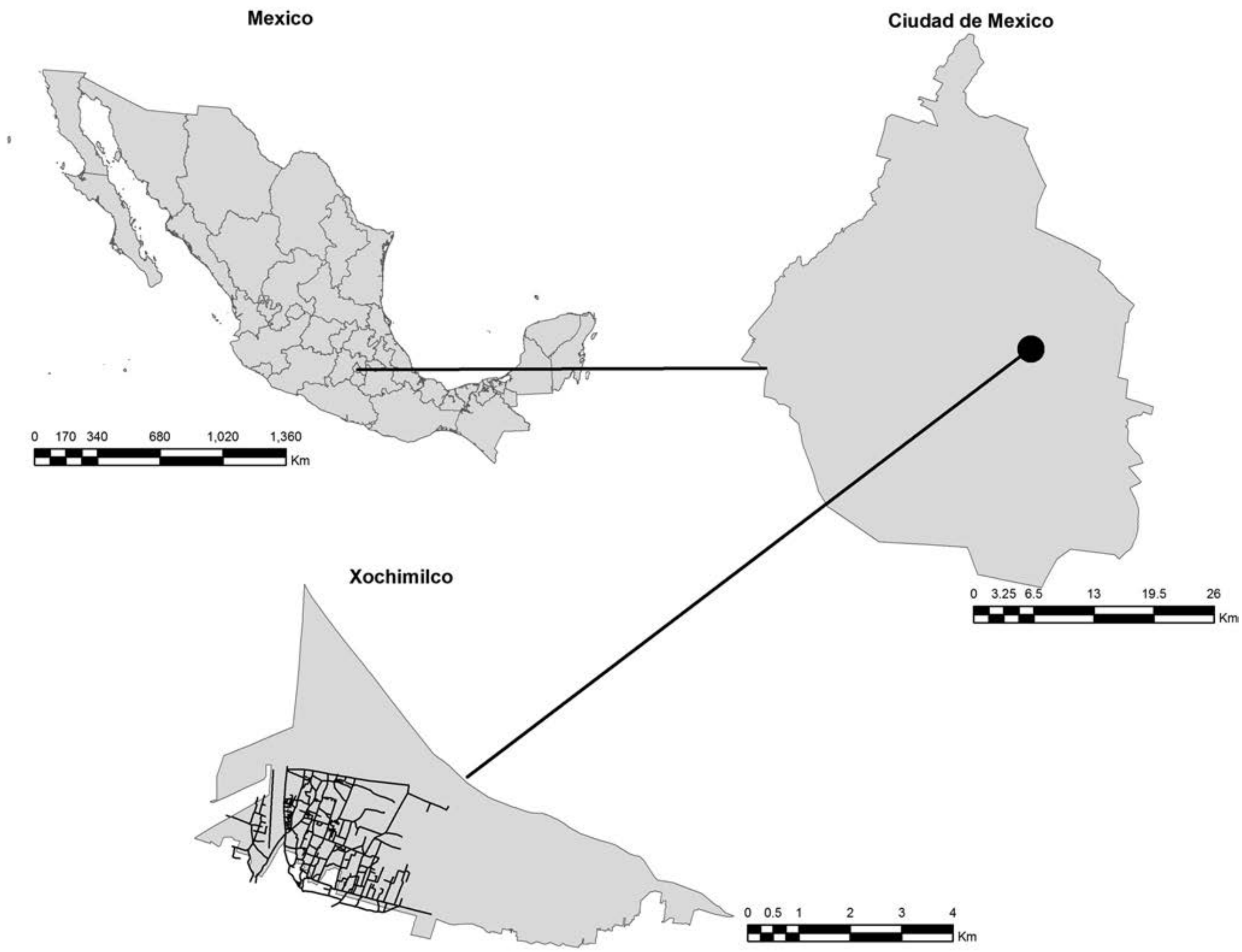

Figure 2. Xochimilco located within Mexico City.

introduced in 1980 (Bustamante Castellanos 2013). Both species can predate axolotls at different egg-juvenile stages and compete for food (Zambrano et al. 2010b). 2) Water quality—Sewage from urban settlements, fertilizers, and pesticides modify the water quality of Xochimilco, which is not homogenous (Zambrano et al. 2009). Water quality seems to correlate with the presence of axolotls in different areas of Xochimilco (Contreras et al. 2009). 3) Urbanization—Axolotls seem stressed by human presence (Zambrano pers obs). For example, urban areas close to canals have higher levels of noise and the axolotl seems to avoid those regions (Contreras et al. 2009).

After identifying the threats, our proposed restoration plan was a program called "Axolotl Refuge." This program used the maze of canals generated by the chinampas construction in the wetland system. The small aquatic distance between two chinampas is useful to build water filters that work as barriers for canals, making them free of exotics and improving water quality for axolotls. These canals become a refuge for axolotls to avoid the mentioned threats (Tovar Garza 2014). The filter is 100 cm wide with stones and emergent aquatic plants. The materials within the filter can improve the quality of the water that enters the canal (Valiente et al. 2010). The siting of these refuges must occur in canals surrounding the chinampas that still work with traditional techniques, avoiding fertilizers and pesticides. Since these filters only reduce pollution and invasion by exotics fish that cannot pass through them, they do not isolate the canal from the rest of the water. The semi-impermeable filter allows native species (mostly small organisms or amphibians) to enter, benefiting from better water quality and finding refuge from the exotics (Ibarra et al. 2013).

To test this restoration program, for six-years (2010–2016) we created more than 20 different experimental refuges, varying from 50 m to 300 m length and from 1 to 4 m wide. We observed the following results. Once the first refuges were in place, we noticed that native species recolonization delayed the restoration process. Therefore, we generate a translocation program of native species, which restored canals in six months (Tovar Garza 2014). This created a native food web structure with a higher abundance of zooplankton (Chaparro-Herrera et al. 2011). Insects and macroinvertebrates, such as crayfish, survived

Figure 3. Traditional farming in Xochimilco with multiple crops. *(Image credit: Luis Zambrano)*

and reproduced (Zambrano et al. 2015). This initial restoration program showed that Xochimilco canals can be highly resilient and return to native species after modifying only two variables: exotics and water quality (VonBertrab and Zambrano 2010, Tovar Garza 2014). Even axolotls reacted in weeks to better conditions. They increased their body weight (unpublished data) and during their reproductive season (in cold weather) laid eggs that were not subjected to exotic fish predation, which suggested a potential population increase within the refuge. The refuge became the habitat for all natives to survive the hostile environment generated by exotics and water pollution. Restoration based on the modification of a critical variable that triggers a modification of the rest of the ecosystem is typical (Rietkerk et al. 2004) in aquatic environments. For example, the reduction of zooplanktivorous fish in northern European shallow lake generates a significant change in the food web structure that altered turbidity of the water (Scheffer et al. 2001, Scheffer and Carpenter 2003). In shallow tropical systems, the abundance of benthivorous fish is highly related to sediment resuspension that also modifies the water (Zambrano and Scheffer 2001, Scheffer et al. 2003).

The Socio-Ecosystem Restoration Project Design

Although both chinamperos and academics shared the general goal of the preservation of Xochimilco, the particular goals of each player were different (VonBertrab and Zambrano 2010). The chinamperos' main goal was to generate better economic benefit from their agriculture work, while scientists looked for ecological knowledge generation (VonBertrab 2013). Therefore, although the refuges were planned considering local producers, the chinamperos' participation was limited since they were enlisted to fulfill the scientific research goals without considering their own needs. The focus of the restoration program was based on the axolotl, using the local producers as mere guardians of the habitat to increase the amphibian capacity. In consequence, the Axolotl Refuge program lacked a critical variable to be sustainable.

Focusing only on the ecological dynamics was the primary constraint of the Axolotl Refuge program because the improvement of the axolotl's habitat proved to be costly and time consuming for local farmers. Individual

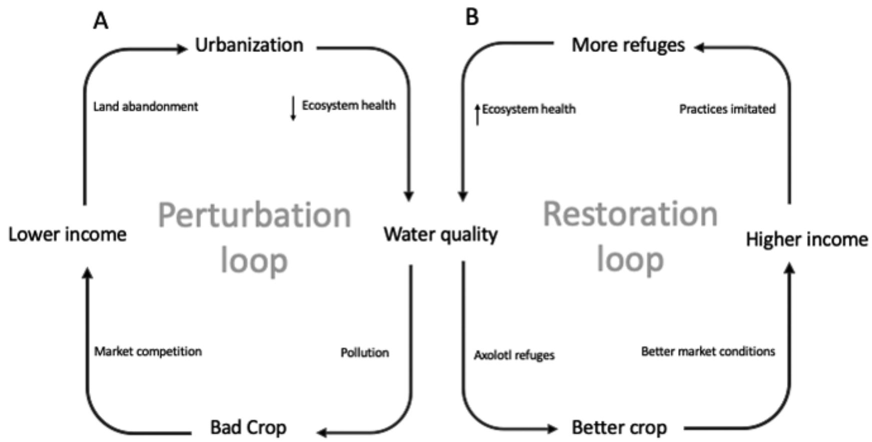

Figure 4. Feedback loops that have generated Xochimilco deterioration (A) and the restoration process feedback loop based on the Chinampa-refuge program (B).

efforts from chinamperos were well-intentioned, but insufficient to restore the wetland. This happened partly because the restoration efforts depended on the good will of chinamperos that could change at any moment, and partly because the Axolotl Refuge needed financial and time resources from farmers with limited resources in both areas. A restoration project in this agricultural area based only on the ecological premise of species protection would ultimately fail without a tangible benefit for the people implementing it.

Once we determined that the original program design could not support a long-term refuge, the project focus was modified from centering only on the ecological interactions, to centering upon the interaction between local farmers, their production, and the axolotl habitat. Based on this new focus, the project changed its name to the Chinampa-Refuge program. A series of workshops hosted by chinamperos and academics from 2015–2017 helped to generate this program. The main result of these workshops developed from the idea that Xochimilco has been hosted traditional farming for 2000 years. Only in the last decades has it changed to other activities causing urbanization and therefore restoration of the area should be attached to the restoration of the traditional agriculture. The redesigned program takes a wider approach to intervention by evaluating the feedback loops of the whole system that are generating the Xochimilco and axolotl's depletion (Contreras et al. 2009). By refocusing the program, we identified key socio-ecosystem variables that need to be addressed to break this cycle of depletion. The implementation of refuges now depends upon variables such as the increasing the income of the local farmers and the social recognition of the chinamperos as food providers and guardians of the wetland ecosystem. In other words, social recognition and direct returns of conservation must be included for local people (Xu et al. 2007, Mesquita et al. 2010). To start this dynamic it will be necessary to subsidize the few chinamperos willing to take the risk of creating the refuges.

Changing the feedback loops

At the beginning of the manuscript, we described the relation of the feedback loops and resilience, which need to be understood to evaluate the pathways for restoration. This described the current feedback loop in the socio-ecosystem of Xochimilco. A crucial first variable for the change in the land use in Xochimilco is addressing water quality because it initiates the perturbation loop (Figure 4a). Since treatment plants now supply the wetland with water containing domestic sewage, pesticides, and fertilizers, the quality is variable and sometimes inadequate (Mazari-Hiriart et al. 2008). Water pollution affects agricultural production, which is the crucial second variable: a bad crop. The Xochimilco products sold in the market are competitively handicapped against other regions because the public believes these products are polluted. This creates the crucial third variable: low income for local producers in Xochimilco. In response, the local farmers either: a) use greenhouses, including fertilizers, pesticides, and water from the aquifer to distinguish their products from chinampas (Merlín-Uribe et al. 2013b), or b) abandon the land to another urban jobs in the area. The abandonment of the land generates an opportunity for illegal urban settlements that empty sewage directly to the water system (Merlín-Uribe et al. 2013a). This urbanization process is the fourth variable (Figure 5), which reduces the ecosystem's health, completing the perturbation feedback loop that restarts with the reduction of water quality (Figure 4a). If this loop continues, there may be a complete urbanization of Xochimilco in a short time (Merlín-Uribe et al. 2013a).

The Chinampa–Refuge Program for restoration can break this perturbation loop (Figure 4a) by focusing on integrating resource management and promoting a restoration loop (Figure 4b) (Banson et al. 2016). The path of change is straightforward because it employs ecological practices already known about canal refuges for axolotls around the chinampas. The refuge for axolotls and the native species require a filter to avoid the presence of exotics such as carp and tilapia, and also to increase water

Figure 5. Urbanization of the wetland. *(Image credit: Ruben Rojas)*

quality for the survival of the native species (Valiente et al. 2010). Therefore, the restoration loop we propose begins with water quality as a crucial first variable (Figure 4b). The Refuge itself is no longer the only goal, but a trigger for a general program to increase the water quality that helps the local biodiversity to survive. The axolotl is being promoted as a flagship species to ensure that products from chinampas with an axolotl refuge is pollutant-free.

The second key element is a better crop (Figure 4b). The restoration of the habitat generates incentives for integrated management of the system at two different levels: economically, more than 80% of the citizens are willing to pay higher prices for a product that grows in a system that conserves the axolotl and the wetland (Vazquez-Mendoza 2018), and socially the interactions among local producers increase the sense of belonging to a group practicing traditional agriculture (VonBertrab and Zambrano 2010). A local certification is now being promoted to increase the possibilities of this growing market based on these two levels.

All the process will support the crucial third variable: a better position in the market will help promote traditional agriculture as economically viable and attractive for other chinamperos. The last and crucial fourth variable is an increase in the numbers of refuges, which will result in more filters, creating large-scale maze-like habitat for axolotls. This maze should increase the species survival capacities, the ecosystem health, and reduce illegal human settlements and greenhouses production; this will shift the perturbation feedback loop to a desirable and resilient socio-ecosystem throughout the restoration feedback loop (Figure 4b). The new program started with five chinamperos in 2017 allowed to sell their product in a local market. In 2020 there are close to 25 chinamperos involved that are creating new strategies to attract more framers.

Other variables are attached to both perturbation and restoration loops. For example, filters must be simple and easy to install and maintain. We already know that rustic filters are capable of increasing the water quality enough for native habitat and safe food production (Tovar Garza 2014). For the farmers that want to create a refuge, these filters should be easy to install and maintain with local material. Otherwise, incorporating the filters would be discouraging to a chinamperos with already intensive labor demands.

A second variable attached to both feedback loops is the opening of a flexible market for these products in the city. This trend goes against a modern market that requests constant and homogenous products supply (Khoury et al. 2014) and therefore is one of the biggest challenges (Nyström et al. 2019). Few chinamperos are able to sustain a traditional market request, such as constant production. Many social and environmental variables may occur to reduce planned agricultural production (e.g., unexpected rains or cold days). Therefore, the market portion of the feedback loop is full of disagreements between consumers and producers that jeopardize the entire relation, and consequently, the restoration program. The number of producers must be large enough to meet the demand of urban society concerned about its wetland. This would stabilize the feedback loop. However, it is unknown how many chinamperos would be needed to meet the demand for food for this particular market. More studies must be done to understand this interaction.

Discussion

The Chinampa–Refuge program can only be successful if it achieves enough refuges to move the whole system from the perturbation feedback loop to the restoration feedback loop. Making this shift requires a structural and cultural change in Mexico City society that includes all stakeholders—from the scientific community and chinamperos to the city government and financial support providers. In delivering restoration, flexibility is a keyword since actions should constantly be changing in the pursuance of the goals generated at the beginning of the project (Handel 2018). These changes are partly the reason most people have a confused understanding of sustainability actions (which are implicit in restoration processes) as being a goal rather than process (Holling et al. 1998).

The opportunities to change from one cycle (the perturbation feedback loop) to another (the restoration feedback loop) is not only dependent on complex ecosystem interactions, but on timing interventions. Within the dynamics of a socio-ecosystem, similar phenomena are in operation that inform the best time to intervene in the feedback loops. The development of each city is dynamic, and variables gain or lose importance over time. This provokes changes in the resilience capacity in which the possibilities of switching to another stable state varies in different periods of urban development (Elmqvist et al. 2019). The modification of the variables that make more accessible the switch from one feedback loop of perturbation to another of restoration should be part of the ecological restoration based on a socio-ecosystem approach.

In the case of Xochimilco, the social concern about the future of the axolotl and its ecosystem are a trigger that could help to change from one feedback loop to another by using the axolotl refuges and modifying the variable in common: the water quality. This can change throughout the implementation of a Chinampa-Refuge for axolotls' program. It is possible to generate the social opportunities for creating a juncture at which we can redirect the feedback loops.

Each urban ecosystem is particular in its own history and ecological interactions. The ecological restoration of each socio-ecosystem, therefore, generates feedback loops that must be characterized to help shape the implementation of any program. Theory and data from diverse academic fields are essential to informing our understanding of critical variables in complex socio-ecosystem interactions.

Acknowledgments

This manuscript was elaborated thanks to the scholarships provided by Consolidación of CONACYT and PASPA program of DGAPA, UNAM. Most of the research has done under the financial support of Secrataria de Cultura, Sitios y Monumentos, and Delegación/Alcaldía de Xochimilco.

References

Alpert, P. 1996. Integrated Conservation and Development Projects. *BioScience* 46:845–855.

Ayala-Perez, V., N. Arce and R. Carmona. 2013. Spatio-temporal distribution of wintering aquatic birds in the Cienega de Tlahuac, Chalco lacustrine plain, Mexico. *Revista Mexicana De Biodiversidad* 8:327–337.

Banson, K.E., N.C. Nguyen and O.J.H. Bosch. 2016. Using system archetypes to identify drivers and barriers for sustainable agriculture in Africa: A case study in Ghana. *Systems Research and Behavioral Science* 33:79–99.

Bartra, R. 2011. *Axolotiada*. Mexico: Fondo de Cultura Económica.

Biswas, S.R., A.U. Mallik, J.K. Choudhury and A. Nishat. 2009. A unified framework for the restoration of Southeast Asian mangroves-bridging ecology, society and economics. *Wetlands Ecology and Management* 17:65–383.

Browne, M., G. Fraser and J. Snowball. 2018. Economic evaluation of wetland restoration: A systematic review of the literature. *Restoration Ecology* 26:1120–1126.

Bustamante Castellanos, E. 2013. Evaluación del potencial pesquero de la tilapia (*Oreochromis niloticus*), en la zona lacustre de Xochimilco, México DF. BS thesis, Universidad Nacional Autonoma de Mexico.

Candiani, V.S. 2014. *Dreaming of Dry Land Environmental Tranformation in Colonial Mexico City*. Stanford, CA: Stanford University Press.

Chambers, J., M. Del Aguila Mejía, R. Ramírez Reátegui and C. Sandbrook. 2019. Why joint conservation and development projects often fail: An in-depth examination in the Peruvian Amazon. *Environment and Planning E: Nature and Space* 0:1–34.

Chaparro-Herrera, D.J. de, S. Nandini, S. S. S. Sarma and L. Zambrano. 2011. Feeding behaviour of larval *Ambystoma mexicanum*. *Amphibia-Reptilia* 32:509–517.

Cilliers, S. 2010. Social aspects of urban biodiversity—An overview. Pages 81–100 in P.W. and J.G.K. Norbert Müller (eds), *Urban Biodiversity and Design*. London, UK: Blackwell Publishing Ltd.

Contreras, V., E. Martínez-Meyer, E. Valiente and L. Zambrano. 2009. Recent decline and potential distribution in the last remnant area of the microendemic Mexican axolotl (*Ambystoma mexicanum*). *Biological Conservation* 142:2881–2885.

Conway, G.R. and E.B. Barbier. 2013. Page 195 in *After the Green Revolution: Sustainable Agriculture for Development*. London, UK: Taylor and Francis Ltd.

Elmqvist, T., E. Andersson, N. Frantzeskaki, T. McPhearson, P. Olsson, O. Gaffney, et al. 2019. Sustainability and resilience for transformation in the urban century. *Nature Sustainability* 2:267–273.

Feinman, G.M. and T.R. Rabiela. 1997. Presente, pasado y futuro de las chinampas. *The Hispanic American Historical Review* 77:328–329.

Giddings, B., B. Hopwood and G. O'Brien. 2002. Environment, economy and society: Fitting them together into sustainable development. *Sustainable Development* 10:187–196.

González, E. and C. Torres. 2014. La sustentabilidad agrícola de las Chinampas en el valle de México: caso Xochimilco. *Revista Mexicana de Agronegocios*. 699–709 doi: 10.22004/ag.econ.173283.

Gonzalez Pozo, A. and F. Roberto Chiapa. 2016. Las chinampas: patrimonio mundial de la Ciudad de México. *Revista de Patrimonio: Economía Cultural y Educación para la Paz (MEC-EDUPAZ)* 1:158–190.

Gregory McPherson, E. 1992. Accounting for benefits and costs of urban greenspace. *Landscape and Urban Planning* 22:41–51.

Handel, S.N. 2016. The Seven Habits of Highly Effective People Who Want to Do Ecological Restoration. *Ecological Restoration* 34:171–172.

Handel, S.N. 2018. The Digital and the Organic. *Ecological Restoration* 9:167–168.

Holling, C.S., F. Berkes and C. Folke. 1998. Science, sustainability, and resource management. Pages 350–352 in *Linking Social and Ecological Systems: Management Practices and Social Mechanism for Building Resilience*. Cambridge, UK: Cambridge University Press.

von Humboldt, A. 2014. *Ensayo Político sobre el Reino de la Nueva España*. Sixth edition. Mexico City, Mexico: Porrua.

Ibarra, A.A., L. Zambrano, E.L. Valiente and A. Ramos-Bueno. 2013. Enhancing the potential value of environmental services in urban wetlands: An agro-ecosystem approach. *Cities* 31:438–443.

Jellinek, S., K.A. Wilson, V. Hagger, L. Mumaw, B. Cooke, A.M. Guerrero, et al. 2019. Integrating diverse social and ecological motivations to achieve landscape restoration. *Journal of Applied Ecology* 56:246–252.

Khoury, C.K., A.D. Bjorkman, H. Dempewolf, J. Ramirez-Villegas, L. Guarino, A. Jarvis, et al. 2014. Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences* 111:4001–4006.

Lot-Helgueras, A. and A. Novelo. 2004. *Iconografía y Estudio de las Plantas Acuáticas de la Ciudad de México y sus Alrededores*. Mexico City, Mexico: Universidad Nacional Autonoma de Mexico.

Mayer, A. and M. Rietkerk. 2006. The dynamic regime concept for ecosystem management and restoration. *BioScience* 54: 1013–1020.

Mazari-Hiriart, M., S. Ponce-de-León, Y. López-Vidal, P. Islas-Macías, R.I. Amieva-Fernández and F. Quiñones-Falconi. 2008. Microbiological implications of periurban agriculture and water reuse in Mexico City. *PLoS ONE* 3:1–8.

Merlín-Uribe, Y., A. Contreras-Hernández, M. Astier-Calderón, O.P. Jensen, R. Zaragoza and L. Zambrano. 2013a. Urban expansion into a protected natural area in Mexico City: Alternative management scenarios. *Journal of Environmental Planning and Management* 56:1–14.

Merlín-Uribe, Y., C.E. González-Esquivel, A. Contreras-Hernández, L. Zambrano, P. Moreno-Casasola and M. Astier. 2013b. Environmental and socio-economic sustainability of chinampas (raised beds) in Xochimilco, Mexico City. *International Journal of Agricultural Sustainability* 11:216–233.

Mesquita, C.A.B., C.G.D. Holvorcem, C.H. Lyrio, P.D. De Menezes, J.D. Da Silva Dias and J.F. Azevedo. 2010. COOPLANTAR: A Brazilian initiative to integrate forest restoration with job and income generation in Rural Areas. *Ecological Restoration* 28:199–207.

Millard, A. 2010. Cultural Aspects of Urban Biodiversity. Pages 56–80 in N. Muller, P. Werner and J.G. Kelcey (eds), *Urban Biodiversity and Design.* New York, NY: Wiley-Blackwell doi:10.1002/9781444318654.

Morehart, C.T. 2012. Mapping ancient chinampa landscapes in the Basin of Mexico: A remote sensing and GIS approach. *Journal of Archaeological Science* 39:2541–2551.

Naiman, R.J. 2013. Socio-ecological complexity and the restoration of river ecosystems. *Inland Waters* 3:391–410.

Naveh, Z. 2005. Epilogue: Toward a transdisciplinary science of ecological and cultural landscape restoration. *Restoration Ecology* 13:228–234.

Nyström, M., J.B. Jouffray, A.V. Norström, B. Crona, P. Søgaard Jørgensen, S.R. Carpenter, et al. 2019. Anatomy and resilience of the global production ecosystem. *Nature* 575:98–108.

Rietkerk, M., S.C. Dekker, P.C. De Ruiter and J. Van De Koppel. 2004. Self-organized patchiness and catastrophic shifts in ecosystems. *Science* 305:1926–1929.

Rojas Rabiela, T. 2004. Las cuencas lacustres del Altiplano Central. *Arqueología Mexicana* 12:20–27.

Scheffer, M. 1998. *Ecology of Shallow Lakes*. London, UK: Chapman and Hall.

Scheffer, M., S.R. Carpenter, J.A. Foley, C. Folke and B. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* 413:591–596.

Scheffer, M. and S.R. Carpenter. 2003. Catastrophic regime shifts in ecosystems: Linking theory to observation. *Trends in Ecology and Evolution* 18:648–656.

Scheffer, M., R. Portielje and L. Zambrano. 2003. Fish facilitate wave resuspension of sediment. *Limnology and Oceanography* 48:1920–1926.

Smith, J.J., N. Timoshevskaya, V.A. Timoshevskiy, M.C. Keinath, D. Hardy and S.R. Voss. 2018. A Chromosome-Scale Assembly of the Enormous (32 Gb) Axolotl Genome. *bioRxiv* DOI 10.1101/373548.

Sosa-Rodriguez, F.S. 2010. Impacts of water-management decisions on the survival of a city: From ancient Tenochtitlan to modern Mexico City. *International Journal of Water Resources Development* 26:675–687.

Sterk, M., I.A. van de Leemput and E.T. Peeters. 2017. How to conceptualize and operationalize resilience in socio-ecological systems? *Current Opinion in Environmental Sustainability* 28:108–113.

Sundkvist, Å., R. Milestad and A.M. Jansson. 2005. On the importance of tightening feedback loops for sustainable development of food systems. *Food Policy* 30:224–239.

Swanstrom, T. 2008. Regional resilience: A critical examination of the ecological framework. Univerisity of Californiua Berkeley, Institute of Urban and Regional Development. *Working Paper Series* No. 2008, 07.

Swanwick, C., N. Dunnett and H. Woolley. 2003. Nature, role and value of green space in towns and cities: An overview. *Built Environment* 29:94–106.

Thomas, R. 1978. Logical analysis of systems comprising feedback loops. *Journal of Theoretical Biology* 73:631–656.

Tovar Garza, A. 2014. Determinación de la estructura trófica de refugios experimentales en Xochimilco, México. MS thesis, Universidad Nacional Autonoma de Mexico.

Valiente, E., H. Tovar, A, D. Eslava-Sandoval and L. Zambrano. 2010. Creating refuges for the axolotl (*Ambystoma mexicanum*). *Ecological Restoration* 8:257–265.

Vazquez-Mendoza, D.L. 2018. Etiqueta chinampera: una herramienta para la conservación de Xochimilco y del axolote, Ciudad de México. BS thesis. Universidad Nacional Autónoma de México.

Vitz, M. 2019. *A City on a Lake: Urban Political Ecology and the Growth of Mexico City*. Durham, NC: Duke University Press.

VonBertrab, A. 2013. De tilapias, chinampas y ajolotes: discursos sobre la restauración ecológica en el lago de Xochimilco. PhD dissertation. Universidad Nacional Autonoma de Mexico.

VonBertrab, A. and L. Zambrano. 2010. Participatory monitoring and evaluation of a Mexico City wetland restoration effort. *Ecological Restoration* 8:343–353.

Voss, S.R., M.R. Woodcock and L. Zambrano. 2015. A Tale of two axolotls. *BioScience* DOI 10.1093/biosci/biv153.

Xu, J.Y., L.D. Chen, Y.H. Lu and B.J. Fu. 2007. Sustainability evaluation of the grain for green project: From local people's responses to ecological effectiveness in Wolong nature reserve. *Environmental Management* DOI 10.1007/s00267-006-0113-1.

Zambrano, L., V. Contreras, M. Mazari-Hiriart and A.E. Zarco-Arista. 2009. Spatial heterogeneity of water quality in a highly degraded tropical freshwater ecosystem. *Environmental management* 43:249–63.

Zambrano, L., H. Cortes and A. Merlo-Galeazzi. 2015. Eat and be eaten: reciprocal predation between axolotls (*Ambystoma mexicanum*) and crayfish (*Cambarellus montezumae*) as they grow in size. *Marine and Freshwater Behaviour and Physiology* 48:13–23.

Zambrano, L., A. Ortiz-Haro and K. Levy-Gálvez. 2014. El axolote como especie bandera en Xochimilco. Pages 421–438 in C.A. Gonzalez-Zuarth, A Vallarino, J.C. Jimemez and A.M Pfeng *Bioindicadores: Guardianes de Nuestro Futuro Ambiental*. Mexico: Ecosur.

Zambrano, L., R. Pacheco-Muñoz and T. Fernández. 2018. Influence of solid waste and topography on urban floods: The case of Mexico City. *Ambio* 47:771–780.

Zambrano, L. and M. Scheffer. 2001. Catastrophic response of lakes to benthivorous fish introduction. *Oikos* 94:344–350.

Zambrano, L., E. Valiente and M.J. Vander Zanden. 2010a. Stable isotope variation of a highly heterogeneous shallow freshwater system. *Hydrobiologia* 646:327–336.

Zambrano, L., E. Valiente and M.J. Vander Zanden. 2010b. Food web overlap among native axolotl (*Ambystoma mexicanum*) and two exotic fishes: carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*) in Xochimilco, Mexico City. *Biological Invasions* 12:3061–3069.

Luis Zambrano (corresponding author) Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Ciudad de México 04510. Mexico. zambrano@ib.unam.mx.

Miguel Ignacio Rivas, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.

Carlos Uriel-Sumano, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.

Ruben Rojas-Villaseñor, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.

Maya Rubio, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.

Horacio Mena, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.

Diana Laura Vázquez-Mendoza, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.

Armando Tovar-Garza, Laboratorio de Restauración Ecológica, Instituto de Biología, Universidad Nacional Autónoma de México. Mexico.