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Ecosystem restoration in Mexico: insights on the project planning phase

La restauración de ecosistemas en México: visiones acerca de la fase de planificación de proyectos

Cristina Martínez-Garza[1*], Moisés Méndez-Toribio[2], Eliane Ceccon[3] and Manuel R. Guariguata[4]

[1] Centro de Investigación en Biodiversidad y Conservación, Universidad Autónoma del Estado de Morelos, Cuernavaca, Morelos, México.
[2] Instituto de Ecología, A.C. Red de Diversidad Biológica del Occidente Mexicano, Centro Regional del Bajío, Pátzcuaro, Michoacán, México.
[3] Centro Regional de Investigaciones Multidisciplinarias, Universidad Nacional Autónoma de México, Cuernavaca, Morelos, México.
[4] Center for International Forestry Research (CIFOR), Lima, Perú
*Author for correspondence: cristina.martinez@uaem.mx

Abstract

Background: A deep discussion of the phases of planning by all stakeholders will help to identify the challenges faced by countries that are embarking on large-scale restoration actions to comply with international agreements.

Question: Was the planning phase of restoration projects done according to international guidance? We evaluated six of the eight aspects of the international guidance for the planning phase of restoration projects carried out in Mexico between 1979 and 2016.

Methods: The information about the restoration projects was compiled using a digital survey composed of 137 questions.

Results: Seventy-five projects with a total area of 1,556,840 hectares were analyzed, mainly in temperate, humid, and deciduous forest. More projects measured the baseline with biotic than with abiotic variables, and social variables were seldom evaluated. Most projects aimed to recover biodiversity or ecosystem services, and they identified a reference ecosystem. Planned budgets included mainly field work.

Conclusions: To promote the integration of ecological, social, and economic priorities, landscape restoration is suggested, since it is done at a scale which maximizes the benefits for nature and people. The inclusion of only field work in the budgets may decrease the total cost, but it may jeopardize project success due to poor planning. Careful and detailed planning of a national strategy constructed by all stakeholders that includes restoration of original ecosystems, agroforestry systems (which facilitate social participation and increase land productivity) and patches under natural succession, and investing in highly trained human resources will allow successful compliance with international restoration commitments.

Keywords: ecosystem services, Forest Landscape Restoration, reference ecosystem, remediation, socioecological complexity, unassisted forest regeneration.

Resumen

Antecedentes: Que todos los interesados participen en una discusión profunda de las fases de planeación de la restauración permitirá identificar los retos para realizar proyectos a gran escala y así cumplir con nuestros compromisos internacionales.

Pregunta: ¿La fase de planeación se realizó de acuerdo con la guía internacional? En este trabajo evaluamos, para proyectos realizados en México (1979-2016), seis de los ocho aspectos de la guía internacional de planeación.

Métodos: Se utilizó una encuesta digital con 137 preguntas.

Resultados: Se analizaron 75 proyectos que cubren un área de 1,556,840 hectáreas principalmente en bosques templados, húmedos y deciduos. Más proyectos evaluaron su línea base con variables bióticas que abióticas; las variables sociales rara vez fueron evaluadas. La recuperación de la biodiversidad o los servicios ecosistémicos fueron metas en la mayoría de los proyectos; el ecosistema de referencia se identificó frecuentemente. Los presupuestos incluían principalmente el trabajo de campo.

Conclusiones: Para favorecer la integración de las prioridades ecológicas, sociales y económicas se sugiere el uso de la restauración del paisaje que maximiza los beneficios para la naturaleza y los seres humanos. Considerar solo el trabajo de campo en el presupuesto disminuye los costos, pero impide la correcta planeación. Una estrategia nacional cuidadosamente planeada por todos los interesados y que incluya áreas de restauración, sistemas agroforestales (que facilitan la participación social e incrementan la productividad de la tierra) y áreas bajo sucesión natural, además de la inversión en capacitación, nos permitirá cumplir exitosamente con los compromisos internacionales en materia de restauración.

Palabras clave: Complejidad socioecológica, ecosistema de referencia, regeneración forestal no asistida, remediación, restauración del paisaje forestal, servicios ecosistémicos.

Ecological restoration aims to recover the attributes, function, and conditions of damaged ecosystems (SER 2004). This intervention is vital to environmental conservation given current rates of deforestation; for example, from 2010 to 2015, 7.6 million of hectares were deforested worldwide (FAO 2016). The recovery of large areas of degraded ecosystems has become urgent to reverse the widespread threats of human exploitation of nature (Lamb *et al.* 2005). In March 2019, the United Nations declared the 2021-2030 "Decade for Ecosystem Restoration" (UN 2020), which seeks to promote ongoing initiatives, such as the Aichi Target 15 of the Convention on Biological Diversity (CBD) which calls on countries to restore 15 % of degraded lands by 2020 (CBD 2010). Further, the Bonn Challenge, a global effort promoted by the German Government in 2011, proposes the restoration of 150 million hectares of forest by 2020 and 350 million hectares of forest by 2030 (Bonn-Challenge 2019). Also, the 20x20 Initiative aims to restore 20 million hectares of forests in Latin America by 2020 (Initiative 20x20, 2019). Finally, eight of the 17 sustainable development goals to change our world (UN 2015) may be achieved with restoration activities; for example, goal 17 (life on land) is directly addressed with restoration actions, while goals 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 5 (gender equality), 6 (clean water and sanitation), 16 (peace, justice and strong institutions) and 13 (climate action) may benefit from the implementation of ecosystem restoration. Currently, 16 countries in Latin America have committed to restoration efforts, while two countries have committed to defining a national restoration strategy (Initiative 20x20, 2019). However, by 2016, only four countries had developed national or subnational strategies to implement their restoration targets (Méndez-Toribio *et al.* 2017).

The implementation of a restoration initiative at any scale requires careful planning. Available international guidance on restoration planning includes Section 8 of the Primer of the Society of Ecological Restoration (SER 2004), Section 3 of the International Principles and Standards for the Practice of Ecological Restoration (hereafter "The Standards"; McDonald *et al.* 2016, Gann *et al.* 2019), and the "Practitioner's Guide" by the International Union of Forest Research Organization (Stanturf *et al.* 2017). These documents coincide on several elements that should be included in the planning phase (see Table S1): a) stakeholder engagement-this is principle 1 of "The Standards", as it is recognized that engaging stakeholders ensures benefits for nature and society; b) rationale as to why restoration is needed, which refers to the scope (broad geographic or thematic focus), vision (desired condition) and targets (native ecosystem) of projects; c) ecological description of the site, or the baseline, defined as "*the initial condition of the site at the beginning of the restoration process*". This description may include biotic, abiotic, physiographic, and social elements, as well as the potential for natural regeneration; d) goals and objectives; e) designation and description of the reference ecosystem, if available, based in six key attributes: (i) Absence of threats, (ii) Physical conditions, (iii) Species composition, (iv) Structural diversity, (v) Ecosystem function and (vi) External exchange; f) context assessment, including prioritization; g) explicit plans, schedules and budgets for site preparation, installation and post-installation activities, including a strategy for prompt mid-course corrections (adaptive management); h) monitoring protocols to determine whether targets, goals and objectives will be met and to carry out adaptive management as needed; i) strategies for long-term protection and maintenance of the restored ecosystem; and j) monitoring of an untreated (control) site for comparison.

The objective of this analysis was to evaluate the extent to which the key elements mentioned above are being addressed in the planning phase of restoration projects in Mexico. Here, we assess restoration projects in Mexico over the last 37 years, established by the government, academia, and Non-Governmental Organizations (NGOs) (Méndez-Toribio *et al.* 2018). We include an evaluation of items (b) through (g) above in relation to restoration planning. This analysis will be useful in the preparation of a national strategy for Mexico. Evaluation of item (a) above can be found in Ceccon *et al.* (2020a). We hope that the present analysis will help in identifying the challenges faced by countries that are embarking on large-scale restoration actions to comply with international agreements and prioritize further efforts.

Materials and methods

The data were collected in 2015 and 2016. First, during a workshop entitled "Challenges and prospects to comply with international agreements on Ecological Restoration" (original in Spanish: *Retos y perspectivas para cumplir los acuerdos internacionales en materia de Restauración Ecológica*) held in Mexico City in November 2015, attendees generated a list of actors and discussed how to identify the projects. Several complementary means were used. Second, we carried out a google search using the keywords restaur*, recuper*, restor*, recover* *México*

and *vegetación*. We also consulted directly with people and institutions that carry out conservation actions. Third, we reviewed abstracts from scientific meetings, including the meeting of the Botanical Society of Mexico and Mexican Scientific Society for Ecology since 2002, the 2011 Society for Ecological Restoration meeting held in Yucatán, Mexico, and the First Mexican Symposium on Ecological Restoration in 2014. Fourth, we examined databases of ecological restoration projects including the Global Restoration Network, EcoIndex, databases of the National Council for the Use and Knowledge of Biodiversity (CONABIO), National Institute of Ecology and Climate Change (INECC), and the Mexican network for environmental restoration (REPARA). We also searched online documents and institutional and academic libraries. Finally, we identified 239 entities (people, academic, governmental institutions, and civil society organizations) from the Mexican Conservation Directory (Gutiérrez & Ayala 2013) that mention restoration actions within their mission statements. This broad search identified a sample of 188 projects, which was reduced to 150 by excluding projects: (1) that addressed aquatic or marine rather than terrestrial ecosystems, (2) where information about the diagnostic phase was the only one available, (3) where the responsible person could not be reached and/or technical reports were not available, (4) the digital survey (see below) was not completed during the dates available or (5) institutions did not have relevant information about their projects.

The information was structured using a digital survey composed of 137 questions. This survey format was adapted to the Mexican context from Murcia & Guariguata (2014) in a participatory fashion during the abovementioned workshop. The information from the projects was gathered via LimeSurvey ver. 2.65.0 (www.limesurvey.org). The survey was sent to people involved in the 150 projects mentioned above. Additionally, people and institutions were contacted by phone to verify details. Answers were received for 75 projects implemented from 1979 to 2016 and they were accepted in good faith and without field validation. Although it was not possible to have all 137 answers for all projects, given the exhaustive search, we are confident that this analysis includes a robust and representative sample of restoration efforts for terrestrial ecosystems (Table S2).

The geographical distribution of the restoration projects was defined according to the classification of the Terrestrial Ecoregions of Mexico and elevation belts (INEGI *et al.* 2008). The analysis included information from the *Comisión Nacional Forestal* (CONAFOR, National Forestry Commission). The distribution of CONAFOR's restoration areas was characterized independently of the rest of the projects. This institution has carried out 9,817 projects since 2013 in most Mexican states, all with the same planning phases and objectives; thus, they were considered one large-scale project. The information was organized in Excel® spreadsheets and further processed using the "plyr", "dplyr", "tibble" and "tidyr" libraries of the free access R environment (R Core Team, 2020).

Results

Scope and targets. The total area of the projects analyzed was 1,556,840 hectares. Sixty-seven percent of the projects covered areas < 1,000 ha, 23 % of the projects covered areas from 1,001 to 10,000 ha, and 9 % of the projects covered areas >10,000 ha (Table S3). Seventy percent of the restoration areas established by CONAFOR were in mountain ranges in temperate forest at altitudes > 1,500 m asl (Figure 1). Sixty percent of the projects established by other institutions were in humid and deciduous forest at altitudes < 200 m asl (Figure 2). Most of the projects were established at a landscape (63 %), basin (65 %) or ecosystem scale (45 %).

Ecological description of the site. Baseline. The most frequently identified threat was extensive cattle ranching (53 %), followed by fragmentation (41 %; Table S4). In 52 % of the projects, a baseline was established using biotic, abiotic, physiographic and/or social variables: biotic variables were the most frequently used (43 %), followed by abiotic variables (25 %) and physiographic variables (12 %); social variables were the least used (8 %).

Potential for natural regeneration. In the survey, five abiotic or ecological variables to measure the potential for natural regeneration to occur were offered. In 36 % of the projects, at least one variable was assessed (Table S5). The evaluation of abiotic conditions, such as temperature or humidity, was the most mentioned (28 %). The presence of biological corridors, such as riparian vegetation, was the least mentioned (11 %). The distance to the nearest patches of natural vegetation (19 %) and the presence of a bank of seedlings (17 %) or seeds (15 %) were also mentioned.

Goals. Most projects aimed to recover biodiversity (96 %), or ecosystem services (92 %; Table S6). Of those aimed at recovering biodiversity, the majority focused on plant (81 %) or bird species (43 %); in 40 % of the projects, the goal was to recover the whole biotic community.

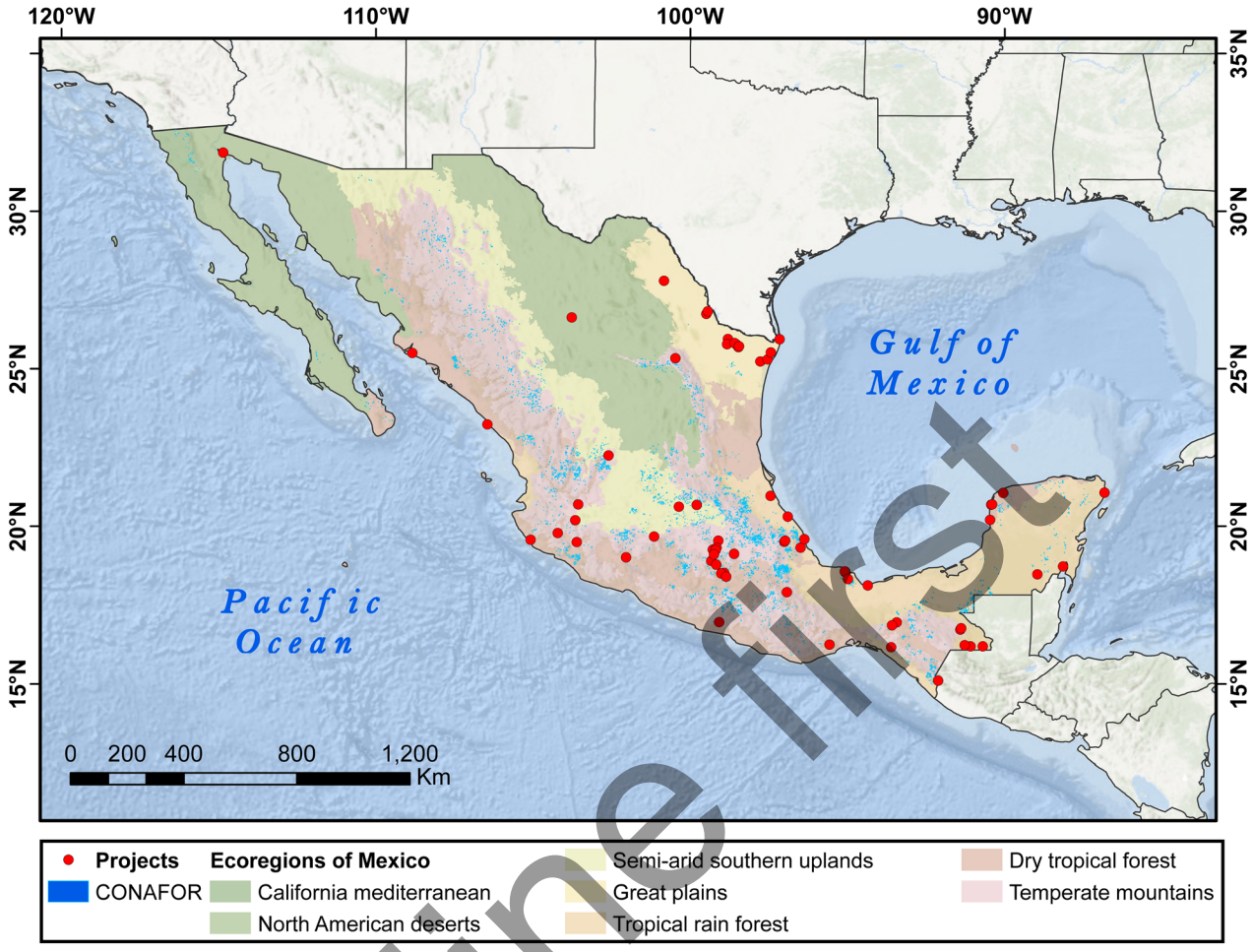

Figure 1. Distribution of ecological restoration areas according to the ecoregions established by the National Commission for the Knowledge and Use of Biodiversity (CONABIO) of CONAFOR (blue dots) and those operated by other institutions (red dots). Flat Coordinate System. Conical conic projection of Lambert, Datum: WGS 1984

The recovery of other groups, such as mammals (26 %) or insects (19 %) was less mentioned. In 40 % of the projects, the elimination of exotic species was considered the main goal.

The analysis of the goals related to the recovery of ecosystem services revealed that 85% of the projects were seeking the recovery of regulating services (*e.g.*, climate regulation, pest and disease control, or plant-animal interactions such as seed dispersal and herbivory), 63 % aimed to recover provisioning services (*e.g.*, food, fiber, fuel or freshwater), and 37 % of the projects aimed to recover cultural services (*e.g.*, spiritual or religious values or knowledge systems; Table S6). Finally, the recovery of habitat for species at risk of extinction, including the goal of reconnecting vegetation fragments, was established in 53 % of the projects.

For the analysis of the social-economic goals, three categories were offered (Table S7): (a) environmental rehabilitation (*e.g.*, bioengineering in gullies or slopes, bioremediation); (b) silvopastoral productivity or biodiversity recovery in agroecosystems (*e.g.*, establishment of windbreak fences, biological control) and (c) other processes (*e.g.,* generating local employment, complying with government mandates). The main goal mentioned by the highest percentage of projects was the generation of local employment (86 %).

Designation and description of the reference ecosystem. Eighty-eight percent of the projects identified a reference ecosystem. To identify reference ecosystems, four criteria based on international guidance were suggested in the survey (74 % of the projects used > 2 criteria): (a) remnant vegetation in the landscape (mentioned by 59 %

of the projects); (b) local knowledge of the former ecosystem (49 %); (c) ecological or floristics studies from the region (45 %) and (d) studies of potential natural vegetation *sensu* Holdridge (1967) (40 %).

Context assessment and prioritization. Fifty-two percent of the projects used ecological or social criteria to prioritize restoration actions. Forty-five percent of the projects prioritized the recovery of forest cover (Table S8). Soil conservation and the recovery of ecosystem services were criteria mentioned in 30 % of the projects. The presence of endemic species and occurrence of fires, pests, or diseases were mentioned in 18 % of the projects. The number of people benefitted (11 %) and the vulnerability to climate change (8 %) were the least mentioned criteria.

Explicit plans, schedules, and budgets. Eighty percent of the projects established some schedule and 62 % established steps to follow based on specialized handbooks and/or internal protocols. A chart of expected results was reported for 80% of the projects (Figure S1; N = 65). Sixty-eight percent of the projects established results in the short term, 26 % in the medium term and 18% in the long term. Regarding financial plans, 85 % (64 projects) reported some information, but only 50 % of those included at least one of the six steps offered in the survey (see Table S9). Most projects (88 %; N = 32) had a financial plan that included *Implementation* (step 4), 69 % included *Monitoring* (step 5), and 66 % of the projects included *Maintenance* (step 6). *Scheduling* (step 2) was included in the financial plan of 41 % of the projects, whereas steps 1 and 3 - *Diagnosis* and *Pilot projects*- were included in the financial plan of about half of the projects. Only 16 % of the projects performed a cost-benefit-effectiveness analysis as part of their financial plan. Of those, only three projects specified the criteria for the analysis, and the analysis was currently in progress in only two of the projects.

Discussion

The objective of this analysis was to evaluate the extent to which key planning steps of the planning phase of ecological restoration projects are being addressed in Mexico. Seventy-five projects carried out from 1979 to 2016 were analyzed, including 9,817 sub-projects of CONAFOR (considered here as a single, large-scale project, since they all shared a similar planning strategy). Other studies gathering information on restoration projects had similar sample size for longer time periods or larger areas. For example, in Colombia, 119 projects were implemented over a period of 62 years (since 1951; Murcia & Guariguata 2014), while Latawiec *et al.* (2016) gathered 123 studies for restoration projects involving minimal intervention across four biogeographic realms (Indo-Malay, Afrotropic, Australasia, Neotropic). Still, many more studies may exist in Mexico, but availability of information, especially from the oldest projects, precluded their integration in this analysis. To guide our discussion, we use the connection between the planning items [c,d,f] and the six key attributes of a reference ecosystem (planning item [e]) included in the SER Standards (Gann *et al.* 2019; see Table 1). Each of the key attributes can be related to the variables measured in planning item [c], which refers to the Ecological description of the site to restore and includes the baseline and the potential for natural regeneration. Also, each key attribute is connected to Goals and objectives (planning item [d]).

The first key attribute of a reference ecosystem is the Absence of threats (Table 1). All of the projects analyzed identified threats as part of the baseline; the most important one was extensive cattle ranching. Further, identifying the potential for natural regeneration allows planning for adequate restoration treatments (Gann *et al.* 2019). When a high potential for natural regeneration is identified, minimal intervention (Guzmán-Luna & Martínez-Garza 2016) or unassisted forest regeneration (Chazdon & Guariguata 2016) is suggested to reduce restoration costs (Clewell & McDonald 2009). Some predictors of natural regeneration potential are the size, duration, and severity (Zermeño-Hernández *et al.* 2015, Guariguata & Ostertag 2001) or degree of transformation and occupation of disturbance (Latawiec *et al.* 2016). The areas under extensive cattle ranching experience high intensity disturbance (Guariguata & Ostertag 2001), intensive occupation (*sensu* Latawiec *et al.* 2016) and are classified as sites with a high ecological disturbance index (*sensu* Zermeño-Hernández *et al.* 2015) - areas with the lowest potential to recover biodiversity under natural regeneration. In general, the potential for natural regeneration increases when sites are found on steep slopes, closer to native vegetation remnants, within (or adjacent to) protected areas, and far from populated areas (Borda-Niño *et al.* 2020, Crouzeilles *et al.* 2020). Ecological goals related to this key attribute refer to eliminating threats, which is the first action of any restoration project to favor natural processes of recovery (Chazdon & Guariguata 2016, Gann *et al.* 2019). Also, the elimination of exotic species, which favors the recovery of native species (Aguirre-Muñoz *et al.* 2016), was mentioned in ca. half of the projects (see below). Finally, in polluted sites after productive activities, the elimination

of threats is part of the set of *restorative practices* known as remediation, reclamation or rehabilitation, all of which are meant to recover ecosystem function; these practices are considered *allied activities* to ecological restoration as some of these sites may later be subject to ecological restoration (Gann *et al.* 2019).

The second key attribute of a reference ecosystem refers to Physical conditions (Table 1). For the baseline, few projects measured abiotic variables; this may be because some of them, like level of soil nutrients, require equipment and/or are expensive to measure. Other abiotic attributes, such as local climate may be found in governmental databases; for example, the *Comisión Nacional del Agua* (CONAGUA, National Water Commission) has a national weather service with information from 5,500 weather stations in all the states of Mexico (smn.cna.gob.mx). Some of the variables measured in the baseline, such as soil and climate (precipitation and temperature; Zermeño-Hernández *et al.* 2015) are also predictors of natural regeneration potential. Finally, improving physical conditions is part of the goal of habitat recovery and regulating ecosystem services (*i.e.*, climate regulation), since the changes in physical conditions follow vegetation development (*i.e.*, Lebrija-Trejos *et al.* 2011).

The third key attribute of a reference ecosystem refers to Species composition (Table 1). For the baseline, more than 40 % of the projects measured biotic variables, specifically vegetation attributes. Some biotic attributes, such as vegetation cover, can be measured with minimal effort. Others, such as flora and fauna inventories, are often carried out by trained people. For the planning items [c] Natural regeneration potential and [d] Goals, this key attribute is referred to as biodiversity. Biodiversity is a response variable of the potential for natural regeneration, and its recovery was the most common goal reported (96 %). In this evaluation, the most mentioned groups to be recovered were plants and birds, which are involved in important ecosystem functions (see below). Finally, in many cases, biodiversity recovery depends on the elimination of exotic species; for example, the not-for-profit organization *Grupo de Ecología y Conservación de Islas, A. C.* eradicated 58 populations of invasive mammals from 37 Mexican islands, resulting in the recovery of 227 colonies of endemic seabird species and the protection of 147 native mammal, reptile, bird and plant taxa (Aguirre-Muñoz *et al.* 2016).

The fourth key attribute of a reference ecosystem refers to Structural diversity (Table 1). For the baseline, variables such as vegetation cover, structure (i.e., richness, density, basal area) and diversity are included in this regard. For the Natural regeneration potential, basal area is a response variable (Guariguata & Ostertag 2001) and improving this structural attribute is a goal included as Habitat recovery and the ecosystem service of provisioning (see below).

The fifth key attribute of a reference ecosystem refers to Ecosystem Function (Table 1). Some of the ecosystem functions measured in the baseline are seed bank, seed rain, recruitment, phenology, and primary productivity; further, seed rain, seed bank and recruitment are considered response variables of the Natural regeneration potential (Zermeño-Hernández *et al.* 2015). Also, at least one of the evaluated projects (#62; Table 1S) was related to the recovery of natural disturbance regimes which favor natural regeneration. Ecosystem functions are related to the provision of ecosystem services (Díaz *et al.* 2005), currently referred to as "nature's benefits to people" to include other knowledge systems (Díaz *et al.* 2015). The recovery of ecosystem services was also a nearly ubiquitous goal (92 %) as was biodiversity recovery. Regulating services, which refer to the benefits people obtain from the regulation of ecosystem processes (*i.e.*, climate regulation, invasion resistance, herbivory, pollination, seed dispersal, regulation of human diseases, and water purification; Díaz *et al.* 2005), was the most frequent goal. Seed dispersal, a regulating service targeted by restoration goals (Howe 2016), is connected to diversity of plants and dispersal vectors, like birds. As stated above, plants and birds were the most mentioned groups aimed to be recovered. Further, supporting services, which refer to processes such as primary production and nutrient and water cycling, were also frequently mentioned.

The sixth key attribute of a reference ecosystem refers to External Exchange (Table 1). This attribute also connects to planning item [f] Context assessment. Some of the physiographic variables measured in the baseline, such as the location and distribution of patches, are also important predictors of natural regeneration potential related to the description of matrix elements, such as the amount of contiguous forest cover (Crouzeilles *et al.* 2016) and measures of permeability and hospitability (Prevedello & Vieira 2010). Half of the projects mentioned goals related to increasing area and connectivity.

Social goals do not fall under the six attributes of reference ecosystems; they are included as Principle 1 of the Standards (Gann *et al.* 2019; Table 1). Our evaluation showed that very few projects included social variables as part of their baseline, although some social goals were established (see below). Social variables may need to

be evaluated by trained people (Meli *et al.* 2019b) while some may be calculated with international databases. For example, the Human Development Index (HDI) which is based in life expectancy, education, and income (http://hdr.undp.org/en/content/human-development-index-hdi), is a predictor of potential for natural regeneration, since the lowest recovery of biodiversity by natural succession is likely to occur in countries with intermediate HDI (Latawiec *et al.* 2016). In this study, one third of the projects described goals for long-lasting social benefits, such as increasing silvopastoral productivity or biodiversity in agroecosystems, while for > 80 % of the projects, the main goal was to generate local employment, an immediate but short-term benefit. Also, projects carried out in urban or peri-urban areas may have long-lasting social benefits related to both mental and physical health (Twohig-Bennett & Jones 2018). In this study, at least 10 of those projects were in urban or peri-urban areas of the states of Jalisco, Mexico City, Michoacán, Quintana Roo and Veracruz (see Table S1). On the other hand, strategies to increase land productivity (*e.g.*, silvopastoral, agroecosystem), facilitate social participation by generating income for landowners (Ceccon 2013). Goals related to environmental rehabilitation were less frequently mentioned; of those, few mentioned decontamination (4 %), and none mentioned bioremediation, although one project reported results related to bioremediation (Méndez-Toribio *et al.* 2018). This was striking because according to data from the Mexican Secretary of the Economy, by 2016, there were 25,355 concessions for mining activities covering 36,363,766 hectares; these activities generate highly negative social and environmental impacts and require remediation actions (Alfie-Cohen 2015). A framework for ecological risk assessment (ERA) is used by environmental toxicologists in contaminated ecosystems to inform remediation (USEPA 1992), usually without the participation of restoration ecologists. There is an overlap in planning for ERA and for ecological restoration projects, especially in planning item [c] Ecological description of the site. Integrating ecological and social restoration goals in ERA would allow the recovery of ecosystem function in impaired ecosystems (reviewed in Kapustka *et al.* 2016). Reconciling ecological and socio-economic goals and stimulating participation of restoration ecologists in remediation projects could improve the success of ecosystem recovery.

Social goals are integrated with ecological goals in the concept of Forest Landscape Restoration (FLR; Stanturf *et al.* 2017). FLR is a planning, implementation and monitoring approach that aims to restore landscape functionality by providing benefits to both people and biodiversity: it promotes a balance among ecological, social, and economic priorities. FLR is related to the key attribute (vi) External exchange and planning item [f] Context assessment, which includes prioritization (Table 1, red box). In this study, of the seven suggested criteria to prioritize areas to restore (see Table S8), four were related to social and three to ecological criteria. On average, the projects evaluated

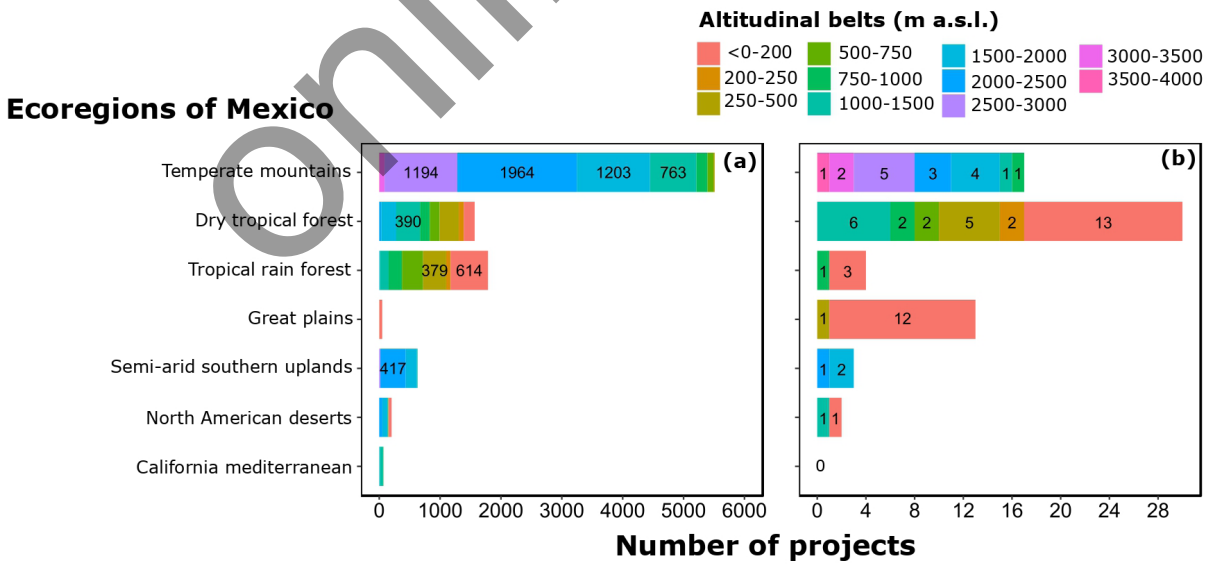

Figure 2. Number of restoration projects by ecoregions and altitudinal belts according to the classification made by the National Commission for the Knowledge and Use of Biodiversity (CONABIO) of (a) the 9,817 subprojects carried out by the National Forestry Commission (CONAFOR) and (b) the 74 carried out by other institutions.

Table 1. Connection between the six key attributes of a reference ecosystem (in green) and the planning items [c,d,f]. The ecological description of the site (item [c]) includes the variables measured to set the baseline (in yellow) and those measured to predict the Natural Regeneration potential (in orange). For the natural regeneration potential, predictors are in italics and response variables are in normal font. The establishment of goals (item [d]) includes ecological (in blue) and social ones (in purple) which are included in Principle 1 of the Standards (Gann *et al.* 2019). Goals related to criteria for prioritization (*). The red box shows the attributes included in the concept of Landscape Restoration.

[e] Key attributes	[c] Ecological description of the site		[d] Goals
	Baseline	**Natural Regeneration potential**	
(i) Absence of threats	Threats	*Size, duration and severity*[1,2] *Extensive or intensive transformation or occupation*[3]	Eliminating threats (Minimal Intervention)
(ii) Physical conditions	Abiotic variables. Soils (Physical traits, nutrients, erodability)	*Soil*[1]	Habitat recovery
	Water (Physicochemical characterization, evaluation of the hydroperiod)	*Climate (Precipitation)*[1]	Regulating Ecosystem Services
	Climate (Temperature)	*Climate (Temperature)*[1]	
(iii) Species composition	Biotic variables. Animals (inventories: birds, other vertebrates, insects, macro aquatic invertebrates)	Biodiversity[3]	Biodiversity* Provisioning Service
(iv) Structural diversity	Vegetation (Cover, structure, diversity)	Basal area[2]	Habitat Recovery Provisioning Service
(v) Ecosystem function	Functional attributes of the ecosystem: Seed bank, Seed rain, recruitment, phenology Primary productivity	Seed bank, recruitment, seed rain[1]	Ecosystem Services*: Regulating Supporting
(vi) External exchange **[f] Context assessment**	Physiographic variables. Preparation of maps, location and distribution of patches, geophysical characteristics	*Contiguous forest cover*[4] *and matrix permeability and hospitability*[5]	Supporting services Habitat recovery, Increase area and connectivity
	Social variables. Social-economic characterization, demand for environmental services	*Social-economic factors (Human Development Index)*[3]	Principle 1. Social-economic: Silvopastoril productivity, agroecosystems Cultural Services

[1] Zermeño *et al.* 2015, [2] Guariguata & Ostertag 2001, [3] Latawiec *et al.* 2016, [4] Crouzeilles *et al.* 2016, [5] Prevedello & Vieira 2010

here included ecological goals more frequently (31 %) than social goals (17 %), while economic goals were not explicit. An additional four social (land ownership, existing agreements, accomplishment of legal guidelines, water availability) and two ecological criteria (level of degradation, habitat provision for fauna) were volunteered by the interviewees. Currently, there are prioritization maps for one region in the state of Chiapas (Orsi & Geneletti 2010) and the upper Mixtec region of the state of Oaxaca (Uribe *et al.* 2014) that will allow for better planning of actions. Those maps include a cost-benefit analysis, stakeholder preferences, and recovery of functional aspects of forest ecosystems. Further, Mexico has a nationwide map for the prioritization of sites to restore (Tobón *et al.* 2017); there, the relevance of social-economic criteria was recognized but has not yet been covered, given its complexity (see below). A return-on-investment restoration prioritization framework developed for California, USA (Wilson *et al.* 2011) could help to implement a similar plan in Mexico, but again, the high levels of socioecological complexity of Mexico, including biophysical and socioeconomic conditions, as well a unique modes of land ownership (reviewed in Ceccon *et al.* 2015) must be included. For example, FLR aims at generating productive landscape

units while protecting areas for biodiversity maintenance; by balancing these priorities, productive units benefit from natural areas (Meli *et al.* 2019a). Here, it is important to highlight that in Mexico, as in other megadiverse countries (*e.g.*, Overbeck *et al.* 2015, for Brazil), non-forested ecosystems such as grasslands, thornscrub or dunes cover a similar area to forest ecosystems, suffer similar percentage of losses (Sánchez-Colón *et al.* 2009, Challenger & Dirzo 2009), host high diversity (see Martorell *et al.* 2017) and provide important services (*e.g.*, Box 13.2 by Aguirre *et al.* in March *et al.* 2009). Restorers should not attempt to transform these areas into forest, e.g. by establishing plantings (*i.e.*, afforestation), because such actions decrease biodiversity and negatively affect ecosystem provisioning services (Veldman *et al.* 2015). Natural versus productive units should be balanced in both forested and non-forested ecosystems (*e.g.*, Box 9.4 by Sifuentes in Bezaury-Creel & Gutiérrez-Carbonell 2009). Hence, we suggest that the concept of Forest Landscape Restoration be expanded to *Landscape Restoration* to include non-forested ecosystems. In conclusion, Landscape restoration favors the integration of ecological, social, and economic priorities at a scale that maximizes the benefit for nature and people; balancing these priorities is a challenge for countries with high socioecological complexity.

Planning item [g] which refers to explicit plans, schedules and budgets is developed in section 3 of the SER Standards (Gann *et al.* 2019), where four steps are suggested to develop restoration plans (see Table S7). The first step, *Planning and design* includes analyzing logistics, which considers schedules, planning charts, budgets, and securing political and financial support and permits. Even though a high percentage of the analyzed projects had some schedule, only 50 % had a financial plan considering some of the steps. In general, steps involving field work, such as Implementation (step 2), Monitoring (step 5) and Maintenance (step 6) were more frequently considered in the budget (74 %) than those involving desk work (50 %). Insufficient budgeting for the planning phase at the expense of field work (Implementation) may be due to the limited amount of money allocated to restoration by governments and other funding institutions that favors rapid action without careful planning. This results in funding calls focused mostly or exclusively on Implementation, with the Planning and design phases done without funding, often prior to the official start of the project. Further, the Monitoring and Maintenance, steps usually favored in the calls to finance restoration ecology proposals (the science) are not allowed in ecological restoration proposals (the practice). It has been argued that to increase success in both the science and the practice of restoration, all projects should be established as experiments (Systemic experimental restoration *sensu* Howe & Martínez-Garza 2014). The emphasis on field work in the budget at the expense of the planning phase may decrease total nominal costs, but it jeopardizes the success of projects; poor planning, and poor or nonexistent monitoring result in the loss of valuable information for future projects.

In conclusion, 78 % of the projects assessed here included some of the critical items of the planning phase (ranging from 36 to 100 %; Table S10). Monitoring actions allow the evaluation of projects' success, which can be measured as the percentage of achievement of the planned goals (Gann *et al.* 2019). Of the 75 projects evaluated in this study, 52 % of them reached > 50 % of the planned ecological goals, while collaboration between individuals (social goals) improved in most of the projects (Méndez-Toribio *et al.* 2018). However, the percentage of achievement may be delayed due to factors other than planning, for example, the duration of the projects (< 12 years for 64 % of these projects; Méndez-Toribio *et al.* 2018) and biophysical, institutional, social, or financial constraints. In this study, low degree of social bonding, and lack of commitment from the participating communities were the most frequently mentioned limitations. These limitations may arise due to the fact that social participation is mostly limited to the Implementation step of restoration (see Ceccon *et al.* 2020a).

The urgency of a National Strategy. Planning item [b] refers to the scope (broad geographic or thematic focus), vision (desired condition) and targets (native ecosystem) of restoration projects. The evaluation of this item for Mexico showed that most ecological restoration projects have been implemented at small scales and not necessarily in the ecosystems experiencing the greatest degradation. For example, restoration projects led by CONAFOR were done mostly in the temperate forest, even though globally 97 % of tropical dry forest is endangered (Miles *et al.* 2006). In Mexico, by 1990, only 27 % of the dry forest ecosystem was intact (Trejo & Dirzo 2000) but only 10 projects were found for that ecosystem. Another striking example is mangroves; around the world, 35 % of the original area of mangroves has been destroyed (Valiela *et al.* 2001), 5 % percent of the worldwide area is found in Mexico, and between 1970 and 2015, 11 % of mangrove area was lost while perturbed area increased 15 fold, from 1,192 ha to 18,332 ha (Valderrama-Landeros *et al.* 2017). However, we were able to find only one mangrove restoration project. Further, the latest global cost-effectiveness

analysis on ecological restoration showed that to maximize biodiversity conservation and climate change mitigation, wetlands and forests should be targeted, while to minimize overall project costs, restoration of arid ecosystems and grasslands shall be prioritized (Strassburg *et al.* 2020). This highlights the need for developing a national restoration strategy that focuses its efforts on a differential manner.

Following the experience from Latin American countries including Brazil and Colombia, to implement and follow-up large scale projects, it is necessary to: (i) review and reflect on the lessons learned, particularly from large-scale national and international projects (Rodrigues *et al.* 2009), (ii) design innovative governance structures where multiple stakeholders come together (Pinto *et al.* 2014), (iii) implement a framework of public policies, laws, local regulations, and incentives that complement and support existing ones (Guariguata & Brancalion 2014, Chazdon *et al.* 2020), (iv) understand the pervasive disconnects between the proposed objectives and the political interests that arise around restoration initiatives (Baker *et al.* 2014), (v) align the conservation priorities of scientists with those of public policy makers (Karam-Gemael *et al.* 2018), and (vi) install mechanisms that allow multiple sectors of society to participate in restoration projects, including citizen-driven initiatives. In Mexico, it will be especially important to incorporate the cultural aspects of indigenous people: about 43 % of the Mexican territory is owned as ejidos (collective land concessions created after the Mexican revolution), and about 9 % by agrarian communities (FAO 2018) that harbor 68 indigenous groups (FAO 2018, CONABIO 2018). In these territories, cultural practices have evolved over thousands of years (Alcorn & Toledo 1998). Currently, these groups live in conditions of extreme poverty (CONEVAL 2018). Ecological restoration in Mexico must therefore be carried out with effective social participation, including local stakeholders in all stages of the project and incorporating their socioeconomic needs and traditional knowledge that, in the long run, contribute to poverty reduction (Ceccon *et al.* 2020b). Ecological restoration projects should include the human dimension to incorporate issues related to education, health, gender perspective and reduction of violence (Ceccon *et al.* 2020a, b). Therefore, investment in highly trained human resources (Meli *et al.* 2019b, Newton *et al.* 2012) and a focus on socio-cultural aspects are essential to conceive, plan and execute large-scale ecological restoration actions.

A national strategy will benefit from our analysis and the deep discussion about planning: our analysis shows that the major threat to ecosystems in Mexico is extensive cattle ranching. Areas impacted by this high intensity disturbance have the lowest potential to recover biodiversity under natural succession, and therefore establishment of native plant species need to be included. On the other hand, agroforestry systems that increase land productivity and facilitate social participation are considered extensive occupation and low intensity disturbance, with the highest potential to recover biodiversity under natural succession (Latawiec *et al.* 2016, Zermeño-Hernández *et al.* 2015). Further, even under scenarios of low potential for natural regeneration, planning item [j] advises the establishment of One untreated control plot to facilitate interpretation of response to treatments (Table S1). Establishing untreated areas within treatments emulates the heterogeneity existing in nature (reviewed in Howe & Martínez-Garza 2014). Favoring landscape restoration with areas dedicated to restoration of native ecosystems, agroforestry systems and patches under natural succession will maximize ecological and social restoration goals. Furthermore, by integrating ecological and social variables that are already measured for the baseline, predictions of natural regeneration potential become more precise (see the Ecological Disturbance Index for tropical areas; Zermeño-Hernández *et al.* 2015, Latawiec *et al.* 2016) and therefore, appropriate treatments can be chosen. Current programs from the Mexican government which fund the establishment of native trees provide immediate (labor payments) and long-lasting benefits (*i.e.*, silvopastoral productivity; *Sembrando vida*; Sowing life; Gobierno de México 2019), but it is important to avoid promoting afforestation. A deep discussion of the planning phase of restoration may start with workshops including actors from governmental institutions, private foundations, non-governmental organization, academia and owners of the land; the workshops may be structured by Mexican states, using the classification of the regions established by CONAFOR or by ecosystems. This careful and detailed planning of a national strategy, together with current government restoration plans, inclusion of the human dimension and the investment in highly trained human resources, will allow us to successfully comply with our international restoration commitments and to advance in at least eight of the 17 goals for the sustainable development of the world.

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Supplementary data

Supplemental material for this article can be accessed here: https://doi.org/10.17129/botsci.2695

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