Received: 29 November 2022 | Revised: 30 June 2023 | Accepted: 5 July 2023

DOI: 10.1111/rsp3.12706

ORIGINAL ARTICLE

Depopulation and ecological degradation, two dimensions of marginalization, and peripheralization. Ecosystem integrity as an assessment factor in local revitalization

Liliana Castillo-Rivero[1] | Marine Elbakidze[2,3] | Philip McCann[4] | Frans J. Sijtsma[5]

[1]University of Groningen, Faculty of Spatial Sciences, Economic Geography Department, Groningen, Netherlands

[2]Swedish University of Agricultural Sciences, Uppsala, Sweden

[3]Faculty of Geography, Ivan Franko National University of Lviv, Lviv, Ukraine

[4]Alliance Manchester Business School, University of Manchester, Manchester, UK

[5]Faculty of Spatial Sciences, University of Groningen, Groningen, Netherlands

Correspondence
Liliana Castillo-Rivero, University of Groningen, Faculty of Spatial Sciences, Economic Geography Department, Landleven 1 Faculty of Spatial Sciences, Groningen 9700 AB, Netherlands.
Email: l.castillo.rivero@rug.nl

Abstract

Addressing the pressure that population growth puts on the environment has become a high-level policy priority. Less discussed is the role of population decline in either enhancing or degrading the natural environment, and how the its reshaping can help new forms of de-peripheralization and de-marginalization. A long-term trajectory of marginalization and peripheralization of depopulating places can be reversed in certain situations by adopting a more holistic and sustainable analytical and policy framing. To do this, here we integrate different types of diagnosis frameworks. The first, based on factors that the literature indicates as factors leading to negative effects of depopulation, for which the revitalization of such places is suggested, and the second, proposed in this paper, which adds the integrity of the ecosystems involved in places undergoing depopulation processes. Our findings suggest that as we add ecosystem integrity factor to observations, in some cases, revitalization is possible even in the localities displaying the potentially negative effects of depopulation decrease. This suggests that whereas in some places a policy-managed abandonment may be appropriate to release human pressures over such degraded ecosystems, in other cases, revitalization may be a viable alternative for such settlements.

KEYWORDS
depopulation, ecosystem integrity index, marginalization, peripherality, supply and demand of ecosystem services

1 | INTRODUCTION

Recently, the United Nations (UN) called for an urgent Decade on Ecosystem Restoration from 2021 to 2030 that 'aims to prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean, which can help to end poverty, combat climate change and prevent a mass extinction' (UNEP, FAO, 2020). Global crises face at least two major challenges. On the one hand, deep poverty and marginalization occur in many regions of the world, and on the other, depletion and degradation of natural environment have passed thresholds in many regions of our planet.

Marginalization is a phenomenon that is expressed in the relegation of an individual or group to conditions of disadvantage, exclusion, or inferiority, that is, to the margins or periphery of their context. Marginalization is a multidimensional phenomenon that includes economic and financial (Dimitrov, 2016; Murakami & Hamaguchi, 2021; Tagai et al., 2018); cultural, political, or institutional (Baah et al., 2019; Melgaço, 2021; Molla, 2018), demographic (Dimitrov, 2016; Heffner & Latocha, 2020; Tagai et al., 2018); and environmental and ecological (Fuerst-Bjeliš, 2020; Kousis, 1998; Levers et al., 2021; Malin et al., 2019; Nayak et al., 2014) dimensions.

In this study we understand depopulation as a manifestation of marginalization that can be deepened by the inability of the remaining inhabitants to satisfy their demand for the services that ecosystems can provide them. The links between population decline and ecological responses are documented in the literature (Agnoletti et al., 2019; Angelstam et al., 2021; Benayas et al., 2007; Brandolini et al., 2018; García-Ruiz & Lana-Renault, 2011; Lasanta et al., 2015; Martínez-Abraín et al., 2020; Plieninger et al., 2014, 2015; Rimal et al., 2019; Rodrigo-Comino et al., 2018; Sitzia et al., 2010; Uchida & Ushimaru, 2014; Van Leeuwen et al., 2019). Population decline often leaves settlements partially or entirely derelict, with complex ecological and environmental consequences. In some cases, the ecological effects are conceived as being positive, given that nature may reclaim these largely abandoned places, with re-wilding processes occurring naturally. In other cases, depopulation in regions with arid climate, traditional agriculture systems, or in mountainous areas is associated with negative environmental effects, including land abandonment. We call arid climates, presence of traditional agricultural systems, and location in mountainous areas as Factors of Negative Ecological Effects of Depopulation (FNEED).

The aim of this study is to explore the possibilities of ecological restoration and reversal of marginalization in regions with diverse conditions of ecological integrity where marginalization derived from depopulation. We apply the concept of ecosystem integrity (Conabio-Geoportal, n.d.; Mora, 2017) as a variable depending to some degree on the presence of FNEED, and as a variable with the potential to inform the capacity of ecosystems to provide their services demanded by the remaining inhabitants in depopulated settlements. We examine the extent to which the balance between the capacity of ecosystems to provide services to inhabitants in depopulating areas offers opportunities for helping regions undergoing peripheralization and marginalization to revitalize. Our approach allows us to propose a diagnostic guide that could help designing public policy recommendations for the revitalization of settlements undergoing depopulation.

Mexico was selected as a case study. Mexico is a country that has recently gone from decades of high population growth to fertility rates just above replacement levels, and with an expected long-term national population decline for the remainder of the current century. Today, population decline is a phenomenon that is experienced in all parts of Mexico. There are currently 199,390 settlements in the country (INEGI, 2020), and about 36% of them showed a population decline during the period 2000–2020, and 16% of settlements have been completely abandoned and officially classified as 'in walls or ruins' or 'vacated' (INEGI, 2021). The detailed patterns of localized population decline in Mexico are seen to cover many different regions, natural environments, and types of geographies (Castillo-Rivero et al., 2021), and Mexico provides an interesting test case for examining the ways and the extent to which depopulation is associated with marginalization, peripheralization, or ecological recovery.

We combine indices capturing information on the ecological integrity of local ecosystem with information on the demand for ecosystem services by local residents. We do this in different topographical and physiographic contexts facing depopulation to investigate the potential for local ecological revitalization as a means of reversing socioeconomic peripheralization and marginalization. We find that even in places with classic physiographic features associated with depopulation and socioeconomic peripheralization and marginalization, there are notable cases in which ecological recovery is perfectly viable. This gives grounds for plausible policy approaches aimed at local revitalization based on ecological principles.

To examine these issues, the rest of the article is organized as follows. The second section presents a conceptual framework framed around the current literature and evidence. In the third section, we present the methods employed in this research and outline the distinctiveness and novelty of the approach adopted. In the fourth section, the results are presented, and in the fifth section, we provide some conclusions of this study.

2 | CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 | Demographics and ecosystems

The changes in ecosystems derived from human intervention are undeniable, and population growth and rapid urbanization processes in the world have played a key role in this. However, global population growth trends point to demographic decline by mid-century and for the rural areas by 2020 (Coleman & Rowthorn, 2011; UN, 2018), bringing an end to a period of almost uninterrupted worldwide population growth for about three centuries (Cilluffo & Ruiz, 2019; Lutz & Gailey, 2020; Lutz et al., 2001). The mechanics of decline can be traced to a prolonged reduction in fertility nearly everywhere in the world, to a greater or lesser extent depending on the region, so by mid-century, the structural changes will be well on their way to turning growth into decline for many parts of the world (Harper, 2016; Reher, 2007).

These complex demographic trends give rise to different implications in terms of relationships between population change and the pressure humans exert on ecosystems, either due to their intervention and alteration of ecosystems or to their abandonment or cessation of such interventions. The ecological impacts of human intervention and the alteration of ecosystems are very clear. Between 1960 and 2000, the world population doubled to 6 billion people, which led to increasing demand for ecosystem services and modification of the planet's biomes. While tropical dry forests have been the most affected by agricultural conversion, temperate grasslands, broadleaf forests, and Mediterranean forests have also been converted to agricultural use by up to 35% (MA, 2005). The pressures on ecosystems due to agricultural conversion have contributed to climate change, and have also resulted in being sources of contamination for water bodies due to the deposition of synthetic fertilizers and pesticides and the implementation of irrigation systems, as well as causing the loss and fragmentation of the habitats of animal and plant species (Hardelin & Lankoski, 2018, IPBES, 2018). In addition, the increase in demand for meat and other animal products has led to the intensification and continuous extension of the use of the world's pastures for livestock in marginal land areas in bioclimatic and edaphological terms, with triggered desertification, wood encroachment, and deforestation (Asner et al., 2004).

The increased demand for products derived from agriculture and forestry has resulted in a loss of 13 million hectares of forests per year, equivalent to the size of Greece (Jenkins & Schaap, 2018; UN, 2022). In addition, the deterioration of the drylands has resulted in the desertification of 3.6 billion hectares equivalent to more than 20%

of the total area of the terrestrial globe (Jenkins & Schaap, 2018). Deforestation and desertification have led to climate change, and thus have had a regressive impact on the fight against extreme poverty, given its negative impact on the lives and livelihood of millions of people worldwide. In the same vein, urbanization processes in the world have had adverse effects on the ecosystems within cities through the increase of built-up areas and nitrogen deposition that promotes eutrophication, soil acidification, and poor air quality (Decina et al., 2020), as well as encroaching into rural areas (MA, 2005). Climate change and land use change are estimated to be the main causes of global biodiversity loss by 2050 (OECD, 2012).

However, as mentioned before, negative ecological impacts have been observed from the other side of the demographic coin, that is, from scenarios in which there is a cessation of human intervention in ecosystems. Traditional extensive small-scale agricultural systems, sustained for centuries, are home to a high diversity of plant and animal species. About 90% of all farms in the world are traditional agricultural systems and cover 60% of the planet's arable land (Queiroz et al., 2014). In Latin America, examples of such traditional land-use systems are the cultivation of cocoa or *milpa*; in Japan *Santoyama* landscapes, and in Europe oak wooden pastures. Scholars show that the depopulation and consequent abandonment of these traditional agricultural systems leads to the loss of biodiversity, esthetic and cultural landscape values, and sources for sustainable livelihood for remaining populations (Angelstam et al., 2021; Benayas et al., 2007; Lasanta et al., 2015; Plieninger et al., 2014).

Other ecological impacts have been documented, such as greater susceptibility to fires due to the lack of land management, soil erosion, alterations in carbon sequestration and the hydrological cycle (Lasanta et al., 2015), and the degradation of natural wildlife refuges resulting in wild animals moving into human settlements (Martínez-Abraín et al., 2020). Although the adverse effects of agricultural land abandonment depend on the specific geographical, socioeconomic, and political contexts, in general stronger adverse effects occur, mainly in extensively deforested areas, regions with arid climates, and mountainous areas (Benayas et al., 2007; García-Ruiz & Lana-Renault, 2011; Sitzia et al., 2010).

2.2 | Ecosystem integrity index

An important element of our approach involves linking an ecological integrity index to the issue of depopulation. Figure 1 sketches out a simple schema that links depopulation as a situation of marginalization with the ecosystem integrity of the locality. Demographically vulnerable localities in arid, mountainous, or traditional agricultural areas are also often vulnerable to low levels of ecosystems integrity, in which the local demand for ecosystem services cannot be provided by the local ecosystems. In these cases, depopulation means that these localities can find themselves becoming increasingly peripheral and marginalized in the ecological dimension, deepening the generalized situation of marginalization.

In our research linking depopulation to socioeconomic peripheralization and marginalization, we employ an ecosystem integrity index (EII), which, according to Semarnat (2015), captures the 'conditions in which ecosystems are found, not only in their quantity (land-cover) but in their quality (in terms of the integrity of their components, interactions, and processes)'. The ecological integrity of ecosystems is a characteristic resulting from processes and mechanisms that sustain complex ecological interactions, including predator–prey hierarchies. The concept of an EII is understood as a latent and complex variable, which is based mainly on spatial information and theoretical models of ecological hierarchies (Mora, 2017). When ecological degradation occurs, the ecological hierarchy is interrupted, and the EII can be used to help identify the presence of those interruptions due to ecosystem degradation.

In Mexico, the National Commission for the Knowledge and Use of Biodiversity (CONABIO) provides an EII measure (Conabio-Geoportal, n.d.; Mora, 2017) specific to the ecological features of Mexico. The theoretical model and analysis framework of the EII is based on data on the interactions of the predator–prey systems for 239 species of mammals in Mexico as a function of the changes registered in their potential habitat and their current conditions (Mora, 2017). Methodologically, the ecological integrity model includes a spatial analysis based

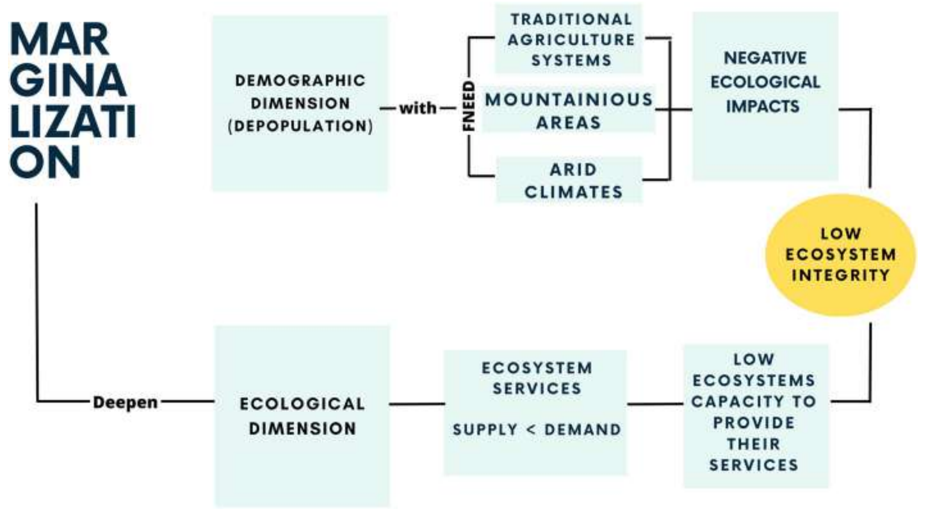


FIGURE 1 Marginalization. Demographic and ecological dimensions through low ecosystem integrity.

on geographic information and expert knowledge on predator–prey interactions. Through a niche-based species distribution model (SDMs), the major variables were defined to build the conceptual framework used in the theoretical model and subsequently serve for hypothesis testing through a structural equation model (SEM). The SEM estimates the values of the latent hypothesized unobservable variables that add important information to the analysis of the ecological interactions and to the overall knowledge of ecological integrity (Mora, 2017). We then link these data to demographic data at the local and regional levels, in very different topographical and physiographic contexts.

3 | METHODS

To detect regions with FNEED, we analyzed the spatial distribution of depopulating settlements within different types of ecosystems existing at the national scale in Mexico. For identifying mountainous areas in Mexico, we used the polygons data available in a special dataset called El Relieve como atractivo natural (Conabio, 2008). The ecosystems were associated with land covers that obey different ecological and anthropogenic units, using the Union Layer classification, which integrates in a single digital layer information on the distribution of the vegetation covers according to the National Institute of Statistics and Geography (INEGI) Land Use and Vegetation classification system (INEGI, 2017). Then, through literature review, we identify their services (Balvanera et al., 2009) (See Annex A1).

To identify depopulating settlements, we used census data for 2000 and 2020 (INEGI, 2000, 2020) with the dataset from the Historical Archive of Geostatistical Locations to identify disappeared settlements, officially declared as ‘in ruins or walls’ or ‘unoccupied’ (INEGI, 2021); and the national point vector georeferencing framework. We selected settlements in which population decreased from 2000 to 2020. All identified depopulating settlements were intersected with Union Layer classification from INEGI corresponding to the year 2017 in a new layer to identify the land use/covers in each selected settlement using a geographic information system (GIS) (INEGI, 2017). The set of depopulating settlements existing in 2020 were intersected with land use/cover layer corresponding to the year 2017 (INEGI, 2017).

3.1 | Study area

On the local scale, we selected 37 settlements within three provinces with different physiographic characteristics: (1) Eje Neovolcánico, (2) Sierra Madre Occidental, and (3) Sierra Madre Oriental. These three provinces represent contrasting ecological (Figure 2) and demographic characteristics (Table 1).

The Eje Neovolcánico province, in the center of the country, has large chains of volcanos, the highest peaks of the country, and is more than 5,000 m above sea level (MASL). This physiographic province extends from the western coast of the Pacific Ocean to the eastern coast of the Gulf of Mexico. This province has the largest number of settlements and population in the country (Table 1). This might be one of the reasons why this physiographic province has the highest levels of ecosystem degradation. Apart from settlements, its predominant land cover is arable land.

The Sierra Madre Oriental province is a narrow mountainous system formed mainly by folded sedimentary rocks and extending from the northeast and lying parallel to the Gulf of Mexico until it reaches the center fringe of the country. Although its territorial extension is slightly more than one-third greater than the Eje Neovolcánico province, the density for both its settlements and population is only 27%, and 6%, respectively, compared with that of the Eje Neovolcánico province, reflecting lower levels of local ecological degradation. Its predominant land cover is shrubland.

The Sierra Madre Occidental province is the most extended mountainous system of the country, ranging from the northwest and traversing across all of the western side of Mexico. Its mountains range from 2,440 MASL to 3,500 MASL, constituting the western sheer steep edge of the central and arid plateau of the country. It is the least populated province among the selected ones. This province also has the lowest degrees of ecological degradation in comparison with the most populated Eje Neovolcánico province. The predominant land cover is forest.

3.2 | Linking ecosystem services supply and demand, land covers, and ecosystem integrity

Following the approach of Burkhard et al. (2012), we develop a supply matrix (Annex A3) that spatially links the land use/cover units of each studied settlement with ecosystem services (Annex A1). To approach the ecosystem capacity to provide such services, the EII was identified for each settlement (Conabio-Geoportal, n.d.; Mora, 2017) (Table 2). Each matrix cell is filled with colors. High values (red) are assigned when the EII is equal to or greater than 70%; intermediate values (yellow) are assigned when the EII is equal to or greater than 50% and less than 70%; low values (orange) are assigned when the EII is less than 50%; the cell is empty when the ecosystem did not provide the service (Table 2). Since a vector of settlements is punctual, and considering how restrictive it is to assign the EII only to a vector point, we have added an extra qualification considering a broader spatial vision. Because the studied settlements are distributed in three physiographic provinces in which one type of land cover dominates – agriculture, scrubland, or forest (Figure 2) – each studied settlement was also linked to the EII of the dominant land cover.

3.3 | Demand for ecosystem services

To capture the local demand for ecosystem services, we did 132 face-to-face interviews in 37 settlements following the methods presented in Elbakidze et al. (2017). The respondents were randomly approached, and their gender and age were balanced as much as possible during the process of data collection. The interview manual was developed using Survey Monkey software (www.surveymonkey.com). The respondents were asked to select the ecosystem services that they considered important for their well-being from a predetermined list of ecosystem services using four options: important, slightly important, not important at all, and do not know (Annex A2). The ecosystem services classification was based on the Millennium Ecosystem Assessment (MA, 2005), including provisioning, regulating, and

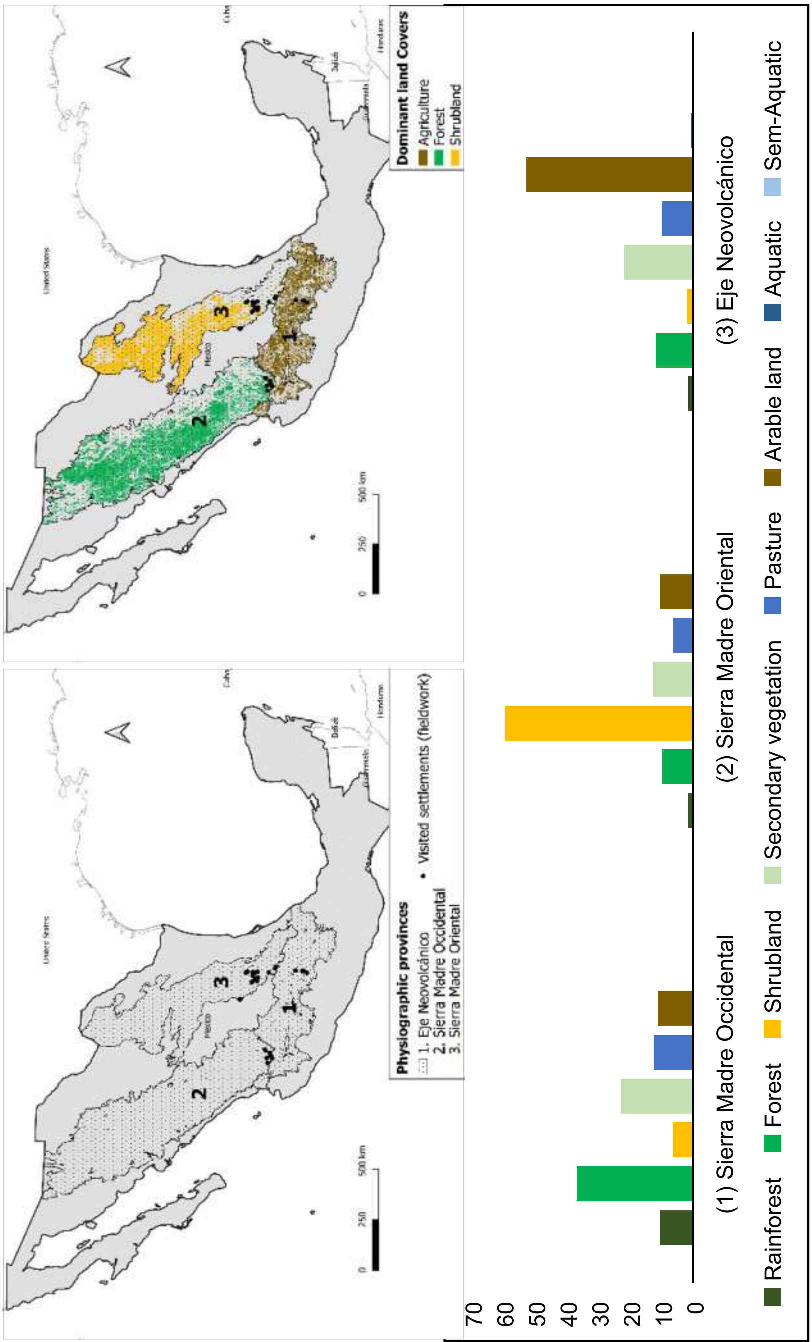


FIGURE 2 Study area: three Mexican physiographic provinces.

TABLE 1 Demographics of selected physiographic provinces.

Province	Area (km^2)	Settlements	Settlement density (per 100 km^2)	Total population	Population density (per km^2)
1. Eje Neovolcánico	158,516.1009	35,647	22	51,704,959	326
2. Sierra Madre Oriental	220,200.0741	14,054	6	4,638,681	21
3. Sierra Madre Occidental	354,466.8085	22,284	6	3,115,037	9

TABLE 2 Combinations of categories of supply and demand for ecosystem services for the depopulating settlements visited in fieldwork.

Supply	Demand	Balance**	icon
High capacity (EII ≥ 70%)*	Important	S=D	●
High capacity (EII ≥ 70%)	Slighly important	S>D	✓
High capacity (EII ≥ 70%)	Not important	S>D	✓
Medium capacity (EII ≥50< 70%)	Important	S<D	✗
Medium capacity (EII ≥50< 70%)	Slighly important	S=D	●
Medium capacity (EII ≥50< 70%)	Not important	S>D	✓
Low capacity (EII ≥0< 50%)	Important	S<D	✗
Low capacity (EII ≥0< 50%)	Slighly important	S=D	●
Low capacity (EII ≥0< 50%)	Not important	S>D	✓
The ecosystem does not provide the service	Important	Demand for services of distant ecosystems	●
The ecosystem does not provide the service	Slighly important	Demand for services of distant ecosystems	●
The ecosystem does not provide the service	Not important	There is neither supply nor demand	

** EII: Ecosystem integrity index*
***S=Supply and D=Demand*

supporting services. We deliberately did not provide any definition for the term 'well-being'. Instead, each respondent had their full freedom to interpret it as they perceived it. To avoid any confusion regarding meanings of listed ecosystem services, each ecosystem service was clearly introduced to respondents with explanations and examples.

In Table 2 we present the features of the demand matrix linking the settlements visited for the fieldwork and ecosystem services locally demanded (Annex A3). As with the supply side, each cell is color coded. High values are depicted as red and are assigned when the respondent said that the ecosystem service was important for their well-being, intermediate values are depicted as yellow and were assigned when the respondent said that the ecosystem service was slightly important for their well-being, and low values depicted as white were assigned when the respondent said that the ecosystem service was not important at all for their well-being.

The demand of ecosystem services, as revealed by the stated preferences of the fieldwork interviewees, was contrasted with supply of ecosystem services, estimated by the EII variable (Figure 4). In the case of our matrices, when it is said that the supply is greater than the demand, or vice versa, it refers to the fact that the capacity of the local ecosystems to supply is greater/lower than the importance assigned to them by local inhabitants for their well-being. After obtaining the matrix of the balance between supply of and demand for ecosystem services from Table 2, these balances have been contrasted for each settlement as to whether they present FNEED or not.

3.4 | Factors for negative ecological effects of depopulation (FNEED)

As already mentioned, the factors widely discussed in the literature in which depopulation has shown negative ecological effects due to land abandonment (FNEED) are traditional agroecosystems, arid climate, and mountainous areas. Each of these key geographical vulnerabilities are widely present in Mexico.

3.5 | Traditional agriculture

In Mexico, traditional agriculture is composed of the *milpa*. The *milpa* is a traditional polyculture system, whose main species is corn, accompanied by species such as zucchini, beans, chilies, and tomatoes. In addition, around 300 edible plants, some domesticated and some wild, have been registered as all dependent on the Mexican *milpa* system. Each species reaches different heights when growing and spread out differentially. Corn grows upward, zucchini to the sides, beans and edible herbs occupy the intermediate spaces, and other edible plants are interspersed or on the margins of the *milpa*. This structure allows the species to not compete with each other, maintaining an optimal soil fertility, a better fixation of its nutrients, and a greater possibility of biological control of pests. The *milpa* provides habitats for many animal and plant species, constituting an ecosystem rich in genetic and cultural resources, and serves as the food base for millions of Mexican families (Conabio, 2016). Given the great diversity of climatic conditions in the country, and the vast species cultivated, the *milpa* is characterized as regularly rainfed agriculture, but of differing durations. In this work, we consider annual, permanent, or semi-permanent rainfed agriculture *milpa*.

3.6 | Arid climate

In Mexico, the arid and semi-arid climates are classified with an average annual rainfall of 300 mm to 600 mm, having two variants: a warm one with an average annual temperature greater than 18 °C and a cold one with lower temperatures. The very arid climate regions register average temperatures of 18 °C to 22 °C, with extreme cases of more than 26 °C, and with annual rainfalls of 100 mm to 300 mm on average (García, 1988; Semarnat, 2010; Vidal-Zepeda, 2005).

3.7 | Hills and mountains

Approximately one-third of Mexico is flat, and more than the half of the national territory is above 1,000 MASL (García-Martínez, 2008). Svarichevskaya (1978) classifies mountains into a scale for an entire continent: the highest (over 5,000 m), high (3,000 m to 5,000 m), intermediate (2,000 m to 3,000 m), and low (1,000 m to 2,000 m); hills (600 m to 1,000 m), intermediate (300 m to 600 m), and low (up to 300 m) (Svarichevskaya, 1978 cited in Conabio, 2008; Lugo-Hubp, 1989). A very significant share of Mexico is therefore characterized by landscapes ranging from low to high mountainous areas.

4 | RESULTS AND DISCUSSION

4.1 | National scale

We show proportions of depopulating settlements considering FNEED in Mexico. According to the literature, when depopulation occurs in zones with traditional agriculture, some negative consequences can occur, such as soil erosion, loss of biodiversity and homogenization of the landscape, and loss of esthetic and cultural landscape values and sources for sustainable livelihood for remaining populations (Agnoletti et al., 2019; Angelstam et al., 2021; Benayas et al., 2007; Brandolini et al., 2018; Lasanta et al., 2015; Plieninger et al., 2014, 2015; Uchida & Ushimaru, 2015; Van Leeuwen et al., 2019). About 29% of the Mexican settlements in depopulation were located in these kinds of territories (Table 3).

The adverse effects can be deepened when land abandonment in such territories is accompanied by arid climate and location in mountainous areas; in such cases, depopulation leads to soil erosion, changes in the hydrological cycle

TABLE 3 Depopulating settlements with FNEED in Mexico (2000–2020), %.

FNEED	%
Traditional agriculture	29
Traditional agriculture and mountainous zones	21
Traditional agriculture and arid climate	6.5
Traditional agriculture and mountainous zones and arid climate	4.2

Abbreviation: FNEED, Factors of Negative Ecological Effects of Depopulation.
Source: INEGI (2017). Conabio (geographic metadata catalog) based on Lugo-Hubp et al. (1992).

and freshwater supply, and increased fire frequency. About 21% of the settlements in depopulation are located in territories with traditional agriculture in mountainous areas. About 6.5% are located in territories with traditional agriculture and arid climate, and 4.2% are located in areas that meet all these characteristics.

As Figure 3 shows, depopulating settlements are scattered all over Mexico. Each of the types of vulnerable topographies and geographies outlined above are present across whole swathes of Mexico, such that the peripheralization and marginalization vulnerabilities examined in the paper affect many parts of the country.

These settlements are at risk of becoming more peripheral both in demographic and ecological terms given the negative effects of depopulation and the vulnerability of the local ecosystems and their likely inability to provide for the remaining populations. As shown in Figure 3, they are spread across vast areas of Mexico and are not confined to any one particular part of the country.

At the same time, as we see in Figure 4, many of the areas that are also characterized by weak and vulnerable ecosystem integrity tend to be in the central regions of Mexico, both mountainous regions at altitude and low level and coastal regions, as well as some areas in the northern arid regions. Both depopulation (Castillo-Rivero et al., 2021) and ecosystem vulnerability are features of many parts of Mexico and are not evident solely in a small number or types of places.

4.2 | Local scale

In our fieldwork, the respondents demanded a wide range of ecosystem services; this is why the matrices for the ecosystem services demanded by the respondents in the studied settlements are generally full (Annex A3). However, the matrices of service supply provided by local ecosystems are quite pallid due to the high level of ecosystem degradation in and around the studied settlements, especially in the Eje Neovolcánico province. In this province, 88% of respondents' selections of ecosystem services as 'important' or 'slightly important' for their well-being were linked to ecosystems with low supply capacity (EII ≥ 0 < 50%). About 17% of respondents' selections were linked to ecosystem with low supply capacity in the Sierra Madre Occidental province, and 7% in the Sierra Madre Oriental (Annex A3).

Out of 37 studied settlements, 35 presented FNEED, and 21 out of those 35 settlements showed negative supply and demand ratios. In these 21 settlements, the condition of demographic marginalization is reinforced by ecological marginalization. The other 14 settlements showed only positive ratios, even though all FNEED features were present in some of them (in 6), namely traditional agriculture and being both arid and mountainous. In these settlements, the situation of demographic marginalization is not deepened by ecological marginalization. We also observed that there were two settlements with no FNEED features, even though one also showed negative supply and demand ratios, while the other showed positive ratios (Figure 5).

The differences between the provinces studied should be noted. Practically all of the 13 out of 14 settlements that presented FNEED and positive supply–demand ratio belong to the province with intermediate levels of

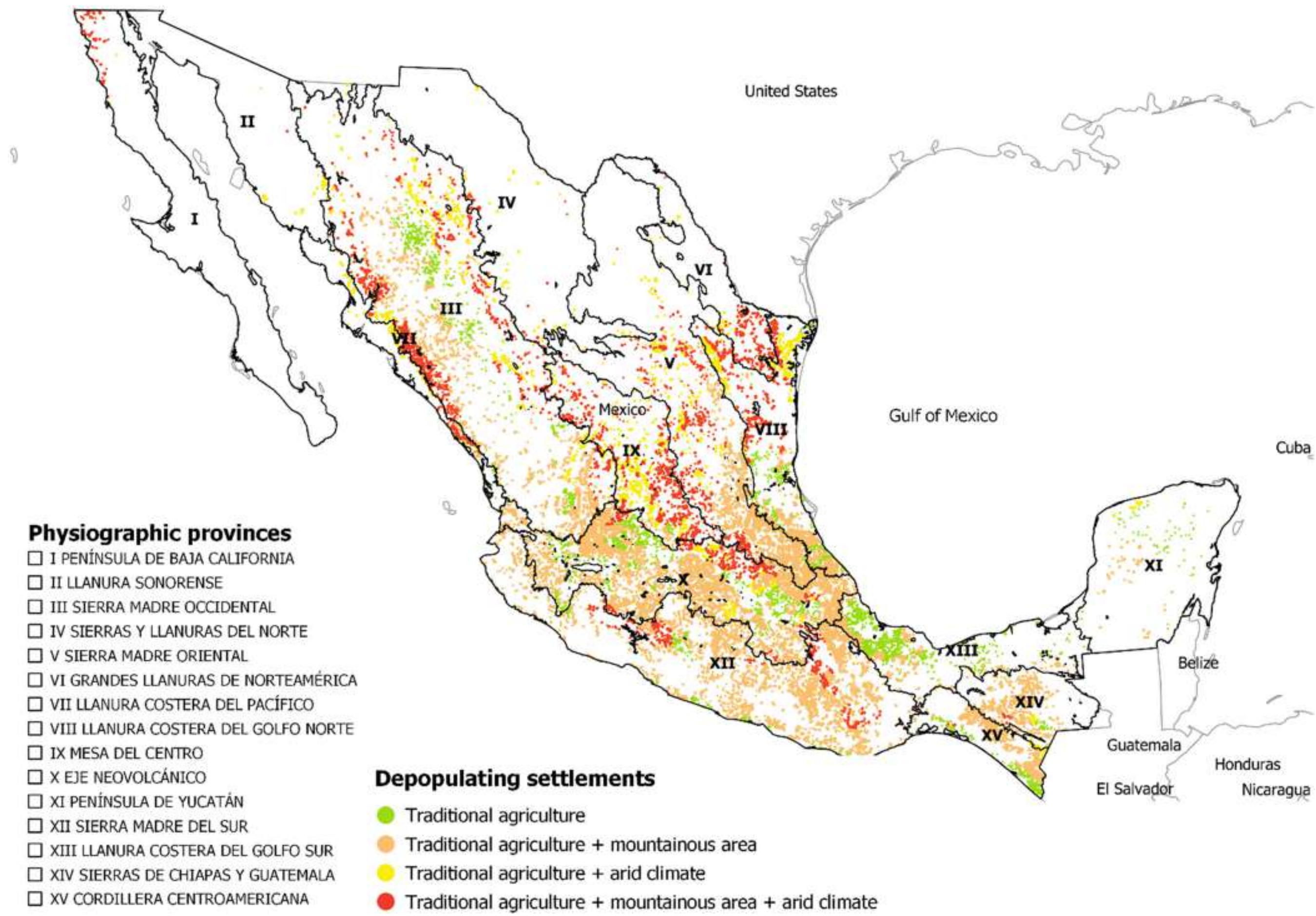


FIGURE 3 Depopulating settlements with Factors of Negative Ecological Effects of Depopulation (FNEED) in Mexico (2000–2020).

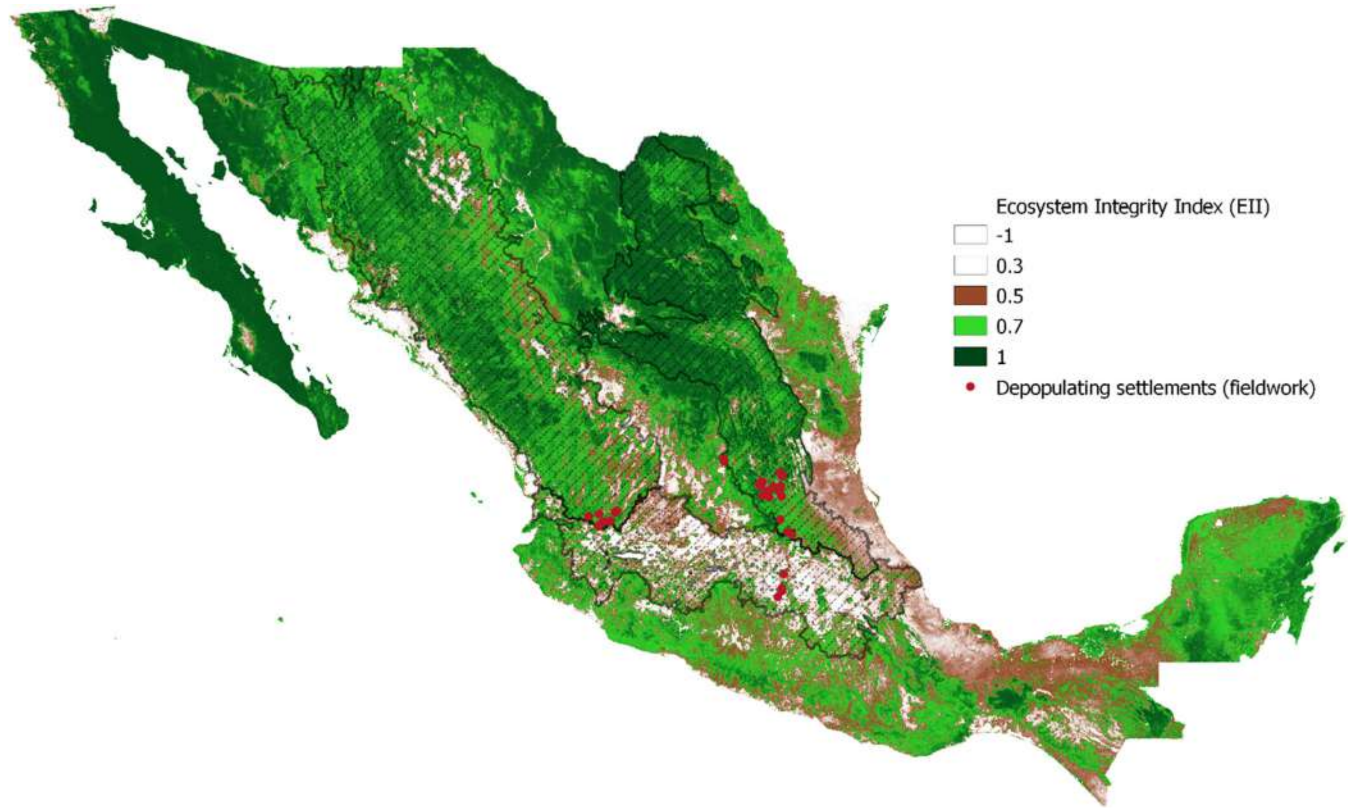


FIGURE 4 Ecosystem integrity index and the studied settlements.

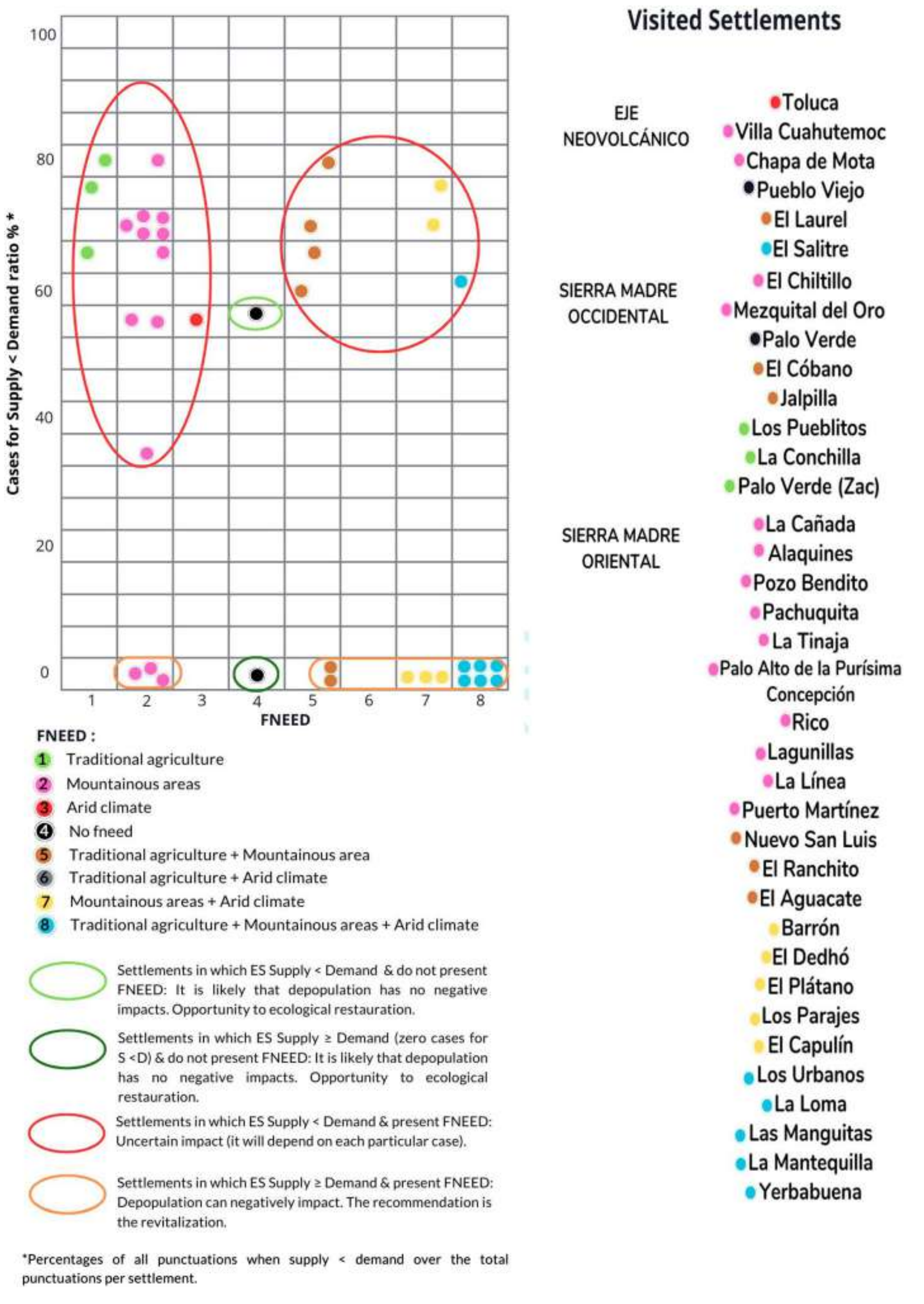


FIGURE 5 Negative supply and demand ratio. Diagnoses of depopulation effects.

population density and low settlement density, in comparison with the other physiographic studied provinces (Table 1), and whose dominant land cover is shrubland –the Sierra Madre Oriental. This difference suggests that in this province, although its settlements presented FNEED, depopulation has not been translated into ecosystem degradation. These cases point out the existence of important factors accompanying the presence of FNEED that can influence the integrity and capacity of its ecosystems to offer their services. These factors may be related with regional density of settlements and population, regional dominant land cover, and probable rates of population

TABLE 4 Diagnoses guide and policy recommendations.

Category	Supply and demand ratio	FNEED	Diagnoses	Recommendations
1	S ≥ D	Yes	Depopulation can negatively impact	Revitalization
2	S ≥ D	No	Depopulation has no negative impacts	Opportunity for ecological restoration
3	S < D	Yes	Depopulation can negatively impact	Uncertain
4	S < D	No	Depopulation has no negative impacts	Opportunity for ecological restoration

Abbreviation: FNEED, Factors of Negative Ecological Effects of Depopulation.

decline (the duration period, long or short, in which depopulation has been crossing the region, in the case in which depopulation is a young phenomenon there, and its ecological impacts not having been manifested yet).

4.3 | A diagnosis guide for public policy

To propose a diagnostic guide, the attributes of each settlement are observed. Such attributes obey two fundamental aspects: on the one hand, the presence of FNEED, and on the other hand, the balance between supply and demand of ecosystem services (ES). The basic recommendations for those settlements presenting FNEED is revitalization, meanwhile for those with negative supply and demand ratios there is an opportunity for ecological restauration. The analysis of the ES supply–demand ratio shows that there are various cases in which an ecologically led revitalization option looks entirely plausible. However, for settlements that are located in areas with FNEED and display a negative balance as well, the recommendation would depend on the specific features in each particular case. This is because a revitalization option is compromised by ecosystem degradation and its low capacity to deliver the ecosystem services demanded. In some cases, this ultimately results in a deepening of the peripheralization and marginalization of the settlements in question. Table 4 sets out the combinations of FNEED features, the supply and demand characteristics of the locality's ecosystem integrity, and the likely diagnoses and policy recommendations.

In Figure 5 we show the diagnoses link to recommendations for the studied cases. The *y*-axis shows the percentage of scores when the supply of ES was less than the demand, per settlement (see balance matrix in Annex 3). On the *x*-axis, we show the situation of all the settlements, presenting FNEED or not. Each point represents each settlement. The settlements that are in the upper part of the figure are those with a high percentage of cases with a negative balance between supply and demand. As observed, most of these cases are of settlements with FNEED that lie in category 3 of Table 4. On the other side, the lower part of the figure contains the settlements with a low percentage or zero cases with a negative balance between supply and demand. These settlements lie in category 1 of Table 4, for which revitalization is recommended.

As seen in Figure 5, the majority of the fieldwork localities facing population decline are areas in which depopulation and socioeconomic peripheralization are also places where ecological degradation is also a resulting key feature. The future for these places is uncertain at best, and in all likelihood, increasingly problematic both demographically and ecologically. At the same time, there are a small number of localities where the possibilities for revitalization, including ecological responses, are very realistic. These are grouped at the foot of Figure 5. These insights of differential socioeconomic–ecological trajectories have been driven by linking empirical measures of EII to the perceptions and insights of local inhabitants derived from fieldwork interviews. This multi-methods approach provides a way forward for policymakers to consider priorities and opportunities for revitalization and redevelopment on sustainable grounds in places experiencing peripheralization and marginalization.

5 | CONCLUSIONS

This article addressed two dimensions of regional and local peripheralization and marginalization, namely demographic decline and ecological degradation, and explored how they can be mutually reinforcing by introducing the concept of ecosystem integrity. At the national scale we explored most notable factors that tend to be associated with negative ecological impacts (FNEED) on places. At the local scale, we identified that the ecosystems in depopulating settlements with FNEED tend to present lower levels of ecological integrity, and the supply of ecosystem services tends to be lower than the demand. We proposed a diagnostic guide for public policy intended to point to the possibilities of ecological restoration and the reversal of peripheralization and marginalization in a depopulation context.

At the local scale the importance of other factors emerges in different contexts that accompany the presence of FNEED. In this study, those different contexts were marked by the different characteristics of provinces under analysis. We found that the population and density of settlements, as well as dominant land cover, which reflect some of the differentiating characteristics between the studied provinces, can play an important role in how the FNEED influences ecosystem integrity within the depopulating contexts. Fieldwork research specific to a country or set of regions is necessary to better understand these factors in different places and how they might contribute to the deepening or ameliorating of demographic marginalization and peripheralization.

In general, however, we conclude that the joint observation of population decline together with ecological integrity and the supply–demand balance of ecosystem services opens the new way for considering more integrative policies in these complex environments facing demographic peripheralization and marginalization. If depopulation has negative effects on the integrity of the local ecosystems, then these local ecosystems will lose their capacity to supply the services needed by local inhabitants for their well-being, thus deepening the demographic peripheralization and marginalization in which the remaining populations live.

ORCID

Liliana Castillo-Rivero https://orcid.org/0000-0001-9531-8799

REFERENCES

Agnoletti, M., Errico, A., Santoro, A., Dani, A., & Preti, F. (2019). Terraced landscapes and hydrogeological risk. Effects of land abandonment in cinque Terre (Italy) during severe rainfall events. *Sustainability*, *11*(1), 235. https://doi.org/10.3390/su11010235

Angelstam, P., Manton, M., Yamelynets, T., Fedoriak, M., Albulescu, A. C., Bravo, F., Cruz, F., Jaroszewicz, B., Kavtarishvili, M., Muñoz-Rojas, J., Sijtsma, F., Washbourne, C. L., Agnoletti, M., Dobrynin, D., Izakovicova, Z., Jansson, N., Kanka, R., Kopperoinen, L., Lazdinis, M., … Zagidullina, A. (2021). Maintaining natural and traditional cultural green infrastructures across Europe: Learning from historic and current landscape transformations. *Landscape Ecology*, *36*, 637–663. https://doi.org/10.1007/s10980-020-01161-y

Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E., & Harris, A. T. (2004). Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources*, *29*, 261–299. https://doi.org/10.1146/annurev.energy.29.062403.102142

Baah, F. O., Teitelman, A. M., & Riegel, B. (2019). Marginalization: Conceptualizing patient vulnerabilities in the framework of social determinants of health—An integrative review. *Nursing Inquiry*, *26*(1), e12268. https://doi.org/10.1111/nin.12268

Balvanera, P., Cotler, H., Aburto Oropeza, O., Aguilar Contreras, A., Aguilera Peña, M., Aluja, M., Andrade Cetto, A., Arroyo Quiroz, I., Ashworth, L., & Guevara Sanginés, A. E. (2009). Estado y tendencias de los servicios ecosistémicos. In *Capital natural de México* (Vol. II, pp. 185–245). Estado de conservación y tendencias de cambio.

Benayas, J. R., Martins, A., Nicolau, J. M., & Schulz, J. J. (2007). Abandonment of agricultural land: An overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *2*(57), 1–14. https://doi.org/10.1079/PAVSNNR20072057

Brandolini, P., Cevasco, A., Capolongo, D., Pepe, G., Lovergine, F., & Del Monte, M. (2018). Response of terraced slopes to a very intense rainfall event and relationships with land abandonment: A case study from cinque Terre (Italy). *Land Degradation & Development*, *29*(3), 630–642. https://doi.org/10.1002/ldr.2672

Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Mapping ecosystem service supply, demand, and budgets. *Ecological Indicators*, *21*, 17–29. https://doi.org/10.1016/j.ecolind.2011.06.019

Castillo-Rivero, L., McCann, P., & Sijtsma, F. J. (2021). A multi-scale approach to rural depopulation in Mexico. *Regional Science Policy & Practice*, *13*(4), 1328–1347.

Cilluffo, A., & Ruiz, N. G. (2019). World's population is projected to nearly stop growing by the end of the century. *Pew Research Center*, *17*.

Coleman, D., & Rowthorn, R. (2011). Who's afraid of population decline? A critical examination of its consequences. *Population and Development Review*, *37*, 217–248. https://doi.org/10.1111/j.1728-4457.2011.00385.x

Conabio. (2008). Geographic metadata catalog, actualized in 2008, based on Lugo-Hubp, J., F. Aceves-Quezada et al., 1992.

Conabio. (2016). La milpa. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Cd. de México. México. Content: Mahelet Lozada Aranda y Alejandro Ponce Mendoza. https://www.biodiversidad.gob.mx/diversidad/sistemas-productivos/milpa

Conabio-Geoportal. (n.d.). National Information System on Biodiversity (SNIB). Available at: http://www.conabio.gob.mx/informacion/gis/

Decina, S. M., Hutyra, L. R., & Templer, P. H. (2020). Hotspots of nitrogen deposition in the world's urban areas: A global data synthesis. *Frontiers in Ecology and the Environment*, *18*(2), 92–100. https://doi.org/10.1002/fee.2143

Dimitrov, D. (2016). Factors for the economic marginalization of the northwestern statistical region and tools for its overcoming. *Zbornik Radova-Geografski Fakultet Univerziteta U Beogradu*, *64*, 131–144. https://doi.org/10.5937/zrgfub1664131D

Elbakidze, M., Angelstam, P., Yamelynets, T., Dawson, L., Gebrehiwot, M., Stryamets, N., Johansson, K. E., Garrido, P., Naumov, V., & Manton, M. (2017). A bottom-up approach to map land covers as potential green infrastructure hubs for human well-being in rural settings: A case study from Sweden. *Landscape and Urban Planning*, *168*, 72–83. https://doi.org/10.1016/j.landurbplan.2017.09.031

Fuerst-Bjeliš, B. (2020). Environmental response to marginality: Between borderlands and Littoralization in the eastern Adriatic. In *Globalization, marginalization and conflict* (pp. 75–87). Springer.

García, E. (1988). *Modificaciones al sistema de clasificación climática de Köppen Para adaptarlo a las condiciones particulares de la República Mexicana*. Talleres Offset Larios.

García-Martínez, B. (2008). *Las regiones de México. Breviario geográfico e histórico*. El Colegio de México.

García-Ruiz, J. M., & Lana-Renault, N. (2011). Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region–a review. *Agriculture, Ecosystems & Environment*, *140*(3–4), 317–338. https://doi.org/10.1016/j.agee.2011.01.003

Hardelin, J., & Lankoski, J. (2018). Land use and ecosystem services. OECD food, agriculture and fisheries, papers no. 114.

Harper, S. (2016). *How population change will transform our world*. Oxford University Press.

Heffner, K., & Latocha, A. (2020). Desolated villages as examples of spatial, economic and social marginalization in the polish-Czech borderland and their current transformations. In *Responses to geographical marginality and marginalization* (pp. 123–142). Springer.

INEGI. (2000). XII General Population and Housing Census 2000.

INEGI. (2017). *Conjunto de Datos Vectoriales de Uso de Suelo y Vegetación. Escala 1:250 000. Serie VI (Capa union), escala: 1: 250 000. edición: 1*. Instituto Nacional de Estadística y Geografía. Aguascalientes.

INEGI. (2020). Principales resultados por localidad (iter). Mexico.

INEGI. (2021). Historical archive of geostatistical locations (AHLG). Online: https://www.inegi.org.mx/app/geo2/ahl/

IPBES. (2018). The IPBES assessment report on land degradation and restoration. In L. Montanarella, R. Scholes, & A. Brainich (Eds.), *Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany* (pp. 744).

Jenkins, M., & Schaap, B. (2018). Forest ecosystem services. In United Nations Forum on Forests. April

Kousis, M. (1998). Ecological marginalization in rural areas: Actors, impacts, responses. *Sociologia Ruralis*, *38*(1), 86–108. https://doi.org/10.1111/1467-9523.00065

Lasanta, T., Nadal-Romero, E., & Arnáez, J. (2015). Managing abandoned farmland to control the impact of re-vegetation on the environment. The state of the art in Europe. *Environmental Science & Policy*, *52*, 99–109. https://doi.org/10.1016/j.envsci.2015.05.012

Levers, C., Romero-Muñoz, A., Baumann, M., De Marzo, T., Fernández, P. D., Gasparri, N. I., Gavier-Pizarro, G. I., Waroux, Y. L., Piquer-Rodríguez, M., Semper-Pascual, A., & Kuemmerle, T. (2021). Agricultural expansion and the ecological marginalization of forest-dependent people. *Proceedings of the National Academy of Sciences*, *118*(44), e2100436118. https://doi.org/10.1073/pnas.2100436118

Lugo-Hubp, J., & Aceves-Quezada, F. (1992). *El relieve Como atractivo natural, en* Estados de los componentes naturales del medio ambiente, *V.2.1* atlas Nacional de México. *Vol II. Escala 1:4000000*. Instituto de Geografía, UNAM.

Lugo-Hubp, J. L. (1989). *Dicionário geomorfológico*. Universidade Nacional Autónoma de México, Instituto de Geografia.

Lutz, W., & Gailey, N. (2020). *Depopulation as a policy challenge in the context of global demographic trends*.

Lutz, W., Sanderson, W., & Scherbov, S. (2001). The end of world population growth. *Nature*, *412*(6846), 543–545. https://doi.org/10.1038/35087589

Malin, S. A., Ryder, S., & Lyra, M. G. (2019). Environmental justice and natural resource extraction: Intersections of power, equity and access. *Environmental Sociology*, *5*(2), 109–116. https://doi.org/10.1080/23251042.2019.1608420

Martínez-Abraín, A., Jiménez, J., Jiménez, I., Ferrer, X., Llaneza, L., Ferrer, M., Palomero, G., Ballesteros, F., Galán, P., & Oro, D. (2020). Ecological consequences of human depopulation of rural areas on wildlife: A unifying perspective. *Biological Conservation*, *252*, 108860. https://doi.org/10.1016/j.biocon.2020.108860

Melgaço, L. (2021). Challenging peripherality through access to the internet? Socio-spatial practices of the connected rurban. *Urban Research & Practice*, *14*(1), 73–93. https://doi.org/10.1080/17535069.2019.1655091

Millennium ecosystem assessment, M. E. A. (2005). *Ecosystems and human well-being* (Vol. 5). Island press.

Molla, T. (2018). Peripherality and educational disadvantage. In *Higher education in Ethiopia* (pp. 81–100). Springer.

Mora, F. (2017). A structural equation modeling approach for formalizing and evaluating ecological integrity in terrestrial ecosystems. *Ecological Informatics*, *41*, 74–90.

Murakami, Y., & Hamaguchi, N. (2021). Peripherality, income inequality, and economic development in Latin American countries. *Oxford Development Studies*, *49*(2), 133–148. https://doi.org/10.1080/13600818.2021.1880559

Nayak, P. K., Oliveira, L. E., & Berkes, F. (2014). Resource degradation, marginalization, and poverty in small-scale fisheries: Threats to social-ecological resilience in India and Brazil. *Ecology and Society*, *19*(2), art73. https://doi.org/10.5751/ES-06656-190273

OECD. (2012). Environmental Outlook to 2050: The consequences of inaction, Highlights. https://www.oecd.org/env/indicators-modelling-outlooks/49846090.pdf

Plieninger, T., Hartel, T., Martín-López, B., Beaufoy, G., Bergmeier, E., Kirby, K., Montero, M. J., Moreno, G., Oteros-Rozas, E., & Van Uytvanck, J. (2015). Wood-pastures of Europe: Geographic coverage, social–ecological values, conservation management, and policy implications. *Biological Conservation*, *190*, 70–79. https://doi.org/10.1016/j.biocon.2015.05.014

Plieninger, T., Hui, C., Gaertner, M., & Huntsinger, L. (2014). The impact of land abandonment on species richness and abundance in the Mediterranean Basin: A meta-analysis. *PLoS ONE*, *9*(5), e98355. https://doi.org/10.1371/journal.pone.0098355

Queiroz, C., Beilin, R., Folke, C., & Lindborg, R. (2014). Farmland abandonment: Threat or opportunity for biodiversity conservation? A global review. *Frontiers in Ecology and the Environment*, *12*(5), 288–296. https://doi.org/10.1890/120348

Reher, D. S. (2007). Towards long-term population decline: A discussion of relevant issues. *European Journal of Population/Revue Europeenne de Demographie*, *23*(2), 189–207. https://doi.org/10.1007/s10680-007-9120-z

Rimal, B., Sharma, R., Kunwar, R., Keshtkar, H., Stork, N. E., Rijal, S., Rahman, S. A., & Baral, H. (2019). Effects of land use and land cover change on ecosystem services in the Koshi River basin, eastern Nepal. *Ecosystem Services*, *38*, 100963. https://doi.org/10.1016/j.ecoser.2019.100963

Rodrigo-Comino, J., Martínez-Hernández, C., Iserloh, T., & Cerda, A. (2018). Contrasted impact of land abandonment on soil erosion in Mediterranean agriculture fields. *Pedosphere*, *28*(4), 617–631. https://doi.org/10.1016/S1002-0160(17)60441-7

Semarnat. (2015). Informe de la Situación del Medio Ambiente en México 2015. Compendio de Estadísticas Ambientales, Indicadores Clave de Desempeño Ambiental y de Crecimiento Verde. México.

Semarnat. (2010). Atlas geográfico del medio ambiente y recursos naturales.

Sitzia, T., Semenzato, P., & Trentanovi, G. (2010). Natural reforestation is changing spatial patterns of rural mountain and hill landscapes: A global overview. *Forest Ecology and Management*, *259*(8), 1354–1362. https://doi.org/10.1016/j.foreco.2010.01.048

Svarichevskaya, Z. A. (1978). Gori. In K. N. Paffengolts (Ed.), *Gueologuichesky slovar* (pp. 183–184). Niedra.

Tagai, G., Bernard, J., Šimon, M., & Koós, B. (2018). Two faces of peripherality: Labour markets, poverty, and population dynamics in Hungary and Czechia. *Regional Statistics*, *8*(2), 19–45. https://doi.org/10.15196/RS080204

Uchida, K., & Ushimaru, A. (2014). Biodiversity declines due to abandonment and intensification of agricultural lands: Patterns and mechanisms. *Ecological Monographs*, *84*(4), 637–658. https://doi.org/10.1890/13-2170.1

Uchida, K., & Ushimaru, A. (2015). Land abandonment and intensification diminish spatial and temporal β-diversity of grassland plants and herbivorous insects within paddy terraces. *Journal of Applied Ecology*, *52*(4), 1033–1043. https://doi.org/10.1111/1365-2664.12443

UN. (2018). 2019 revision of world population prospects. United Nations Department of Economic and Social Affairs.

UN, United Nations. (2022). The sustainable development goals report 2022.

UNEP and FAO. (2020). Strategy of the UN decade on ecosystem restoration. Nairobi and Rome. Draft 6 February 2020.

Van Leeuwen, C. C., Cammeraat, E. L., de Vente, J., & Boix-Fayos, C. (2019). The evolution of soil conservation policies targeting land abandonment and soil erosion in Spain: A review. *Land Use Policy*, *83*, 174–186. https://doi.org/10.1016/j.landusepol.2019.01.018

Zepeda, R. V. (2005). *Las Regiones Climáticas de México*. Instituto de Geografía. UNAM.

How to cite this article: Castillo-Rivero, L., Elbakidze, M., McCann, P., & Sijtsma, F. J. (2023). Depopulation and ecological degradation, two dimensions of marginalization, and peripheralization. Ecosystem integrity as an assessment factor in local revitalization. *Regional Science Policy & Practice*, 1–22. https://doi.org/10.1111/rsp3.12706

APPENDIX A: ECOSYSTEM SERVICES, AND ASSOCIATED LAND USE AND LAND COVERS

Service	Ecosystem/land use & cover type that provides the service
Biochemical and genetic resources	
Wild food – commercial	
Wild food – subsistence	All ecosystems
Wild medicine	
Bioenergy	Arable land, forest
Firewood	Forests, jungles, bushes, mangroves, deserts
Fodder	Pasture, enclosures, agricultural field (food supplements), bushes, xeric scrubland, jungles, and forests
Food agricultural commercial - agriculture	
Food agricultural subsistence - agriculture	Arable land
Fresh water – drinking	Inland terrestrial and aquatic ecosystems
Health	All ecosystems of the country
Timber	Forests and jungles
Air quality regulation	
Climate regulation – Local	
Climate regulation – Global	
Water regulation	All terrestrial, aquatic, and marine ecosystems
Water purification and waste treatment	
Natural hazard regulation	All terrestrial ecosystems
Erosion regulation	Terrestrial ecosystems
Disease regulation	
Natural disturbance	
Noise regulation	
Pest regulation	All ecosystems
Pollination	
Seed dispersal	
Water circulation	all terrestrial, aquatic, and marine ecosystems
Habitat species	
Nutrient cycling	
Photosynthesis	All ecosystems
Primary production	
Species	

Source: Balvanera and Cottler (2009)

APPENDIX B: SURVEY QUESTIONS AND GENERAL FEATURES OF RESPONDENTS

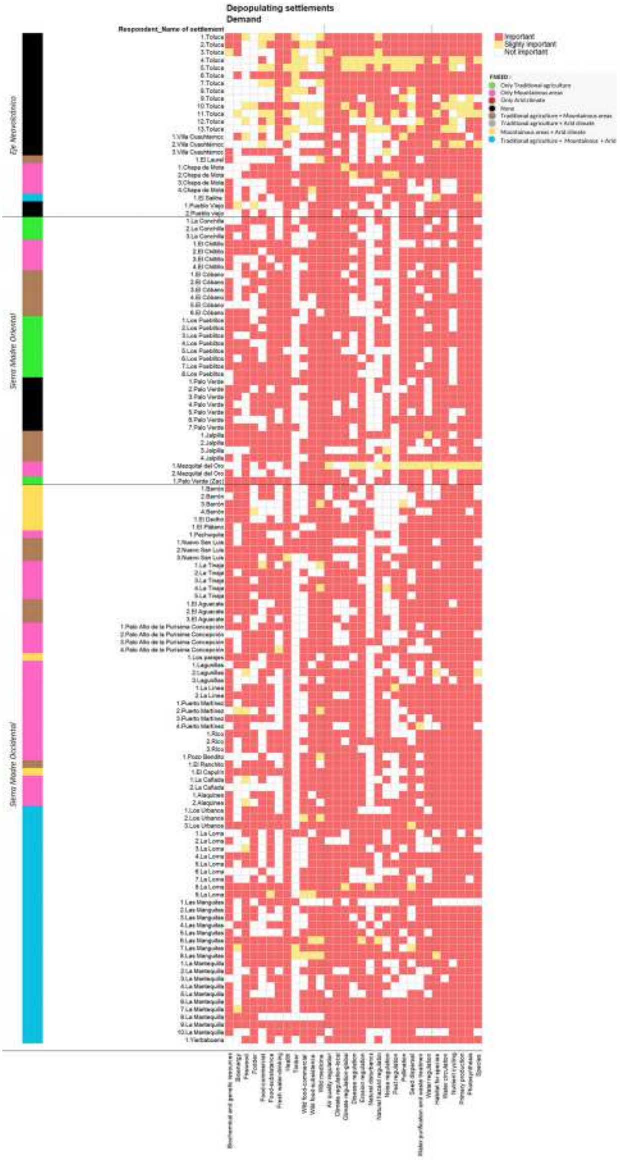
The importance of the Ecosystem Services

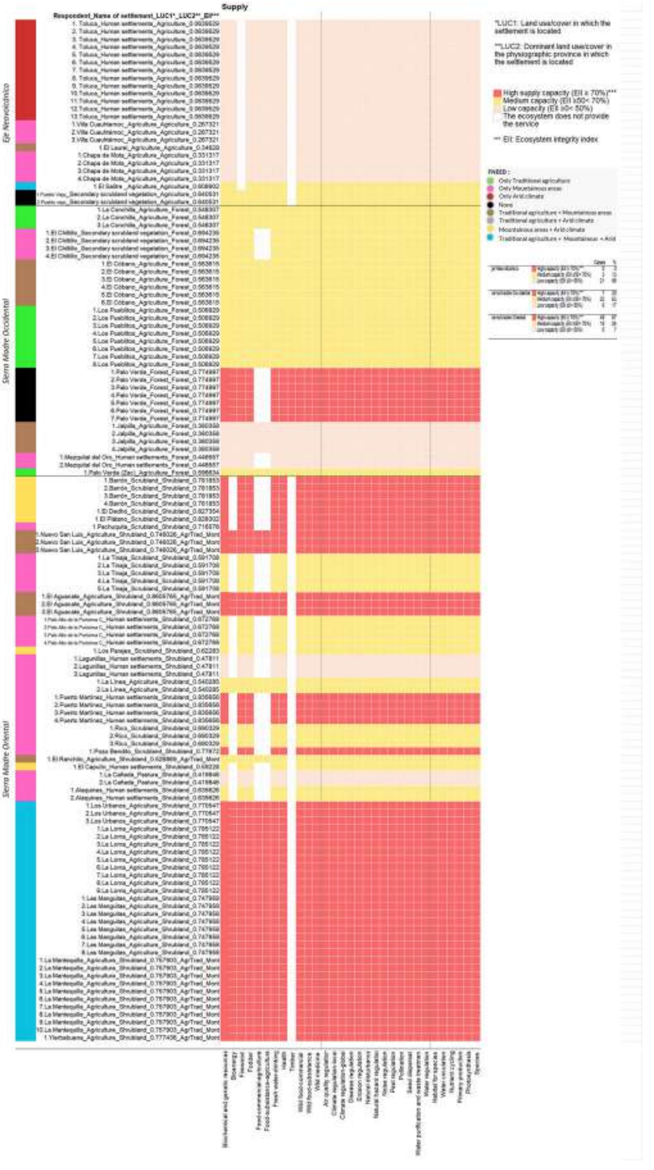
Question. What products/services from the landscape (nature) are important for your personal well-being?

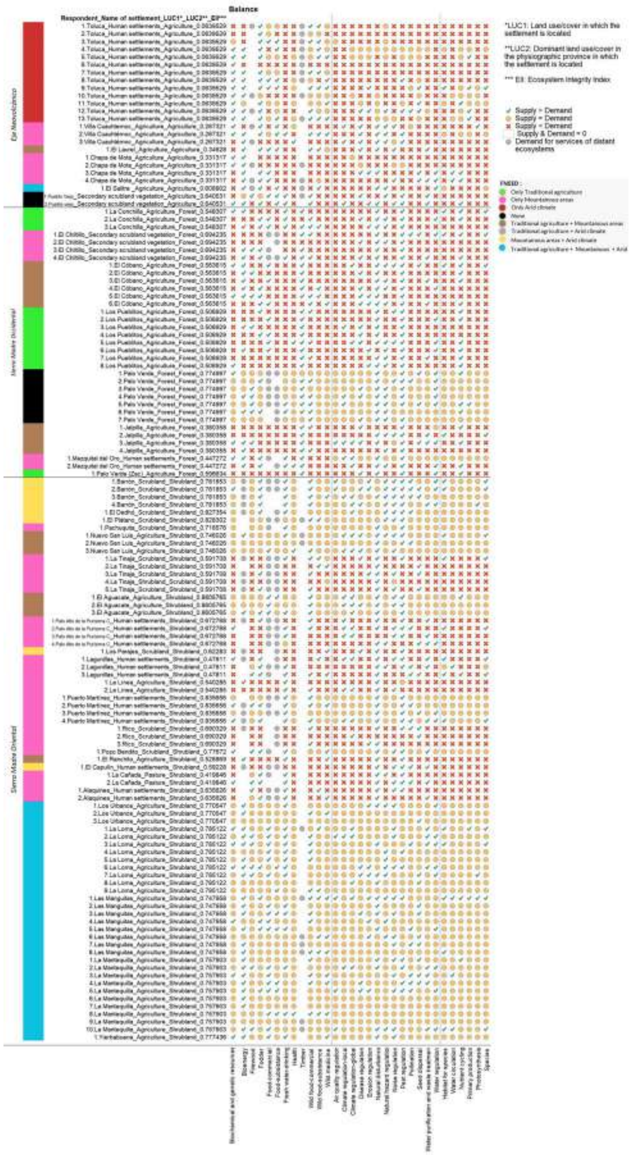
	Important	Slightly important	Not important	Do not know
Air quality regulation	○	○	○	○
Biochemical and genetic resources	○	○	○	○
Bioenergy	○	○	○	○
Climate regulation - global	○	○	○	○
Climate regulation - local	○	○	○	○
Disease regulation	○	○	○	○
Erosion regulation	○	○	○	○
Firewood	○	○	○	○
Fodder	○	○	○	○
Food - commercial	○	○	○	○
Food - subsistence	○	○	○	○
Fresh water - drinking	○	○	○	○
Habitat species	○	○	○	○
Health	○	○	○	○
Natural disturbance	○	○	○	○
Natural hazard regulation	○	○	○	○
Noise regulation	○	○	○	○
Nutrient cycling	○	○	○	○
Pest regulation	○	○	○	○
Photosynthesis	○	○	○	○
Pollination	○	○	○	○
Primary production	○	○	○	○
Seed dispersal	○	○	○	○
Species	○	○	○	○
Timber	○	○	○	○
Water circulation	○	○	○	○
Water purification and waste treatment	○	○	○	○
Water regulation	○	○	○	○
Wild food - commercial	○	○	○	○
Wild food - subsistence	○	○	○	○
Wild medicine (wild plants, animals)	○	○	○	○

Features of respondents	Respondents
Employment	
Employed in primary sector	11
Employed in secondary sector	4
Employed in terciary sector	54
Housewife	46
Student	5
Retired	2
Unemployed	10
Education	
Primary school	24
Secondary school	36
College/High school	26
University	4
No education	42
Age	
18-25	22
26-35	19
36-45	30
46-55	20
56-65	11
66-75	17
76-85	12
ND	1
Gender	
Female	86
Male	46

APPENDIX C: SUPPLY, DEMAND, AND BALANCE MATRICES




Supply
Eje Neovolcánico
Sierra Madre Occidental
Sierra Madre Oriental
*LUC1: Land use/cover in which the settlement is located
**LUC2: Dominant land use/cover in the physiographic province in which the settlement is located
High supply capacity (EII ≥ 70%)***
Medium capacity (EII ≥50< 70%)
Low capacity (EII ≥0< 50%)
The ecosystem does not provide the service
*** EII: Ecosystem integrity index


Balance
*LUC1: Land use/cover in which the settlement is located
**LUC2: Dominant land use/cover in the physiographic province in which the settlement is located
*** EII: Ecosystem Integrity Index
Supply & Demand = 0
Demand for services of distant ecosystems
Only Traditional agriculture
Only Mountainous areas
Only Arid climate
None
Traditional agriculture + Mountainous areas
Traditional agriculture + Arid climate
Mountainous areas + Arid climate