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Article

One Shared Region and Two Different Change Patterns: Land Use Change in the Binational Californian Mediterranean Region

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Abstract: The Californian Floristic Province, ranging from Northern California, USA, to the northwestern portion of the state of Baja California, Mexico, is a region of great biological richness that has a high risk of loss of species due to the effect of human activities. The main stressor that threatens its biodiversity is the change in land use and vegetation cover, which severely impacts the environmental and socio-economic systems' functioning, affecting the provision of environmental services including the maintenance of biodiversity. The Tijuana River Watershed (TRW) is located within this floristic province. It has experienced rapid population growth during the last 50 years, demanding development of infrastructure in areas where native vegetation existed. As a binational watershed, it is an ideal area to study the processes involved in fragmentation and connectivity of natural environments, since both countries, while sharing the same environment, contrast greatly in their economic and social systems, which impose different pressures to these shared natural resources. Our research addresses change in vegetation cover and land use in the TRW, analyzing the changes and differences between Mexico and the United States. This analysis will be a basis to propose future management strategies for the conservation of ecological processes and biodiversity, according to the policies and actions for land management and conservation in both countries.

Keywords: land use and vegetation cover; Tijuana River Watershed; California floristic province; Tijuana; San Diego; binational

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1. Introduction

Conservation efforts have identified areas of greater biological richness and those that present high risk of loss of species due to human activities. These regions are known as hotspots [1] and of the 34 currently defined around the world, one is the Californian Floristic Province, which is shared between the northern portion of Baja California in Mexico and the states of California and Oregon in the United States (U.S.) (Figure 1). This province is characterized by a Mediterranean climate, a high diversity of communities, and many endemic species of flora and fauna, many of which are threatened by the expansion of urban areas, pollution, and roads construction [1–3].

Figure 1. Binational and local settlement of Tijuana River Watershed. Source: Produced with information from http://www.cec.org/ and http://trw.sdsu.edu (accessed on 1 April 2013).

One of the main threats to biodiversity in Hotspots is the change in land use and cover, which severely impacts environmental and socio-economic systems, and affects sustainability, provision of food and supplies, maintenance of biodiversity and vulnerability of populations and ecosystems [4]. These changes in land use and vegetation cover occur through five driving forces: natural, socio-economic, policy-legislation, technology and cultural [5]. Due to their importance in conservation biology, the study of land use and cover change is one of the most important issues in current ecological and environmental research [6].

Since 1940, Northwestern Mexico and Southern California have exhibited accelerated population, urban and economic growth [7]. Three of the main factors that promoted this growth are (1) the ending of the U.S. "Programa Bracero" in 1964, which caused the return of workers from the U.S. to Mexico, (2) the beginning of the industrialization of the Mexican side of the border in 1965 [8], and, (3) the resulting population growth demanding areas for housing and the development of infrastructure, which caused the conversion of land with native vegetation or agriculture [9].

The Tijuana River Watershed (TRW), which covers parts of both countries in this region, was particularly affected by these processes and offers an ideal setting to study socio-economic and political influences on fragmentation and connectivity of natural environments, as those factors diverge widely on both sides of the border [10]. Historically, in the TRW, the planning processes have stopped at the border of each country, and no consideration has been given to binational conservation actions and shared resources. Hence, current public and private policies, legislation at the different levels of government in both countries, and the actions and financial resources geared to the management and conservation of natural resources differ greatly in both directions from the border [11].

The presence, maintenance, loss, change, recovery and use of the natural cover and land use have been integrated in the concepts of Land Use and Land Cover [12–14]. These concepts of Land Cover and Land Use are commonly confused in most land assessments, including those derived from satellite imagery [14]. Nonetheless, these concepts have been used commonly for at least the last 25 years [13]. Some approaches, merge the two terms in a single Land Use and Vegetation Cover concept, and derived from this, the Land Use and Cover Change (LUCC) analysis. The land cover/land use couplet has been adopted by much subsequent work and has become the goal and base for many land assessments, where the differences between land cover and land use are frequently noted but not analyzed [13]. Although some authors recommend the separate use of these terms, in this work the term Land Use and Vegetation Cover (LUVC) is used, considering that land-soil classification systems in the two countries are based on the coupled land cover/land use concept. In both Mexico and the U.S., data publishers obtained land use and cover information in order to develop a land use and land cover classification system for each country, that could be used in planning land use and management activities for government and private organizations [15].

Changes in land use and cover link to the occupation of the territory by humans in the TRW, which began in 1829 when a land grant that included what is now Tijuana and parts of San Ysidro was granted. In 1876, an urbanization policy commenced in Baja California. Settlement of the region continued slowly until the 1960s and 1970s, when a boost of the business sector, investment in infrastructure in the Tijuana River and migration increased the pace of land occupation [16]. From the 1970s onward, human settlements grew and the region developed heavily. Between 1972 and 1994, the watershed lost 200 km^2 of native vegetation from 85 patches in Mexico and 110 km^2 from 87 patches in U.S. [10].

This process of change in land use from natural to urban occurs in three phases: pre-urban vegetation, construction phase, which exposes bare soil for one to three years, and mature phase with impervious surfaces and vegetation. The process has varied through time. Thus, areas recently urbanized in Tijuana (1994–2002) had a higher soil fraction (40%) and a lower impervious surface fraction (20%) than areas urbanized prior to 1938 (17% soil and 62% of impervious surface). This pattern of urbanization in Tijuana resulted in higher percentages of bare soil, and possibly high sediment production potential for decades following the later urbanization [17]. More recently, between 1992 and 2005, urban areas and grasslands grew the most in TRW, while coastal scrub and chaparral decreased in surface. The conversion of coastal scrub resulted in a landscape that was more fragmented in 2005 than in 1994 [18].

Our research addresses the change in land use and vegetation cover in the TRW between 1990 and 2011, analyzing general processes of change and addressing the differences of those changes between Mexico and the U.S. We propose that our analyses and results provide the foundation for management strategies for the conservation of ecological processes and biodiversity in both countries.

2. Study Area

The TRW is a 450,000 ha area shared between northwestern Baja California, Mexico and Southwestern California, U.S. A little over 75% is located in Mexico [10,19–21] (Figure 1). The study area included the TRW [22] plus a 10 km band around it, within the terrestrial part of Mediterranean ecoregion [23]. This buffer zone harbors most or all of the TRW's wildlife species and is representative of the vegetation types, habitats and species present inside the TRW. Such a buffer zone allows for 75% of larger area to analyze and will, hence, permit a better understanding of the phenomena under investigation. Additionally, consideration of this larger area will provide a better framework for future research on natural, ecological and socioeconomic phenomena in the region. The TRW does not have an officially recognized boundary by any of the two countries and does not consider areas for or without future urban expansion. Consideration of urban growth, at least to the year 2023, already was suggested to analyze changes in the TRW [24]. The use of this buffer area allows for it since it includes on the Mexican side, Rosarito, the Rosarito-Tijuana Corridor, part of Parque Nacional Constitucion and part of the Valle de Guadalupe-Tecate corridor, places were urban development and conservation took place in the last few years. In the United States, this band includes Chula Vista, Otay Lakes, El Descanso and part of Cleveland National Forest. The study area defined is 780,199 ha, including 445,172 ha of the TRW (other authors have given 53,200, 449,300 and 445,000 ha [10,21,25]) and 335,027 ha of the buffer zone (Figure 1). The use of this TRW buffer allows modeling of the expansion and change of land use and cover in a current context, incorporating areas of impact, growth and conservation that are influencing history and maintenance of processes of land use and vegetation cover and wildlife habitat within the TRW. The boundary is the eastern limit of the Mediterranean zone towards east from TRW.

The topography of the area is of low hills and, in some places, steep slopes. Altitude ranges from sea level to almost 2000 m above sea level [26]. The TRW occupies a region of complex geology on the western slopes of Peninsular Ranges of Southern California and Baja California, in which the dominant rock in the upper watershed consists of Plutonic rocks of Peninsular Batholith. In the lower watershed, the rocks are primarily of Oligocene, Miocene, Pliocene, and Pleistocene ages [27].

The watershed's geomorphology is a reflection of its tectonic history and morphogenetic processes [28]. The study area can be divided in four major geomorphology units: In the east, a wide area of gentle to moderately undulating terrain that extends to the central part of the watershed. In the western part of the previous, predominant flat surface change to undulating landforms, bordered by highly dissected and steeply slopes. Farther west, the landscape changes abruptly in the coastal zone, in which large mesas are comprised of loosely cemented sandstones and conglomerates. Finally, areas downstream and surrounding Tijuana River Valley are comprised of a series of terraces in the valley sides, and a large concrete channel in the valley bottom, the same conditions as in Valle de Las Palmas [28].

The climate is Mediterranean with rain occurring during the winter. TRW displays a wide range of average temperatures and in the lower elevations annual mean temperatures generally range from 16 to 19 °C. Lower temperatures, of 9 to 11 °C, occur in the extreme north and southeast portions of the TWR. Precipitation varies widely throughout the watershed, and annual mean values range from just over 200 mm in the west to nearly 1092 mm in the east [29]. The TRW is part of the California Floristic Province, one of the biodiversity hotspots of the world [1]. The dominant vegetation types are chaparral, coastal scrub, mixed conifer forest, mountain meadows and riparian forest.

Most of the land in this region is devoted to urban spaces, agriculture and the raising of livestock, with each country differing in patterns of land use and vegetation cover [10]. Rapid urban growth in San Diego County and the municipalities of Tijuana and Tecate is destroying and fragmenting natural habitats and negatively affecting the diversity of species that depend on them. Natural resources along the international border are especially vulnerable because they have not been included in regional planning processes with a binational vision [30], resulting in a high and different risk of biodiversity loss between both countries.

3. Experimental Section (Methods)

3.1. Information Compilation

Land Use and Vegetation Maps at a 1:250,000 scale by the National Institute of Statistics, Geography and Informatics (INEGI) were used for Mexico (Table 1). For our analyses, we used maps issued in 1993 (series II maps) and 2011 (series V maps). They are provided in vector format, which we converted to raster format with a resolution of 30 meters, a resolution adequate to couple them with the data for the U.S. and to maintain data resolution and accuracy according to Landsat satellite images used for their creation. For the U.S., we used information by the U.S. Geological Survey (USGS; Table 1) in raster format, with 30-meter spatial resolution, that was generated through classification of Landsat satellite images. We use Landuse and Vegetation cover data products created from 1990 and 2011 LANDSAT images.

Table 1. Source and specifications of input data for Land Use and Cover Change (LUCC) analysis.

Country	Raw Data Source	Resolution	Classification Method	# LUVC Classes
US	1990 Landsat TM	30 m	Unsupervised	21
	2011 Landsat TM	30 m	Decision tree	16
Mexico	1993 Landsat TM	30 m	Supervised	8
	2011 Landsat TM	30 m	Supervised	13

3.2. Land Use and Vegetation Cover Information Standardization

Once information on land use and vegetation cover for both countries was compiled and their georeference standardized, LUVC data was extracted using TRW limits and adjacent buffer zone. In order to analyze the patterns of change in land use and vegetation cover, we standardized the names of the categories of land use and vegetation cover between the two countries. For this, the definition for each LUVC for each country was analyzed, in terms of elements that describe communities, such as life form (trees, shrubs, herbs); function (evergreen or deciduous); and cover or density of dominant species. For urban, agricultural and livestock uses categories, subcategory names were pooled from the original classification. This was done for each country's data set and subsequently standardized between the two countries.

3.3. LUVC Change and Fragmentation Analyses

There are two ways to analyze the change of LUVC: between and within LUVC classes. Change between LUVC classes accounts for conversion from one LUVC class to a completely different class, for example from forest to urban. A change within classes is the modification of the condition of the land-cover type to other within the same category, for example from primary forest to secondary forest [31]. We analyzed the changes between classes, using the Land Change Modeler (LCM) module within IDRISI Selva software, following criteria in Pontius *et al.* [32]. We used LCM tools for the assessment of land cover change, using two land cover maps (earlier and later) with identical land-cover types legends. The change analysis panel provided a rapid assessment of quantitative change by graphing gains and losses by land cover categories. A second tool, net change, exhibited the result of adding the gains and subtracting the losses to the earlier land cover maps. The third LCM tool used was the analysis of the contribution to changes experienced by individual land cover types [33,34]. Analyses were performed at a pixel level, and focused on the transition of the different classes in the earlier land cover map to different classes in the later land cover map [33,35,36]. We created maps of observed changes per category and relationships of changes between categories, measured in hectares and interpreted according to four general processes of LUCC [37]:

1. Deforestation. Loss of primary or secondary natural vegetation cover.
2. Anthropization. Change of natural vegetation cover to any predominantly human use, such as urban or cultivated.
3. Abandonment. Change of cultivated, agricultural or livestock use to a Barren. Changes in any of these original categories to something different than barren are classified either as anthropization or as recovery, depending on the change.
4. Recovery. Change of any non-natural vegetation land use or cover to any natural vegetation cover.

We calculated basic fragmentation metrics, number of patches and mean patch area, for each category and year studied, using Fragstats 4.2.1. Software.

4. Results and Discussion

The standardization of LUCV classes produced 10 shared categories and one category only for Mexico (Table 2). Surface gains and losses were markedly different for the different categories and between the two countries (Figure 2; Table 3). LUVC categories with greatest changes in both countries were: Urban, grassland-herbaceous, shrub-scrub, cultivated, barren, and evergreen forest, which corresponded to 98% of the total area in Mexico and 91% of that in the U.S., in 2011. These categories changed in their rank of occupied surface during the study period (Table 4). In Mexico, urban went from the fifth place to the third; and cultivated from the third to the fifth. In the U.S., urban changed from fourth to third; and evergreen forest from third to fourth. Shrub-scrub remained as the LUVC's most important category in both countries, occupying >60% of total land in both countries and years analyzed (Table 3). This is the characteristic vegetation in the region and the principal habitat available for wildlife [3].

Total area persistence in its original land use and vegetation class from 1993 to 2011 for Mexico was 97% (510,316 ha) and for the United States 85% (219,495 ha). For Mexico, barren, mixed forest and riparian shrub did not persist in more than 80% of their initial surface, while for the U.S., barren, evergreen forest, shrub-scrub and cultivated did so (Table 3). Grassland-herbaceous and urban had the largest surface gain in both countries, with 5666 and 24,218 ha in Mexico; and 3434 and 20,169 ha in the U.S., respectively (Table 3). This is consistent with previous works [10,18], in which urban and grasslands gained from deforestation or vegetation degradation, and grassland-herbaceous was the initial recuperation stage after a burning, grazing, logging or clearing, activities associated with ejidos (a form of land tenure) in Mexico [18,38]. In both countries grassland-herbaceous was lost to Urban (3970 ha in Mexico, and 4927 ha in the U.S.). Gains in grassland-herbaceous were at the expense of shrub-scrub (6949 ha in Mexico and 6994 ha in the U.S.) and, to a lesser degree of cultivated areas and evergreen forest (Figure 3). The grassland-herbaceous habitat is a result of shrub-scrub deforestation or degradation, and, in the near future, it can change to urban or recover to shrub-scrub [39].

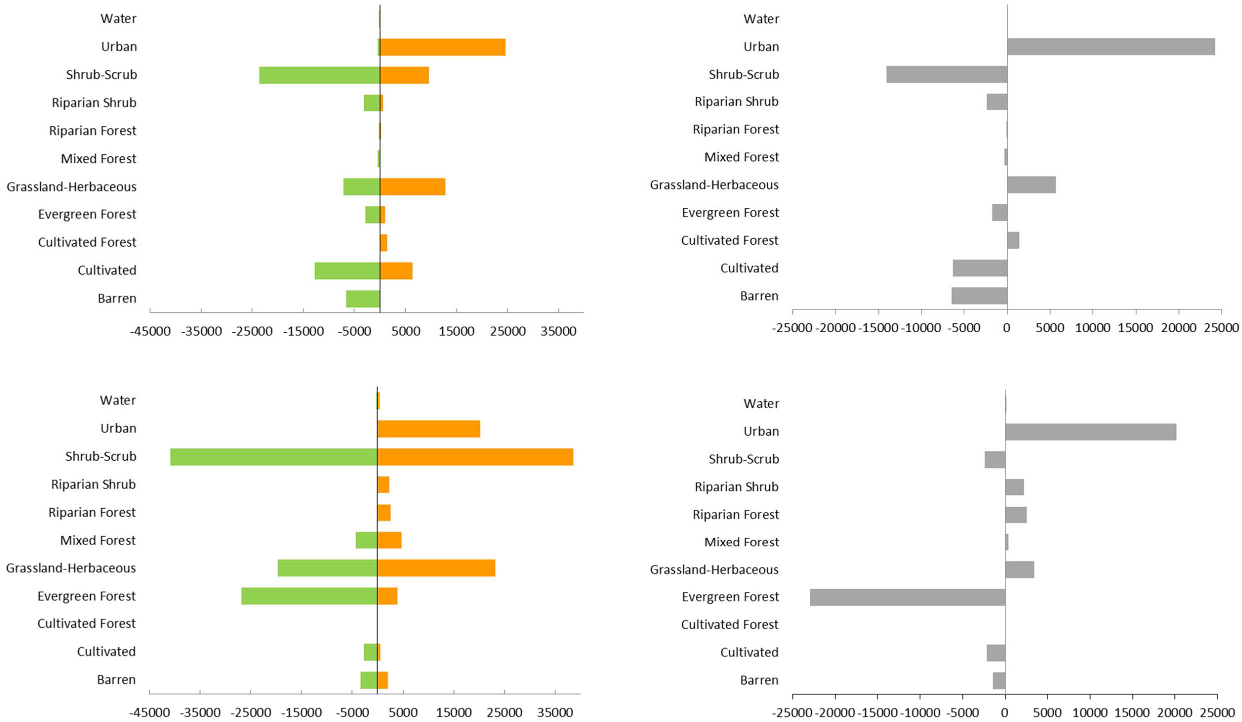

Figure 2. Gains and losses and net change per land use and vegetation cover category. Units are in hectares. (**Left**) gain and loss between 1993 and 2011 in Mexico (**top**) and between 1990 and 2011 in United States (**bottom**). (**Right**) net change in same periods and countries.

Table 2. Standardization of Land Use and Vegetation Cover (LUVC) categories names between countries.

Land Cover Classes (Mexico) as Published in Spanish	Land Cover Classes (United States)	Standardized Class Number	Standardized Class Name
Cuerpo de Agua	Open Water	1	Water
Urbano/Asentamiento Humano	Urban/Developed	2	Urban
Sin Vegetación	Barren	3	Barren
Bosque de Pino	Evergreen Forest	4	Evergreen Forest
Bosque de Pino	Evergreen Forest	4	Evergreen Forest
Bosque de Juniperus	Evergreen Forest	4	Evergreen Forest
Bosque de Pino	Evergreen Forest	4	Evergreen Forest
Bosque de Pino	Evergreen Forest	4	Evergreen Forest
Bosque de Encino	Mixed Forest	5	Mixed Forest
Bosque de Encino	Mixed Forest	5	Mixed Forest
Chaparral	Shrub/Scrub	6	Shrub-Scrub
Chaparral	Shrub/Scrub	6	Shrub-Scrub
Matorral Rosetofilo Costero	Shrub/Scrub	6	Shrub-Scrub
Matorral Desertico Microfilo	Shrub/Scrub	6	Shrub-Scrub
Matorral Desertico Rosetofilo	Shrub/Scrub	6	Shrub-Scrub
Chaparral	Shrub/Scrub	6	Shrub-Scrub
Pastizal Inducido	Grassland/Herbaceous	7	Grassland -Herbaceous
Pastizal Inducido	Grassland/Herbaceous	7	Grassland -Herbaceous
Pastizal Inducido	Grassland/Herbaceous	7	Grassland -Herbaceous
Pastizal Inducido	Grassland/Herbaceous	7	Grassland -Herbaceous
Agrícola y varios agrícola	Cultivated cropland	8	Cultivated
Agrícola y varios agrícola	Cultivated cropland	8	Cultivated
Agrícola y varios agrícola	Cultivated cropland	8	Cultivated
Bosque de Galería	Woody Wetlands	9	Riparian Forest
Bosque de Galería	Woody Wetlands	9	Riparian Forest
Vegetación de Galería	Herbaceous Wetlands	10	Riparian Shrub
Vegetación de Galería	Herbaceous Wetlands	10	Riparian Shrub
Vegetación de Galería	Herbaceous Wetlands	10	Riparian Shrub
Bosque Inducido	NA	11	Cultivated Forest

The area converted to urban was similar in both countries (Table 3). This is remarkable considering that >60% of the entire study area is located in Mexico; hence the proportion of land changed to urban was greater in the U.S. In both countries, urban areas increased at the expense of shrub-scrub, cultivated, barren, and grassland-herbaceous LUVC and, in the U.S., also from mixed forest. This result is similar to a 1992 to 2005 study [18], in which gains were dominated by urban and grassland. From 1993 to 2011 regional urban growth was similar to that for 1971–1994 [10], in that it occurred mostly around the established urban areas and along main highways, mostly in the northern and northeastern TRW.

Table 3. Initial surface and change for each LUVC category, year, and country. Superscript number in LUVC category indicates more that 80% of area persistence, 1 for Mexico and 2 for United States.

	Mexico					United States				
LUVC	**1993 (ha)**	**% of Total**	**2011 (ha)**	**% of Total**	**Observed Change (ha)**	**1990 (ha)**	**% of Total**	**2011 (ha)**	**% of Total**	**Observed Change (ha)**
Water [1,2]	694.44	0.13	705.24	0.13	10.8	11,610.00	4.51	11,754.72	4.56	144.72
Urban [1,2]	19,847.16	3.80	44,066.07	8.43	24,218.91	9035.73	3.51	29,205.63	11.34	20,169.9
Barren	6653.34	1.27	178.65	0.03	−6474.69	3613.86	1.40	2214.72	0.86	−1399.14
Evergreen Forest [1]	69,983.46	13.39	68,260.77	13.06	−1722.69	31,542.84	12.25	8563.86	3.32	−22,978.98
Mixed Forest [2]	1450.17	0.28	1092.51	0.21	−357.66	4461.39	1.73	4851.54	1.88	390.15
Shrub-Scrub [1]	352,368.45	67.43	338,304.51	64.73	−14,063.94	159,784.56	62.03	157,422.42	61.11	−2362.14
Grassland-Herbaceous [1,2]	30,573.45	5.85	36,239.49	6.93	5666.04	34,361.91	13.34	37,796.4	14.67	3434.49
Cultivated[1]	36,333	6.95	30,023.37	5.74	−6309.63	2941.74	1.14	819.27	0.32	−2122.47
Riparian Forest [1,2]	516.15	0.10	507.24	0.10	−8.91	42.66	0.02	2553.48	0.99	2510.82
Riparian Shrub [2]	4185.81	0.80	1782.99	0.34	−2402.82	199.26	0.08	2411.91	0.94	2212.65
Cultivated Forest	0	0.00	1444.59	0.28	1444.59	0.00	0.00	0	0.00	0
TOTAL	522,605.43	100	522,605.43	100		257,593.95	100	257,593.95	100	

Table 4. Rank by occupied surface of LUVC categories with greatest changes. Shaded cells indicate LUVC categories with greatest surface changes.

LUVC Categories	**Rank by Occupied Area in Mexico**		**Rank by Occupied Area in the U.S.**	
	1993	**2011**	**1990**	**2011**
Shrub-Scrub	1	1	1	1
Evergreen Forest	2	2	3	4
Cultivated	3	5	6	6
Grassland-Herbaceous	4	4	2	2
Urban	5	3	4	3
Barren	6	6	5	5

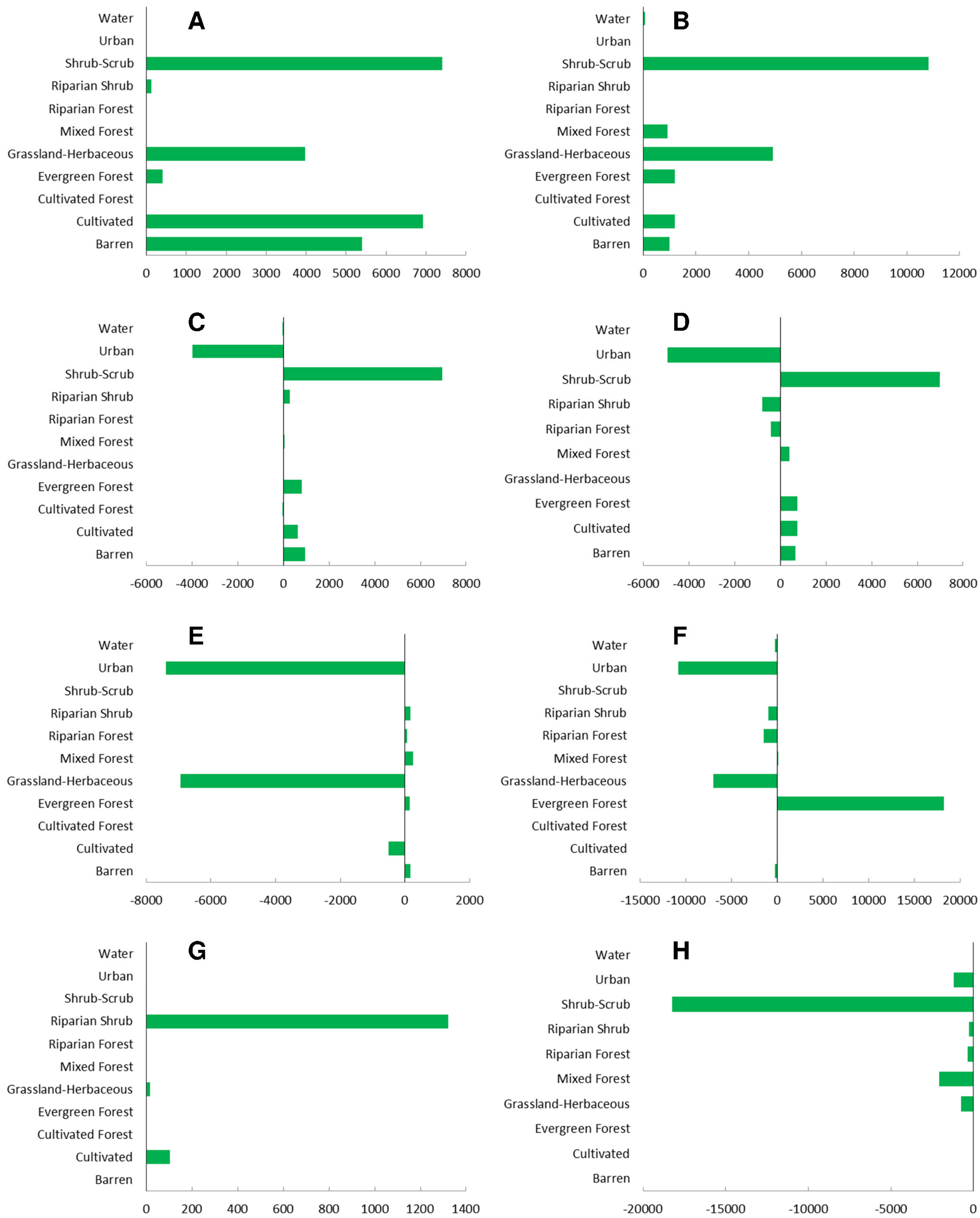

Figure 3. Contributors to net change for five land use and vegetation cover categories with greatest change. Units are in hectares. Mexico (**left**); United States (**right**). (**A**) and (**B**) are for Urban; (**C**) and (**D**), Grassland-Herbaceous; (**E**) and (**F**), Shrub-Scrub; (**G**), Cultivated Forest (only in Mexico); and (**H**), Evergreen Forest (only in the United States).

Shrub-scrub covers >60% of the study area's total surface and is the dominant category and exhibited the greatest change (surface loss and gains) in both countries. Nevertheless, Mexico had the greatest net surface loss in shrub-scrub, with 14,063 ha lost (6949 to grassland-herbaceous and 7396 ha to urban), compared with 2363 ha of shrub-scrub lost in the U.S. (Figure 2; Table 3). Our results were similar to those of other studies, which reported that this was the category that changed most [10,18].

In Mexico, the next two categories with the greatest loss were cultivated and barren (6309 and 6474 ha), but in the U.S., these categories lost less surface (2122 and 1399 ha). In other time periods, these categories exhibited a similar tendency in Mexico [10,18], in the first case due to a lack of irrigation water and in the second, due to its conversion to urban areas.

Lastly, evergreen forests exhibited substantial changes only in the U.S., where it lost 22,978 ha, mostly through conversion to shrub-scrub (18,239 ha), with lower conversion into mixed forest (2080) and urban (1202). In Mexico, only 1722 ha of this category were lost during the period (Figure 3). A new cover category emerged during this period in Mexico, but not in the U.S.: Cultivated forest, which gained surface from riparian shrub, shrub-scrub, cultivated and grassland-herbaceous. Thus, overall, shrub-scrub and evergreen forest exhibited the greatest decrease flows (loss of surface to other categories), while urban and grassland-herbaceous are the LUVC categories gained most surface from other categories (Figure 4).

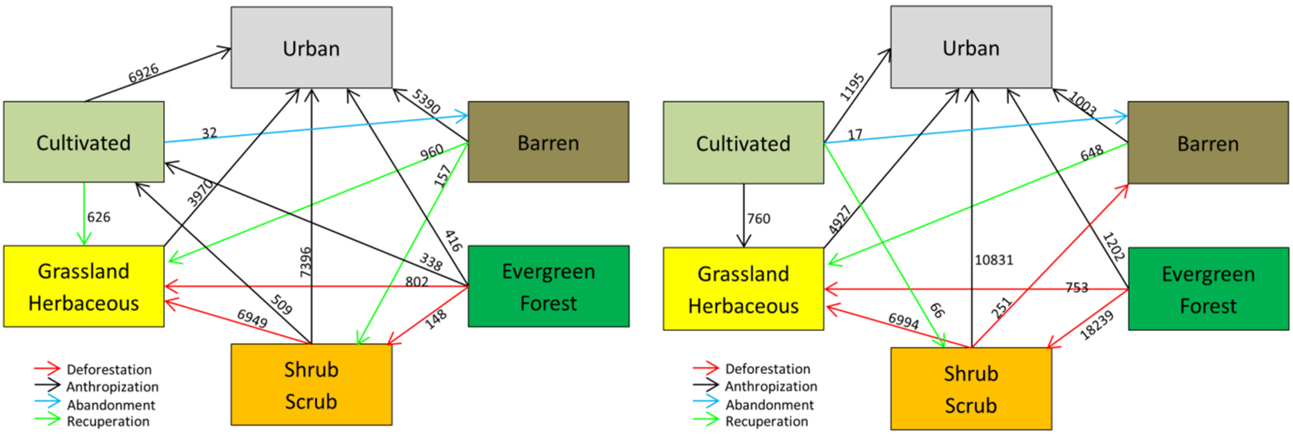

Figure 4. Land use and vegetation cover category transitions and transition processes. Numbers indicate change in hectares. Mexico (**left**); United States (**right**).

The four general change processes described (deforestation, anthropization, abandonment and recuperation) were present in the study area (Figure 4). Anthropization and deforestation were the principal LUCC processes in both countries, considering the number of flows of surface gain and loss. The areas with natural land cover (shrub-scrub, evergreen forest and grassland-herbaceous) lost 29,840 ha compared to the 25,300 in 1970–1994 [10] but differ in the proportion of surface changed in each country: 42% occurred in Mexico and 58% in the U.S., which is strikingly different from the 80% and 20%, respectively, for 1970–1994 [10]. Recuperation in our study was similar to that in 1970–1994 [10], with 61% of habitat recuperation in Mexico and 39% in the U.S.

Between 1993 and 2011, there was a decrease in the number of patches and in mean patch area (Table 5) in Mexico. The first of these evidences defragmentation [40]. Riparian shrub and shrub-scrub had the largest decrease in number of patches and were the LUVC categories that contributed to the emergence of the previously not present cultivated forest (Table 6; Figure 3).

Table 5. General fragmentation metrics.

	Number of Patches		Mean Patch Area (ha)	
Country/Year	**1993**	**2011**	**1990**	**2011**
Mexico	373	359	1422	1029.76
U.S.	124364	14635	8.5	16.27

Table 6. Fragmentation metrics by LUVC and country.

	Mexico				United States			
	1993		2011		1990		2011	
	Number of Patches	Mean Patch Area (ha)	Number of Patches	Mean Patch Area (ha)	Number of Patches	Mean Patch Area (ha)	Number of Patches	Mean Patch Area (ha)
Water	3	231.48	4	176.31	154	75.39	274	42.90
Urban	18	1102.62	38	1159.63	3037	2.98	923	31.64
Barren	1	6653.34	2	89.33	12755	0.28	721	3.07
Evergreen Forest	65	1076.67	55	1241.10	37191	0.85	1330	6.44
Mixed Forest	22	65.92	10	109.25	23407	0.19	1733	2.80
Shrub-Scrub	66	5338.92	56	6041.15	14367	11.12	2528	62.27
Grassland-Herbaceous	102	299.74	104	348.46	29468	1.17	5730	6.60
Cultivated	71	511.73	73	411.28	3337	0.88	52	15.76
Riparian Forest	3	172.05	3	169.08	262	0.16	772	3.31
Riparian Shrub	22	190.26	13	137.15	386	0.52	572	4.22
Cultivated Forest	0	0.00	1	1444.59	0	0.00	0	0.00
TOTAL	373		359		124364		14635	

There was greater landscape fragmentation in the U.S. than in Mexico and more in the early 1990s than in 2011. Mean patch area increased and patch number decreased between these dates. These results indicate land defragmentation, cover recuperation in some sites and LUVC compaction [39,40]. Recuperation involved transformation into the same land use and cover class as in adjacent cells in the 1990s (Figure 5). Defragmentation, despite the loss of natural vegetation, is favorable for wildlife habitat as it enlarges some habitats, compacts the area occupied by a category of LUVC and densifies the available resources for wildlife but probably also causes the loss of some habitat [39]. An example of defragmentation and compaction is the observed urban growth in sites adjacent to those where urban occupation persisted between the early 1990s and 2011 (Figure 5), mainly around Tijuana and Tecate and in Southern California near the border. Additionally, this urban expansion within Northern Tijuana resulted in the loss of natural areas within the city and in the suburbia. In the last ten years urban, agriculture and rural urban land use increase in both countries [41] expanding the previous surface of these land uses, despite similarity in patterns of defragmentation and compaction in some LUVC classes, there are great differences in socio-economic and legal systems, financial resources for conservation and number and surface of protected areas between Mexico and the U.S. [41]. For example, in the U.S., several federal, state, and county conservation programs have existed since the 1990s, with additional programs coming into operation in the last 10 years. In contrast, in Mexico there is a scarcity of new programs, with only those established since or before 1990s still in existence [41,42]. The combinations of these factors have resulted in different fragmentation patterns in the two countries, indicating a different dynamics of change resulting for different conservation policies and planning efforts.

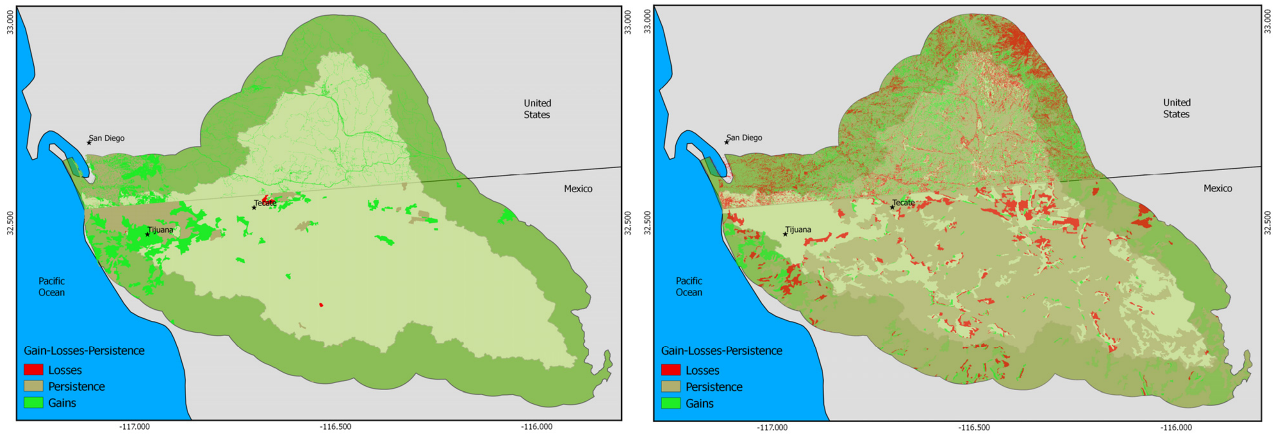

Figure 5. Surface gains, persistence and loss. **(Left)** shows urban land use and vegetation cover category, one which greatest surface gained and **(right)** shows shrub-scrub land use and vegetation cover category, the one with greatest surface lost.

5. Conclusions

(1) Patterns of land use change, change trends and transition processes by LUVC category in the Tijuana River Watershed from the early 1990s to 2011 differ between Mexico and the United States, largely resulting from different conservation policies and planning efforts between two countries.

(2) Changes were toward the anthropization, mainly by the growth of urban areas. In both countries, urban gained surface from shrub-scrub, cultivated, barren, and grassland-herbaceous LUVC categories.

(3) Three categories shared between the two countries had the main gains and losses: Grassland-herbaceous and urban (gain) and shrub-scrub (loss).

(4) The evergreen forest had significant surface changes only in United States, despite having a wide cover in the Mexican part of the TRW.

(5) Shrub-scrub was the dominant wildlife habitat in the area, which makes it the most important LUVC for conservation. It is necessary to analyze the LUVC as wildlife habitats for change, fragmentation and connectivity in order to know the conservation status in the region and contribute to management and conservation efforts.

(6) In Mexico, cultivated forest emerged in 2011 as a new category gaining surface from riparian shrub, shrub-scrub, cultivated, and grassland-herbaceous.

(7) Ten land-use and cover types provide a suitable standardization of LUVC names that can be applied to studies for the entire border between Mexico and the United States.

(8) A 10 km buffer zone surrounding the core of the study area proved helpful, as it comprised larger political, socioeconomical and ecological framework but still reflects the processes occurring within the core area.

(9) There was more fragmentation in U.S. than in Mexico, but, in both countries, we found a trend toward defragmentation.

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Author Contributions

Ricardo Eaton-Gonzalez conducted data analysis and led the preparation of the manuscript. Eric Mellink helped in structuring and editing the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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