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Land Use Changes and Their Perception in the Hinterland of Barranquilla, Colombian Caribbean

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Abstract: The coastal strip of the western peri-urban area of Barranquilla in the Atlántico Department (Colombia) is experiencing changes in human-environment interactions through infrastructure, residential, and tourism projects in a vulnerable landscape. In the hilly area, fragments of biodiverse tropical dry forest still exist in various states of conservation and degradation. To understand the interrelated social, economic, and ecological transformations in the area, we analyzed land use change on the local scale including the local community's perception, because the local community is a key actor for sustainable land use. For the analysis of the interrelated social, economic, and ecological processes, we combined visual interpretation of high-resolution satellite imagery, on-site field land use mapping, and a spatial statistical analysis of the distribution of land use classes with in-depth interviews and a participatory GIS workshop, thus benefitting from the complementary methodological strengths of these approaches. The case study is the rural community of El Morro, which exhibits the typical social, economic, and ecological changes of the coastal strip of the western peri-urban area of Barranquilla. The local community perceives a continuous loss of forest area, but observations from on-site field mapping cannot confirm this linear trend. We observed a gradual replacement of traditional land uses such as smallholder agriculture, charcoal production, and cattle breeding by services for tourism, gated community projects for urban dwellers, and infrastructure projects; these spatial developments have several characteristics of rural gentrification. We conclude that the drivers of environmental degradation have changed and the degradation increased. The development projects of external companies have been rejected by the local community and have induced environmental consciousness among community members. Thus, the local community has become an advocate for sustainable land use in the study area.

Keywords: remote sensing; visual interpretation; participatory mapping; PGIS; gated communities; rural gentrification; tropical dry forest

1. Introduction

Land use changes are often an expression of changes in social and human-environment interactions [1–3]. These changes have a direct impact on ecosystems, ecosystem services, natural resources, and regional climate [4,5]. Holistic approaches including research on different scales and transdisciplinary methods can broaden our understanding of land use changes and their dynamics [2,6]. With this study, we want to augment understanding of the changes in human-environment interactions that have occurred in the Colombian Caribbean since the 1980s, as manifested in land use changes and the local community's perception of these. By analyzing the social, economic, and ecological changes and their drivers, we want to help foster sustainable land uses in the study area. Furthermore, we want to show how local communities can be integrated into research on land use changes and their drivers by considering their perception of these issues.

Two recent studies about land use and land cover changes and their drivers exist for the Barranquilla area: an analysis of the social-ecological history of the Barranquilla metropolitan region [7] and a regional assessment of land cover changes between 1985 and 2017 for the northern part of the Atlántico Department [8]. These studies describe various processes such as urbanization, the abandonment of agricultural land, the dynamics of woody vegetation driven by population concentration, infrastructure projects, sand and gravel extraction, and further socio-economic and political changes [7,8]. A local study could provide a more detailed view of the interaction of drivers and environmental degradation [9]. The peri-urban area of Barranquilla has changed very fast and therefore, the perception of the local population about the land use changes, environmental degradation, and their drivers is especially interesting. Due to the attractiveness of the coastal strip for recreation, gated community projects for urban dwellers have been built and indeed are still under construction in the immediate neighborhood of the rural villages. In parallel, touristic infrastructure is being expanded. Research into other cases has demonstrated that the expansion of touristic infrastructure affects the social and economic life of the village communities [10–12]. Highly biodiverse tropical dry forests represent the natural vegetation of the western hinterland of Barranquilla [13,14]. Due to constant use, only a few dry forest fragments remain and only a small percentage is declared as protected [15,16]. The current woody areas in the hilly coastal strip of the Atlántico Department are predominantly secondary forest or areas in various stages of natural recovery [8,17]. However, they still harbor high biodiversity and provide many important ecosystem services such as carbon storage, water purification, and erosion control [18–20]. It is important to understand how these areas were used in the past and how they could be used sustainably in order to support their conservation and recovery. The local community is a key actor in sustainable land use; although the community does not have a strong voice in the economic and political decision-making processes that structure their livelihoods. Therefore, integrating the rural population into the assessment of land use changes is essential, both for the analysis and to empower the local community [21–23].

Using only remote sensing or only participatory mapping to analyze the interrelation of social, economic, and ecological processes manifested in local land use would not create a complete picture of the situation; the application and combination of both approaches with their complementary methodological strengths is, on the other hand, promising and proven [9,23–26]. High-resolution remote sensing and scientific mapping provide exact quantitative data such as the spatial extent of land uses. Furthermore, we used spatial statistical analysis to check the relevance of location parameters for the land use changes, because they were not mentioned during the PGIS workshop or the interviews. The participatory methods revealed more detailed spatial information and processes connected with their social meaning such as the abandonment of agricultural land due to rising land leases and taxes, and therefore the data is biased by the characteristics of its source. The participatory methods can cover a longer period but are not exact in differentiating data within short time intervals. Therefore, we used a mixed methods research design to understand the local and regional processes of land use changes: visual interpretation of high-resolution satellite images to detect land use changes, on-site field mapping to create a status quo land use inventory, in-depth interviews and a participatory GIS workshop to reveal the land use perceptions of the local community [9,24,26]. High-resolution satellite imagery enables the area-wide mapping of land use, even in inaccessible terrain at the time of the image survey, while field mapping along transects enables the precise recording of land use and improves the quality of land use mapping through validation [6,9,26]. Participative geographic information systems (PGIS) enable community involvement in the production and/or use of spatial information [21,26]. Therefore, PGIS is often used as a tool to integrate local residents and their spatial knowledge in natural resource management and planning [25,27,28]. However, the local residents' spatial perceptions are based on the selection, organization, and interpretation of spatial reality and therefore differ between groups and individuals [29,30]. These processes are structured by the worldviews, interests, and knowledge of the actors, and are dependent on their gender, ethnicity, age, and social and economic status [21,31,32]. Due to the biased elements, the data can only be linked with remote sensing data by integrating the background of the actors. We highlight the purpose for which the different methods are useful by looking at the similarities, differences, and possible biases of the results.

2. Study Area

Location. The village of El Morro is located in a hilly landscape 15 km west of the city limits of Barranquilla, directly uphill of the coastal road to Cartagena (road number 90A). The road currently extends over four lanes [33]. The study area encompasses the villages of El Morro and of Juaruco at its margin. The area expands across the hill range and the subsequent coastal strip characterized by sandy areas and lagoons. Administratively, El Morro and Juaruco are each a *corregimiento*; this term is used in Colombia to define a subdivision of a municipality [34]. The village of El Morro is divided into the districts Camajarú, Barrio Centro, El Roble, El Latal, El Cielo, and El Morrito, and the *corregimiento* El Morro also includes the villages of Bajo Ostión, Puerto Velero, and Caño Dulce. Figure 1 depicts an overview of the study area in its current state with existing infrastructure, settlement areas, local labelling, and simplified relief [35–37]. The map section of Figure 1, with a total area of 40.15 km^2, also corresponds to the area discussed at the PGIS workshop in El Morro. A smaller 11.7 km^2 section around the villages of El Morro and Juaruco was used for the detailed land use mapping including the three gated community projects *El Santuario*, *Jwaeirruku*, and *Velamar* [38,39].

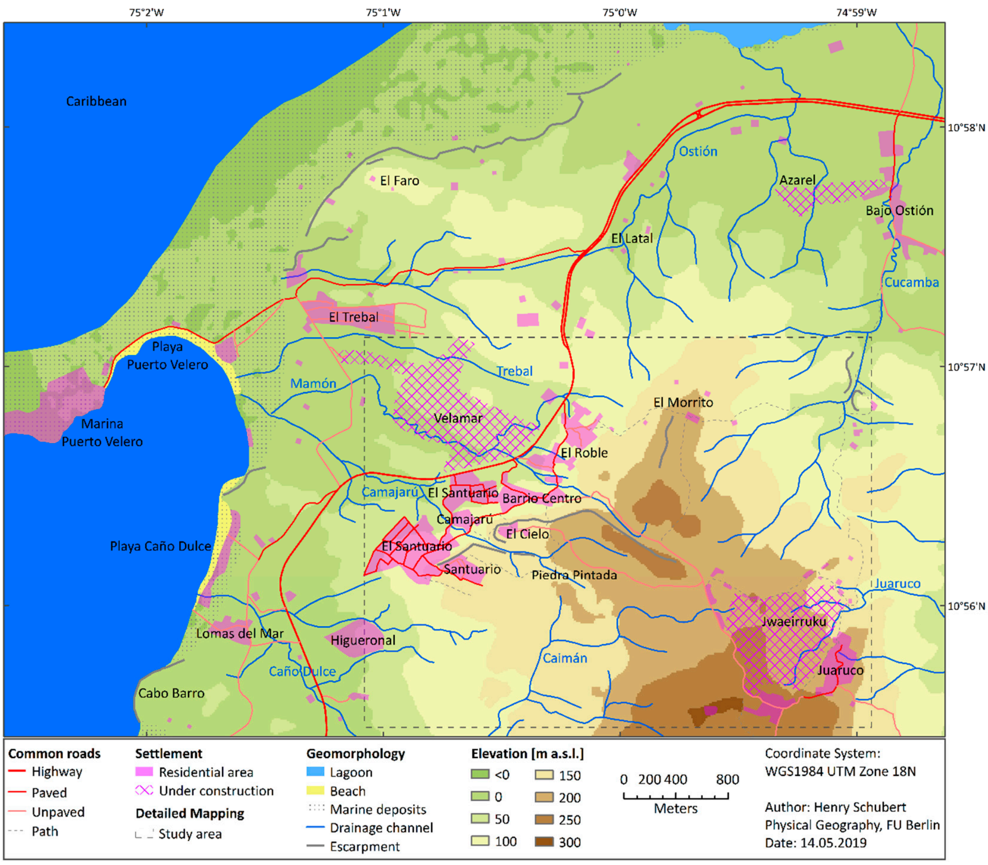

Figure 1. Study area of the villages of El Morro and Juaruco in the Atlántico Department, west of the city limits of Barranquilla, outlining the major road and path network, settlement areas, local labelling, gated community projects, and simplified relief (map based on [35–37]).

Natural landscape. In the study area, the hill range reaches an elevation of 310 m a.s.l.; bedrock consists of poorly compacted Pleistocene to Miocene silt-, sand-, and limestone [40]. Only a few sink areas exist where most recent fluvial deposits overlay the parent bedrock. The most striking relief elements are escarpments, locally up to 50 m high (e.g., near El Cielo and at Cabo Barro) with partly deeply incised channels in which riparian forests occur [41]. Poor slope stability along the escarpments is documented by frequent landslides triggered by intense precipitation events. The landscape is characterized by a patchwork of small agricultural areas, pastures, and woody vegetation areas in various states of conservation and degradation. In the north and west of the study area, along the littoral zone, a strip of maritime and lagoon deposits occurs where major changes have occurred during the last three decades. In particular, the headland of Puerto Velero has formed since 1990 due to artificial coastal fortification and increased sediment loads that were produced by the deepening of the Magdalena River [40,41]. Climatically, the region is characterized by two rainy seasons annually: a shorter one in May to June with monthly rainfall of between 80 and 130 mm, and a longer one in August to November with monthly rainfall of between 100 and 250 mm [42]. The months January to March are very dry with almost no rainfall. The mean annual rainfall varies between 940 and 1040 mm. Monthly mean temperatures vary between 25 and 28 °C [42]. The drainage system is characterized by dry channels draining towards the Caribbean, which have surface discharge only periodically after rainfall events [41]. However, there are some perennial springs with small water basins that were historically important for water supply and determined the location of the settlement areas (see Section 4.2). The soils in the study area are poorly developed, well drained, and frequently alkaline; they are not very fertile with medium to high cation exchange capacity [41].

Social economics. Tubará municipality covers an area of 184.1 km^2 with a total population of 11,022 persons in 2017, of which 6554 lived in the central village of Tubará [43,44]. The revision of the regional development plan listed 507 inhabitants for the *corregimiento* El Morro and 395 for the *corregimiento* Juaruco in 2012 [34]. Individual distributed houses and smaller contiguous villages characterize the settlement structure [34]. Most of the local population identify themselves as *Mokaná*, which is an indigenous group that settled in the area in Pre-Colonial times and was colonized by the Spanish in 1533 [45]. Some places like Piedra Pintada, which show petroglyphs under a rock shelter, and the cemetery *Cipacoa* in the south of Juaruco remain important locations for the indigenous population and document a long settlement history [34,45,46]. Parts of the study area were declared as Natural Reserve and Cultural Heritage by the Tubará municipality in 1995, forming a triangle between El Morro, Juaruco, and *Corral de San Luis* [47], but there is no evidence that this status has been implemented. In 2008, the environmental authority of the Atlántico Department proposed that the district of El Cielo and the village of Juaruco should form the northern edge of a protected area called *Triangulo de la Reserva* [48]. However, this protected area is not yet fully established. The gated community project Jwaeirruku is located within the proposed protected area. In 1991, a mining license for sand and gravel was granted to a local cement company for large parts of the area directly adjacent to the residential districts of El Morro. This led to a conflict with the local population, in particular because the Piedra Pintada and its immediate surroundings would be affected [46,49]. In 2014, the license was returned and no extraction has occurred thus far [50]; however, the cement company still owns the land [51]. Data for agriculture and livestock are only available for the entire municipality of Tubará. Typical is rain-fed subsistence agriculture with small fields of several crops, primarily maize, yucca, and legumes. The cultivated area decreased from about 2015 ha in 1992–1994 to 1353 ha in 2015–2017; contrary to this trend, in 2009 and 2010 there was a short term increase in cultivated land so it accounted for an even greater area than at the beginning of the 1990s [52]. Moreover, between 1990 and 2017, crops were diversified and the ratio of harvested to planted area increased [52]. Livestock farming in the municipality of Tubará is almost exclusively cattle breeding with the number of cattle varying between the years. Overall, there was an increase from 4595 cattle in 2001 to 7018 in 2008 and then a decrease to 6385 cattle in 2017 [53]. In 2017, a total of 173 farms practiced cattle breeding, of which 145 were small farms with less than 50 head of livestock, while one farm had more than 500 head of livestock [53].

Infrastructure. The local transport system is largely based on buses and motorcycle taxis. The buses run every 30 to 40 minutes along the coastal road between Puerto Colombia and Barranquilla in the east to Juan de Acosta and Santa Veronica in the west, with stops at the various access roads. There are waiting points for motorcycle taxis, which ensure onwards transport, for example to Puerto Velero or Juaruco. El Morro and Juaruco each have a primary school in their centers. To attend secondary school and higher education, students need to go to Nueva Esperanza near Santa Veronica or to Puerto Colombia [46,49,54]. In 2019, El Morro was connected to the coastal water pipe from Barranquilla [55], which, to a certain extent, replaced the local water distribution system built in 2001 in Juaruco and the popular rainwater storage tanks. However, some houses are still not connected to the water supply systems, especially the more remote ones, which usually also have no connection to the electricity network. There is no wastewater management in the entire study area [49,54].

3. Methods

3.1. Combatibility of Methods

Although scientific mapping using remote sensing data on the one hand, and participatory mapping in combination with interviews on the other hand, provide complementary data for the analysis, the use of both methods poses the question of compatibility. Mapping is always selective, incomplete, and simplifies the complexity of reality in line with the objectives of the map, the interest of its author, the methods used, knowledge, and data [31,56,57]. We understand scientific mapping using remote sensing data and participatory mapping in combination with interviews as different approaches that produce different results [9,24–26]. The complementarity of scientific mapping and participatory methods is limited; applying these two approaches must therefore address the partialities of the different types of knowledge they produce [21,32]. For this reason, we applied the methods separately in the first stage (see Sections 3.2 and 3.3) to guarantee their inner coherence and the robustness of the results. It follows that we describe the limitations of the results separately (see Sections 5.1 and 5.2). In a second stage, we then align and discuss the results of both approaches showing similarities and differences in the findings, and complementing the data to obtain an overall picture of the effect of social and economic changes on the environment (see Section 5.3).

3.2. Land Use Mapping and Spatial Statistical Analysis

We created four land use maps for the years 2008, 2011, 2013, and 2017/18 based on visual interpretation of high-resolution satellite images and on-site land use mapping in the study area in July 2018 [58,59]. Areas were manually assigned to certain land use classes based on similar structures and band characteristics and the on-site land use mapping. The visual interpretation was mainly performed using four high-resolution satellite images provided by the DigitalGlobe Foundation, two from the beginning and two from the end of the dry season (Table 1).

Table 1. High-resolution satellite data used for land use mapping.

Sensor	Date	Spatial Resolution	Number of Bands
QuickBird-2	22 Mar 2008	2 m	4
WorldView-2	24 Dec 2011	2 m	8
GeoEye-1	21 Dec 2013	2 m	4
GeoEye-1	05 Apr 2017	2 m	4

These images were compared with the images available in Google Earth Pro from 2007 to 2018 to complement land use information where the high-resolution satellite data are incomplete due to clouds and cloud shadows [59]. Due to different recording angles and slight distortions, a correction with the ArcGIS georeferencing tool was necessary so that the road and path junctions of all images fit. We used the adjust transformation, which combines a polynomial transformation and triangulated irregular network (TIN) interpolation techniques [60]. We calculated the area of the mapped polygons for the four maps (2008, 2011, 2013, 2017/18) and determined the total area for each land use class using ArcGIS 10.6.

In July 2018, all public roads and paths of the research area were mapped on-site by walking along the roads and paths; the roadside land uses were also recorded and control points for satellite image analysis were noted [61]. Large parts of the area are privately owned; these areas could not be explored. In the course of this process, we defined the land use classes listed in Table 2, which are based on various studies about land use changes at regional and local scale (among others [62,63]).

Table 2. Land use classes, subclasses, and their definition.

ID	Class	Subclasses and Definition
10	Settlement	Paved roads (ID 11); religious, educational, health, and supply facilities (ID 12); residential area and buildings with home gardens (ID 13)
20	Bare Soil	Paths, unpaved roads, and soccer fields (ID 21); absence of topsoil due to construction activities (ID 22) or due to gravitational mass movements (ID 23)
30	Cleared	Agricultural land with mainly mixed crops and burned areas prepared for agriculture (ID 31); areas with no or only individual trees used as pastures (ID 32); grass strips and cleared areas, which are cleared or kept free for construction activities (ID 33); barren land, degraded areas, and open areas with pioneer vegetation recovery (ID 34)
40	Woody vegetation	Wooded areas dominated by younger trees or visible degradation (ID 41); forests with closed canopy (ID 42); riparian forests along the drainage channels (ID 43)
50	Water	Used and abandoned ponds for livestock (ID 50)

After the land use mapping, we performed a spatial statistical analysis to identify whether the distribution of land use classes displays spatial characteristics and patterns or is random. To this end, we used a digital elevation model with a resolution of 12.5 m recorded by ALOS PALSAR [35], a revised shapefile of the public road and path network based on OpenStreetMap data [36], and a shapefile of the drainage channels [37]. We converted the four land use maps into four rasters with a spatial resolution of 2.5 m, because this is a divider of the spatial resolution of the digital elevation model. Then, we created a raster composite of the four land use rasters and the four raster data maps of elevation (m), slope (%), and inverse distance to public roads and paths (m), and to drainage channels (m) with a cell size of 2.5 m using ArcGIS 10.6. To evaluate spatial patterns and the variations between the land use classes, we calculated firstly the mean values and standard deviations of the four terrain parameters for all raster cells. Then, for each land use class we determined the mean values and standard deviations of the four terrain parameters in the four analyzed years using R-package raster and tested if the deviations between the mean values for the land use classes and the mean values for all raster cells were significant [64].

3.3. Participatory Methods

A total of six in-depth interviews with local leaders and several conversations with them including personal meetings and discussion via a chat platform were conducted in 2017 and 2018 (see interviews [46,49,54,65–67]). The local community of El Morro recognized some of the interviewees as leaders although they have no official position, others hold important offices for the community including a municipal councilor and representatives of the local authority, the indigenous community, the community aqueduct, and the beach huts. The interviewees were selected based on their function within the community, their consequent knowledge, and their leading role in environmental conflicts. We asked other actors such as medium-sized landholders, but did not receive a positive response.

The main questions of the first part of the interviews concerned the current characteristics of the local community, the local economy, politics, nature and environmental issues, and their changes in the last 40 years. Furthermore, we asked about the drivers and actors of change. The second part of the interviews dealt with the local environmental problems and environmental conflicts between the local community, state entities, infrastructure and housing developers, and a mining company since the 1990s. The interviews showed that the social and economic transformations became manifest in land use changes and that the perception of land use changes is key to understanding the environmental problems and conflicts. For a better understanding of the local community's perception of land use changes in the study area, we decided to conduct the PGIS workshop. The interviews and documents of the relevant actors in the study area helped to formulate the focus and questions of the subsequent PGIS workshop. Furthermore, the interviews were used to triangulate information [68] given in the PGIS workshop and as complementary data to better understand the results of the PGIS workshop. For the triangulation, we used different types of sources to compare the obtained information, which gains additional validity by being found in different sources [68].

The core element of the participative methods was a PGIS workshop [9,25,69], which we conducted in the village of El Morro on June 28th, 2018 with 18 participants living in the districts of Barrio Centro, El Latal, El Morrito, and El Roble (Figure 1). The PGIS workshop was conducted in Spanish, which is the mother tongue of all the participants. All workshop participants were actively involved in community life, had limited financial resources, and owned no significant amount of land, and almost all identified themselves as *Mokaná*; some of the participants were related. In short, they belonged to a marginalized group. The participants followed an open invitation issued to the whole community, the tourism sector, and state officials by one community leader, who supported us in the organization of the workshop. The other invited groups did not participate although they responded positively to the invitation.

We divided the participants into four groups of four to five persons according to their position in the community, occupation, and age: "community leaders", "adolescents", "activists", and "housekeepers". The PGIS workshop was structured as follows: (I) presentation round; (II) introduction on how to orientate oneself using maps and aerial images; (III) division into the four groups; (IV) producing land use maps for different time slices; and (V) presentation and group discussion of the results. For the introduction to working with maps and aerial images (II) we divided the participants into two groups to enhance comprehension: using a Google Earth image from 2016, we discussed with the participants which elements were easily recognizable and where specific places were located.

To avoid a prior structuring of the results, blank maps with the road and path network, drainage system, four geographical site names of local peaks, and the coastline were provided for the land use maps to be drawn by the participants for three years (2018, 2001, and 1985). As an aid, we provided seven possible land use classes as examples: water (streams, ponds), beaches and sandy areas, woodlands, forests, pastures, crops, and buildings; the use of these classes was not mandatory. We asked the groups to include further land uses, to draw the spatial distribution of the different land uses, to name important locations, and to add a legend. In addition to the cartographic presentation, we requested the groups to note in brief the land use changes between 1985 and 2001 and between 2001 and 2018. The groups then presented their results to each other. Following the presentation, the entire group discussed the land use changes and their drivers since 1985. The presentation and the plenary discussion were recorded as an audio file for the analysis.

We analyzed the interview material using Qualitative Content Analysis [70] by applying pre-established categories regarding the social, economic, and ecological transformations, and the characteristics of environmental problems and conflicts to the text material; the categories were refined during the evaluation process. In the case of the maps, the analytical focus was the content rather than the spatial extents of land use classes drawn on the maps because the participants focused on drawing symbols instead of areas. The land use classes and elements included in the maps were tabulated [71] and grouped into categories (*nature elements*, *buildings and constructed sites*, *resource exploitation*, *indigenous sites*, *church sites*, and a *special group*) to compare them between the groups of participants and to get an overall picture. We assume that the higher the differentiation, the higher the relevance of the category for the participants; similarly, elements used by more groups are viewed as being more important for the participants [71]. Given the qualitative character of the study, determining how deeply rooted certain elements are is more important than their exact location and spatial extent. The same applies to the workshop participants' discourses on land use changes and their drivers [9,21,71].

The rapid increase in land prices and taxes, often mentioned by interviewees and workshop participants, seemed to be an important driver of land use changes in the study area. We, therefore, analyzed this aspect in more detail. We obtained cadastral data for the study area from the municipal administration and the Instituto Geográfico Agustín Codazzi (IGAC), which operates as the cadastral authority: a shapefile with the limits and codes of the parcels and two tables with land prices for each parcel for 2010 and 2017 [51]. We used the cadastral data to analyze the increase in land prices between 2010 and 2017, and the number of changes of ownership. The cadastral land prices are the basis for determining land taxes; plus other factors such as use of the land and number of buildings [72,73]. If the smallholders do not own land but lease it, they are dependent on the owners who determine the lease fees individually.

4. Results

4.1. Land Use Mapping and Spatial Statistical Analysis

The visual interpretation of high-resolution satellite images combined with the on-site field mapping conducted in July 2018 resulted in four maps depicting land use in the years 2008, 2011, 2013, and 2017/18 (Supplementary Material, Figures S1–S4). The results of the area calculation of the four maps are depicted in Figure 2 and Table 3.

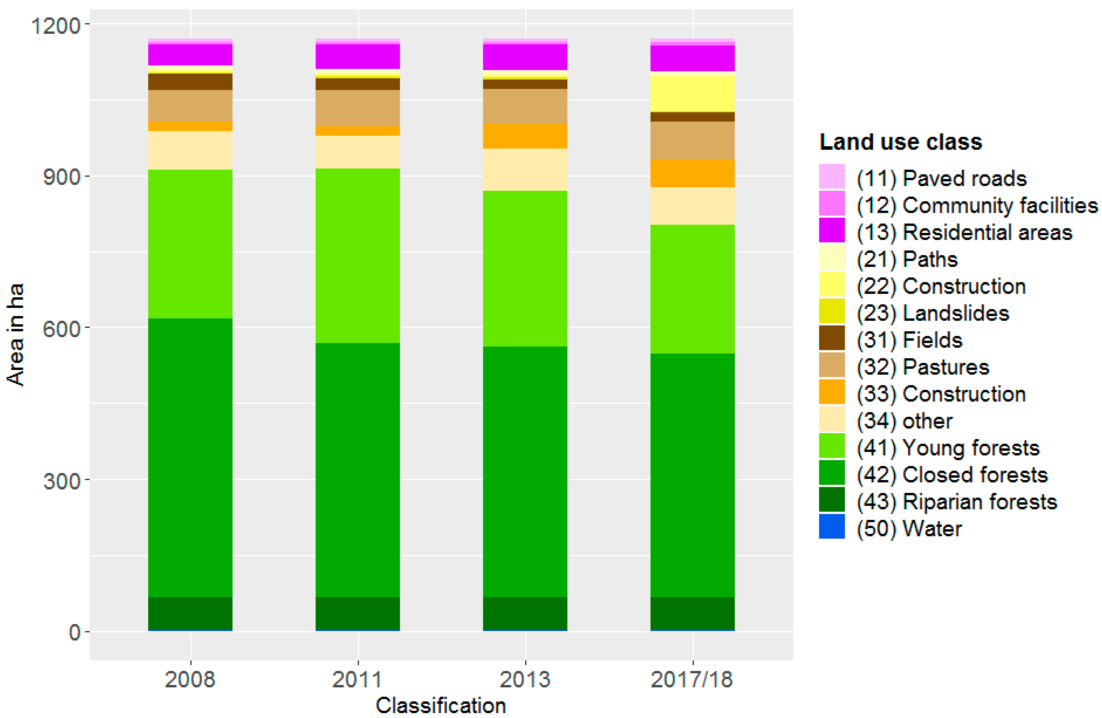

Figure 2. Ratio of land use classes in the detailed mapped area of the villages of El Morro and Juaruco for the years 2008, 2011, 2013, and 2017/18.

Table 3. Changes of area size per land use class in the detailed mapped area of the villages of El Morro and Juaruco for the years 2008, 2011, 2013, and 2017/18.

ID	Class	Area in Hectares				Change 2008–2017/18 [%]
		2008	2011	2013	2017/18	
10	***Settlement***	***52.78***	***60.02***	***61.58***	***65.53***	***24.2***
11	Paved roads	5.68	6.14	6.71	7.73	36.1
12	Community facilities	5.23	5.44	5.44	5.44	4.0
13	Residential areas	41.87	48.44	49.43	52.36	25.1
20	***Bare soil***	***15.86***	***17.54***	***18.12***	***80.47***	***407.4***
21	Paths	9.92	9.73	9.33	8.57	–13.6
22	Construction	3.33	3.43	5.52	68.76	1964.9
23	Landslides	2.61	4.38	3.27	3.14	20.3
30	***Cleared***	***191.02***	***179.49***	***221.08***	***221.20***	***15.8***
31	Fields	32.45	23.33	19.47	17.58	–45.8
32	Pastures	64.11	73.25	69.81	74.72	16.6
33	Construction	17.77	16.79	48.61	55.47	212.2
34	other	76.69	66.12	83.19	73.43	–4.3
40	***Woody vegetation***	***909.48***	***911.85***	***868.11***	***801.70***	***–11.9***
41	Young forests	293.84	345.38	307.46	256.20	–12.8
42	Closed forests	550.62	501.47	495.62	481.36	–12.6
43	Riparian forests	65.02	65.00	65.03	64.14	–1.4
50	Water	0.86	1.10	1.11	1.10	27.9

The sealed areas continuously increased between 2008 and 2017/18, predominantly controlled by the expansion of the *paved roads* and the buildings within the land use class *residential areas*. Particularly in the gated community El Santuario, the *settlement* areas have grown, while concurrently in the traditional villages there was only a slight densification of *settlement* areas with new houses, and in the rural hinterland some farms were even abandoned. In the *bare soil* class, the surface area of the unsealed *path* network decreased slightly between 2008 and 2017/18, which is due to the sealing of paths (e.g., access roads to El Morro, main road in Juaruco) and to the construction of the gated community projects Velamar and Jwaeirruku. These projects are also the cause of the strong increase in the *bare soil construction* and *cleared construction* areas. For the Velamar project, 33.2 ha of *young forest* and 12.4 ha of *pasture* were converted to *bare soil construction* and *cleared construction* areas between 2008 and 2017/18. For the Jwaeirruku project, 4.9 ha of *fields*, 7.3 ha of *pasture*, 18.6 ha of *young forest*, and 6.9 ha of *closed forest* were converted to *bare soil construction* and *cleared construction* between 2008 and 2017/18. The areas affected by *landslides* vary slightly over the years (Table 3); some houses, paths, and a road in El Morro were damaged by landslides in recent decades [54].

The cultivated area has constantly declined and almost halved between 2008 and 2017/18. In contrast, the area of *pasture* fluctuated and increased by 16.6% in the same time interval. Construction activities are the main cause for conversion of *woody vegetation* to *cleared* areas. Overall, *woody vegetation* is the predominant land cover, but there was a decline of 11.9% after 2008, reaching a total coverage by *woody vegetation* of 68.5% in 2017/18. *Closed forest* areas have continuously declined since 2008, while the spread of *young forest* areas was variable; between 2008 and 2011 they even increased by 51.5 ha reaching a total coverage of 29.5% in 2011. The spread of *young forest* areas occurs due to the abandonment of agricultural land, especially *pastures* (Figure 2 and Table 3). The areas covered by the *riparian forest* are very constant and are probably not suitable for other uses due to steep slopes and periodical flooding. Several ponds, which are no longer used, indicate that larger areas now covered with *woody vegetation* were previously used as pastures (Supplementary Material, Figures S1–S4).

The visual interpretation of the high-resolution satellite images reveals some further aspects. Crop cultivation mainly takes place on small subsistence structures farms and is clustered around the village district of El Morrito and the village of Juaruco. We observed many fields with mixed cropping (e.g., a combination of maize, yucca, and beans) and a rotating cultivation system. We found a constant shift between used, burned, and unused areas with natural recovery. Pasture farming had a larger influence on land cover than crop cultivation: major *pasture* areas along the coastal road as well as between the villages of El Morro and Juaruco had been abandoned, while in the east of Higueronal, the *pasture* area was significantly extended. Within a few years, abandoned areas were recovered by tree and shrub vegetation (Supplementary Material, Figures S1–S4). The duration of natural recovery of *cleared* areas depends on the size of the area and the presence of topsoil, ground vegetation, and whether individual trees still exist. Especially, *pastures* can be covered with dense pioneer tree vegetation within 3–5 years. Due to the rapid growth of trees, some recovered areas cannot be distinguished from adjacent forest areas with remote sensing images, even with high-resolution images.

To evaluate spatial patterns and the variations between the land use classes, we calculated firstly the mean values and standard deviations of the four terrain parameters for all raster cells: elevation (158.7 ± 65.5 m), slope (16.7 ± 9.6%), distance to public road and path network (236.9 ± 229.1 m), and distance to drainage channels (129.7 ± 97.6 m). Then, for each land use class we determined the values in the four analyzed years and tested the significance (see Section 3.2). Most deviations between the mean values of the four terrain parameters for the land use classes and the values for all raster cells are strongly significant ($p < 0.001$) due to the large number of cells (Supplementary Material, Table S5). We want to highlight the following spatial patterns resulting from the calculation for each land use class; the following values are for the land use map of 2017/18. *Landslides* occur mainly in the low elevated areas (113.4 ± 35.9 m), as well as in relative proximity to the public road and path network (121.4 ± 99.4 m) and to the drainage channels (91.1 ± 93.6 m). In contrast, the proximity of *landslides* to the drainage channels in 2008 averaged 169.3 ± 100.5 m. *Fields* lie in slightly elevated locations (192.8 ± 46.1 m) and in areas with moderate inclination (15.8 ± 7.9%). *Pastures* also predominantly occur in areas with moderate inclination (12.6 ± 6.5%) and are farther away from the road and path network (296.8 ± 233.7 m) and from drainage channels (165.8 ± 84.4 m) than the *fields* (174.6 ± 173.5 m; 136.7 ± 92.2 m). *Closed forest* areas continuously occur in the high elevated areas (179.6 ± 54.7 m) and frequently cover steep locations (18.0 ± 11.3%); in addition, they are less developed by public roads and paths (distance: 296.1 ± 259.5 m) than the *young forest* areas (elevation: 134.0 ± 68.6 m; slope: 17.0 ± 8.7%; distance to public road and path network: 182.8 ± 148.4 m). Overall, *woody vegetation* areas occur in steeper locations (17.5 ± 10.3%), are less developed by public roads and paths (distance: 264.7 ± 243.4 m), and are nearer to drainage channels (124.0 ± 99.8 m) than all *cleared* areas (14.9 ± 7.6%; distance to public road and path network: 214.6 ± 197.6 m; distance to drainage channels: 142.3 ± 91.0 m; Supplementary Material, Table S5).

4.2. Perception of the Residents

The interviews with the different community leaders revealed that there had been broad social and economic changes in the study area since the building of the principal road from Puerto Colombia in 1982. Before 1982, the main economic activities of the community were agriculture, livestock farming, and fishing for subsistence. The road to Puerto Colombia, and the construction of the coastal road some years later, created social and economic interrelations between the study area and the cities of Barranquilla and Puerto Colombia such as labor migration, local beach tourism, and weekend houses of urban dwellers in El Morro. Since 1982, the economic activities of community members changed from farmers and fishermen to day laborers or unskilled workers in tourism, construction, and the service sector [46,54,65,66].

During the PGIS workshop, each group produced land use maps for the years 2018, 2001, and 1985. We made an in-depth analysis of the 2018 land use maps for each group and used the differences marked in the maps of 2001 and 1985 to highlight the temporal changes. We focused on the overall results of all four groups and compared them with the observations of land use gained from the on-site mapping and visual analysis of satellite imagery.

In the maps of 2018, the four groups used the seven land use classes given, added 15 more land use classes and elements, and included subgroups such as different crops. We grouped the 22 land use elements into six categories: *nature elements* (springs, forests, beaches, mangroves/woody vegetation along the coast, woodlands, animals), *buildings and constructed sites* (houses, restaurants at the beach/beach huts, marina, gated community projects, lighthouse, soccer fields), *resource exploitation* (crop cultivation, fishing, pastures), *indigenous sites* (petroglyph Piedra Pintada, *Cipacoa* cemetery, Juaruco as an indigenous village), *church sites* (chapel, church), and a *special group* (sign for danger). The categories *nature elements* as well as *buildings and constructed sites* show the highest grades of differentiation. Looking at the individual land use elements, we see that all groups mentioned the land use classes *water*, *forests*, *crops*, and the elements *beach huts* or *restaurants at the beaches*. All groups mentioned the traditional sites of water extraction, which are some local springs along periodically draining channels (Figure 3). Nearly all participants named the local springs in the same way. Three groups marked beaches, the marina, and the Piedra Pintada. The other elements were used only by one or two groups. The seven most important elements for the workshop participants, which were used by three or all four groups, are part of the categories *nature elements* (water, forests, beaches), *buildings and constructed sites* (marina, beach huts/restaurants), *resource exploitation* (crops), and *indigenous sites* (petroglyph Piedra Pintada).

Figure 3. (**a**) Local spring in the tropical dry forest at the Cucamba drainage channel; and (**b**) Panoramic view of the village of El Morro. In the background, the Caribbean Sea, the coastal highway (90A), and on the left, the construction site of the Velamar gated community project (photos Schubert, July 2018).

A differentiation of areas covered by woody vegetation was rather rare. Vegetation areas were named *forest* or *dry forest*. Two groups differentiated between *forest* and *woody vegetation along the coast* naming them *mangroves*, and only one group used the class *woodlands*. Three groups differentiated between crops; in two groups up to 12 crops. Cropping areas were drawn mainly around the settlement areas Juaruco, El Morrito, and Bajo Ostión, which could be verified by the on-site field mapping. Only one group marked small-scale pasture areas. In addition, only one group included the projects Jwaeirruku and Velamar in their land use map, but to a significant minor extent. However, in discussion, all groups highlighted the negative consequences of the gated community projects such as deforestation and influencing the soil water balance (Figure 3). The explicit mention of the gated community projects in the discussion shows that the participants perceive them as the major threat to the village community.

Regarding the land use changes since 1985, the community members highlighted that in the past the environment was more abundant (more forests, mangroves, and animals), and they observed less houses, restaurants at the beaches, and no gated community projects at all. However, they pointed out that in 1985, the community used natural resources more intensively than in 2018 through more agricultural activities, charcoal production, hunting, and fishing. Therefore, the participants of the PGIS workshop perceived these activities, in contrast to the new developments, not as creating pressure on the environment but rather as part of traditional land management. In the plenary discussion, the community members indicated that there has been a structural change in the economy since 1985: "*before there were more peasants (...), people lived from the cultivation of crops, fishing, hunting, trees were cut for charcoal, and the streets were paths*" (All the direct quotes were translated into English by the authors).

The participants of the PGIS workshop explained the land use changes by pointing out two main reasons. First, they indicated the involvement of a large part of the population in the tourism sector: "*now there are more beach huts and «caseteros»* [persons who work at beach huts] *(...). It is now the most relevant thing because it brings economic income (...). Before there was only one hotel (...). The marina was not there (...). In the year 1985, even the headland was not there, they called it the «Big Sea» (. . .). We no longer cultivate so much; we depend more on tourism*". Despite this, they made clear: "*we are being displaced by the «caseteros» of Puerto Colombia (...), who have sponsors from other places (...). Around the coast there are many «paisas»* [persons from the Antioquia Department]".

The second factor causing land use changes, highlighted by the participants of the PGIS workshop, is the appearance of large companies buying up land: "*now most of the land belongs to private companies*". The community members emphasized the importance of taxation and its impact: "*we had to sell because of the taxes, they have risen more than 300% (...).* [Local Cement Company] *leaves you with no way out and you must sell (...), you must sell the land to pay the property tax (...). They came from outside and they asked you «How much do you owe on this property?». They pay the debt and give you something else and take the land*".

The cadastral data show that 16 of 53 land parcels located around the gated community projects near the villages of El Morro and Juaruco changed their owners between 2010 and 2017 [51]. The cadastral data and interviews indicate that the companies of the gated community projects mainly bought land from medium-sized landholders [46,51]. The land prices of these 53 parcels located around the gated community projects increased by an average of 13.7 ± 2.8% between 2010 and 2017 [51], which is not congruent with the enormous increase in taxes reported by the participants. However, the potential profit increase from a sale of the land can be significantly higher. Due to the possible profit on the sale and individual decisions of the landowners, the lease fees may have increased enormously, as reported by the participants in the workshop. In 2018, the maximum annual increase in land prices for rural land used for agricultural purposes was raised from 0.32% to 3.0% [72,73], which may have contributed to the impression of the enormous increase in costs in the last decade.

The processes of abandonment of agricultural land, urbanization, and the construction of new infrastructure amount to what the participants called "*the arrival of development*" linked with negative consequences. These include the "*loss of biodiversity and (...) conservation problems*". The following extracts show this recurring discourse in the community:

> *The roads have brought development, but fauna and flora are lost (...).* [Before 1982] *the routes from Puerto Colombia were paths, bridle paths; transport worked by donkey or mule along these paths or along the beach shore (. . .). It was an area where there was no development like today; we had to follow the development (. . .). It is development as they say, but they have also destroyed green areas, forest areas, trees, and crops (...).*

> [The area is being] *affected by urbanization* [gated community] *projects, illegal hunting (...), and because now most of the land belongs to private companies, which are not interested in preserving nature. Around these urban developers, wildlife, fishing, and the «bareque» houses* [traditional construction based on wood and mud] *are lost, which are now made of material* [meaning modern construction materials] *(...).*

> *There was a larger amount of* [wild] *animals such as the howler monkey* [*Alouatta seniculus*], *the «guacamaya»* [genus *Ara*], *and the «guacharaca»* [*Ortalis ruficauda*]. *They are still here, but before there were more (...).*

They refer to the effect of political regulation on the land uses, noting a difference in the reactions of the state to environmental damage, depending on the actor causing it. *"In the past, wood was used to produce charcoal. Now they put you in prison for this (...); the urbanizations* [gated community projects] *deforest and nothing happens"*.

5. Discussion

5.1. Limits of Land Use Mapping and Spatial Statistical Analysis

The area that was mapped in detail covers larger parts of the *corregimientos* El Morro and Juaruco but is only a small section of the coastal strip between Barranquilla and Cartagena. However, it demonstrates the rapid development of infrastructure and construction activities combined with a focus on tourism and local recreation in the region. By limiting the mapping to the villages of El Morro and Juaruco, the land use changes caused by the gated community projects El Santuario, Jwaeirruku, and Velamar were very dominant and led to a rather continuous loss of woody vegetation in the small area between 2008 and 2017/18 (Figure 2). In a study analyzing land use and land cover changes based on Landsat images, an increase in woody vegetation is described for the periods 1985–1990, 1990–2001, and 2010–2017 for the entire municipality of Tubará, as well as for the larger study area of the PGIS workshop, while a loss of woody vegetation was detected between 2001 and 2010 [8]. In spite of variations in woody vegetation losses and gains in the periods, the total extent of woody vegetation areas in the study area of the PGIS workshop remained relatively constant with an average net gain of woody vegetation areas of 0.04 km^2 per year over the whole of the period from 1985 to 2017 [8]. However, this finding and several observations during the scientific mapping contradict the perceptions of the local community who see a linear trend of continuous forest loss since 1982 (see Section 5.3). Given the data available, it is not possible to make statements about the quality of the recovery areas or about a long-term degradation of woody vegetation areas.

The visible analysis of high-resolution satellite images does not provide a basis from which to estimate how intensively *pastures* and *fields* are used, as only a short time slot is captured. In the case of pastures, for example, the intensity of use can only be deduced indirectly from the vegetation density or soil degradation. The visual analysis of high-resolution satellite images cannot identify or differentiate between smaller units (e.g., cultivated crops) or assess the socio-economic impact on the local population. Furthermore, due to large-scale private properties in the study area, field walks with land users or landowners, which could have provided more precise spatial data [9], were constricted. Additionally, land use changes can only be visually analyzed using high-resolution satellite or aerial images if such data is available, which has only been the case since 2008 for the western peri-urban hinterland of Barranquilla. Further issues concern the mapping of the different vegetation areas, thus, due to the completely different appearance of the forest during longer dry periods, *closed forest* areas can be falsely classified as shrubby and disturbed areas. During the dry season, water availability and proximity to drainage channels significantly influence the appearance of vegetation [74]. We recommend choosing multitemporal studies with short time intervals due to the vegetation dynamics. Additionally, to differentiate forest recovery areas reliably from established and closed forest vegetation, a maximum of 2–3-year intervals between the different images are required for reliable image analysis. This is because after 3–5 years, overgrown areas in this location can appear like established and closed forest vegetation even on the high-resolution satellite images. We have tried to minimize these potential errors by using similar recording dates, cross checks, matching with Google Earth images, and on-site field mapping. The mapping methods involve many subjective decisions such as the exact boundaries between land uses, which are expressed in the results [58,59].

The spatial statistical analysis of the distribution of land use classes was performed due to the workshop participants' disregard of location parameters. This allowed us to check whether the distribution of land use classes follows certain patterns or is random. Despite the small size of the area which was mapped in detail, the results of the spatial statistical analysis show spatial patterns of land use do exist, and are subconscious or not worth mentioning for the workshop participants.

5.2. Limits of Participatory Methods

The workshop participants were a relatively homogeneous group of 18 persons of the marginalized rural population in the peri-urban area of Barranquilla. Only some of the participants still practice cropping on a small scale and most of them work in the service sector, but they see themselves as a rural community in the tradition of subsistence farmers. We cannot present and discuss the perceptions of the land use changes of the medium-sized landholders, who are also part of the rural population of the peri-urban area, because they were not available for interviews or the creation of PGIS maps despite several requests. We can only make the observation that interaction and exchange between this group and the local village community is limited. The composition of the participants of the PGIS workshop might explain why they did not include *pastures* into their land use classification, and the major differentiation and importance of crops [71]. The fact that all groups included *beach huts* and their expansion in recent years in their maps demonstrates the importance of this new main source of income for the community [71]. The PGIS maps and interviews show that environmental aspects are vital for the community members, especially local springs and forest areas, which were included by all groups in their maps [46,49,54,65]. The deforestation and the negative impact on water resources caused by the gated community projects are perceived as a threat to the livelihood of the local community and subsistence agriculture. Both impacts are the main reasons for the environmental conflicts [46,49,54]. The inclusion of indigenous and traditional names of springs and indigenous sites shows the self-identification of workshop participants as indigenous, as they noted in the self-descriptions in the questionnaire, and also indicates their wish to transmit their cultural traditions [45]. The PGIS workshop participants have a good spatial idea of the space that they experience and can access such as springs, beaches, public paths in the forest areas, settlements, crops, soccer fields, religious sites, or indigenous sacred places. The land use classes we proposed did not structure the results to any significant extent, because not all the land use classes proposed were used by all groups, land use classes were renamed, and 15 new classes and elements were introduced. This is an important result considering the structural power asymmetries at work between Western and non-Western cultures regarding knowledge and technology [29,30,75]; a situation in which we as white and European researchers are on a different side to the local community. We noticed varied drawing capacities of the participants, but they were not decisive for the content included on the maps. The groups of the "community leaders" and the "activists" presented more detailed maps on environmental aspects, places of the *Mokaná* and the Catholic Church. These differences might be explained by the focus of their activities regarding the protection of the environment and the religious places. One big accomplishment for the local community is the ruling T-011/19 of the Constitutional Court of Colombia from January 2019, which requires prior consultation with the indigenous community of Tubará for several development projects including the gated community projects around El Morro [76].

5.3. Alignment of Scientific and Participatory Mapping

While the PGIS and the scientific land use maps can only illustrate the land use changes, the discussion round during the PGIS workshop and the interviews with the community leaders provide information about the drivers of land use changes. All maps identify the decline of agricultural fields and of woody vegetation and the increase in residential areas during the last decade. The scientific land use maps illustrate that the largest land use changes were caused by the construction of the gated community projects; in contrast, the community members of the PGIS workshop underestimated the spatial extent of the construction sites. In addition, the participants of the PGIS workshop did not recognize the increase in pastures between 2008 and 2017/18 and their large extent over the entire study period in the study area. Both underestimations can be partly explained by a lack of access to the construction sites of the gated community projects and to the pastures, which are mainly managed by medium-sized landholders [46,54]. However, the participants of the PGIS workshop marked other developments such as decreases in animal numbers, charcoal production, hunting, and fishing, which cannot be detected by the visual interpretation of the high-resolution satellite images. The participants did not mention location factors such as elevation, slope, and water accessibility or unusable locations such as incised drainage channels with riparian forests. However, as the spatial statistical analysis shows, these location factors are considered in the land management and the expansion of cultivated, pasture, and settlement areas.

The participants of the PGIS workshop and the community leaders perceived the construction of the first road from Puerto Colombia in the year 1982 as the starting point for all further developments [46,54]. This road and the construction and extension of further roads are perceived as the main drivers of social and economic changes leading to land use changes and environmental degradation. The roads facilitated a higher mobility for the residents of El Morro and Juaruco and opened up the study area for the residents of Puerto Colombia and Barranquilla. Thus, the beaches became interesting for the urban dwellers as a local recreation area, and more tourist infrastructure and weekend houses in El Morro were created. A new development in recent years is the construction of gated communities for urban dwellers in the immediate neighborhood of the local village structures, which is connected with other infrastructure: road fortifications, four-lane extension of the coastal highway, and the construction of a water pipe from Barranquilla. The participants of the PGIS workshop linked these transformations to the presence of external actors, who are taking over the land. The main social changes for the rural population are the abandonment of traditional subsistence practices and the shift to service activities, even if limited [46,49,54,66]. The changes have many characteristics of rural gentrification [77]: the neighborhood is being enhanced with weekend houses, gated community projects, and infrastructure expansion, which leads to an increase in land taxes and lease fees [51]. This is a problem for smallholders, who are no longer able to pay the lease fees or taxes, and they therefore discontinue their activities or sell their land (see Section 4.2). The original rural population has been forced to abandon agricultural activities and to take up other economic activities. This leads to their marginalization and the threat of their displacement. While there is a clear negative trend for cropland, the trend is not so consistent for pasture farming; while some owners have given up their livestock, others have increased their livestock and expanded the land they used [8,52,53]. For the gated community projects, it was mostly the owners of medium-sized estates who gave up their pasture farming and sold their land to construction companies [46,51,54]. Local communities are rarely involved in planning and construction processes and their objections are mostly ignored [46,67].

The processes of rural gentrification described here have not only affected the local economy and community but have also had direct and indirect impacts on the environment. Direct impacts include the conversion of woody vegetation areas, even if most of this was degraded *young forest* and was previously used as pasture, and soil sealing. The conversion affects soil water balance, increases soil erosion risk, and reduces infiltration capacity [78,79]. On the other hand, traditional land use practices are reduced due to rising taxes and other income opportunities. The participants do not perceive their traditional land uses, such as agriculture, charcoal production, hunting, and fishing, as putting pressure on the environment. However, analyses concerning increases in woody vegetation in the northern part of the Atlántico Department since 2001 indicate that the decrease in agricultural (cattle breeding and cropping) and forestry activities (timber extraction and charcoal production) has a large influence on the woody vegetation areas [8,80]. Natural recovery can be assumed because there are no major reforestation projects in the north of the Atlántico Department including the study area [8]. This negation of one's own role in environmental degradation issues and focus on external factors and actors is quite common and has been described by many authors (e.g., [81,82]).

For the study area of the PGIS workshop, the changes in woody vegetation cover are complex due to highly dynamic processes of deforestation and natural recovery. The scientific mapping identified larger recovery areas that had been used as pastures before 2008, and where the ponds for livestock could still be recognized. Besides the coastal highway, there are many abandoned former pastures where natural recovery occurs. In addition, the patchwork of secondary dry forest areas in various stages of conservation and degradation in the study area points to the dynamic of deforestation and recovery. A possible explanation is the neglect of pastures by workshop participants in general; the perception of land use changes by medium-sized landholders would probably be different. However, due to regular rotation, traditional land uses can be considered a relatively stable system, even if there is a high dynamic of deforestation and recovery, the total extent of woody vegetation areas remains relatively constant (see Section 5.1). In contrast, changes in landscape and ecosystems through infrastructure and gated community projects are more profound. In addition, these development projects by external actors sparked dissent and environmental consciousness especially regarding the local springs and the protection of indigenous sites [46,49,54,65]. This change of drivers and actors made the local community advocates of sustainable land use in the study area, but just at the time when members of the community lost their land or land leases. Therefore, the local community only has the possibility to monitor the development projects and report environmental damage to the state entities.

6. Conclusions

The case study shows not only the social and economic processes of rural gentrification but also their impact on the environment. We observed rapid and severe land use changes in the peri-urban Caribbean coastal area west of Barranquilla over the last three decades. Before 2008, the main causes of the loss of woody vegetation areas in the study area were pasture farming, small-scale agriculture, timber extraction, and charcoal production. All the traditional activities, due to regular rotation, enabled a recovery of woody vegetation. Since 2008, the main cause for land use changes is the construction of gated communities, which is linked to the expansion of infrastructure and tourism. Although the situation regarding mining licenses is unclear, another major intervention could be pending in the future. In other parts of the Atlántico Department, the extraction of sand and gravel has already caused larger losses of woody vegetation areas [7,8]. These developments are driven by urban assets, construction companies, and sales of land by medium-sized landholders; and they threaten the remnants of tropical dry forest. The majority of the residents of the peri-urban areas, such as the participants of the PGIS workshop in El Morro, are pushed into a passive role and into socio-economic changes due to a lack of influence and assets. The participants of the PGIS workshop illustrated various changes in land use in their environment and perceived them as a threat to their way of life and to the forest ecosystems. In general, they made only external actors responsible for these changes and neglected the environmental impacts of traditional land use practices. The environmental degradation caused by external actors and the rejection of that caused by the local community has generated environmental consciousness. Furthermore, the community members have learned how to advocate for the environment and the indigenous sites through several land use and environmental conflicts in the past. The spatial statistical analysis of land use changes and its comparison with the locals' perceptions of land use change show that the residents have an understanding of the usability of the landscape: steep areas remain covered by woody vegetation and intensive and extensive land uses alternate. The PGIS workshop showed that participants have a clear idea of what areas and sites should be protected. Therefore, community leaders and members are key partners for conservation and sustainable land use, albeit in the role of "inspectors" rather than as key actors in land use as in the past. An important step for conservation and sustainable land use would be support from state entities on the municipal and the departmental level through the implementation and declaration of the two protected areas and the strict monitoring of the infrastructure and gated community projects. Additionally, studies on biodiversity and the establishment of a monitoring system in the region would be desirable; both could benefit from knowledge transfer between scientists, communities, and users.

In addition to quantifying land use changes and their drivers, the combination of visual analysis of high-resolution remote sensing data and participative methods can be used to strengthen the voice of local communities in the debates and decisions on land use changes and conservation projects. Future analysis and policy programs should not only focus on ecological sustainability, but also on social and economic sustainability, because all three dimensions are interrelated, as we have demonstrated in our research.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/23/6729/s1, Figures S1–S4: Land use maps of El Morro and Juaruco 2008, 2011, 2013, and 2017/18, Table S5: Spatial statistics of land use classes.

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