land

MDPI

Article

Land Cover Dynamics along the Urban–Rural Gradient of the Port-au-Prince Agglomeration (Republic of Haiti) from 1986 to 2021

Waselin Salomon [1,2,*], Yannick Useni Sikuzani [3], Kouagou Raoul Sambieni [4], Akoua Tamia Madeleine Kouakou [5], Yao Sadaiou Sabas Barima [5], Jean Marie Théodat [6,7] and Jan Bogaert [1]

1 Unité Biodiversité et Paysage, Gembloux Agro-Bio Tech, Université de Liège, 2 Passage des Déportés, 5030 Gembloux, Belgium; j.bogaert@uliege.be
2 Campus Henri Christophe de Limonade, Université d'Etat d'Haïti, 1130, Rte Nationale # 6 Limonade, Limonade HT 1130, Haiti
3 Unité Ecologie, Restauration Ecologique et Paysage, Faculté des Sciences Agronomiques, Université de Lubumbashi, Lubumbashi 1825, Congo; sikuzaniu@unilu.ac.cd
4 Ecole Régionale Postuniversitaire d'Aménagement et de Gestion Intégrée des Forêts et Territoires Tropicaux (ERAIFT), Kinshasa 7948, Congo; krsambieni@uliege.be
5 Unité de Formation et de Recherche Environnement, Université Jean Lorougnon Guédé, Daloa 150, Côte d'Ivoire; kouakou.akoua@ujlg.edu.ci (A.T.M.K.); sabas.barima@ujlg.edu.ci (Y.S.S.B.)
6 Faculté des Sciences, Université d'Etat d'Haïti (Haïti), URBATeR, URBALaB, Corner of Joseph and Mgr Guilloux Street, Port-au-Prince HT 6110, Haiti; theodat@univ-paris1.fr
7 Laboratoire de Géographie PRODIG, Campus Condorcet Bâtiment Recherche Sud 5, Université Paris 1, 93 322 Paris, France
* Correspondence: w.salomon@uliege.be; Tel.: +32-465289793 or +509-33511330

Abstract: The landscape of the Port-au-Prince agglomeration in the Republic of Haiti has undergone profound changes linked to (peri-)urban expansion supported by rapid demographic growth. We quantify the land cover dynamics along the urban–rural gradient of the Port-au-Prince agglomeration using Landsat images from 1986, 1998, 1999, 2010, and 2021 coupled with geographic information systems and landscape ecology analysis tools. The results show that over 35 years the acreage of the urban zone increased seven-fold while that of the peri-urban area increased five-fold, to the detriment of the rural zone, which was reduced by 14%. The dynamics of the landscape composition along the urban–rural gradient are characterized by a rapid progression of built-up and bare land in urban and peri-urban zones and by fields in the rural zone, in contrast to the more accentuated regression of vegetation in the peri-urban zone. The landscape of the study area has undergone significant changes due to the high demand for housing resulting from rapid population growth, in the context of a lack of territorial development planning by public authorities. This impacts the sustainability of socio-economic and ecological processes in an area where populations are highly dependent on plant resources. Our results underline the necessity to orient territorial development planning in urban, peri-urban and rural zones through an integrated and participatory approach.

Keywords: remote sensing/GIS; spatial dynamics; landscape metrics; urban–rural gradient; urbanization

check for updates

Citation: Salomon, W.; Useni Sikuzani, Y.; Sambieni, K.R.; Kouakou, A.T.M.; Barima, Y.S.S.; Théodat, J.M.; Bogaert, J. Land Cover Dynamics along the Urban–Rural Gradient of the Port-au-Prince Agglomeration (Republic of Haiti) from 1986 to 2021. *Land* **2022**, *11*, 355. https://doi.org/10.3390/land11030355

Academic Editors: Sara Venafra, Carmine Serio and Guido Masiello

Received: 24 January 2022
Accepted: 19 February 2022
Published: 27 February 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Human impact on the natural landscape has been increasing since the advent of sedentarization coupled with the emergence of agriculture [1,2]. The creation and extension of cities resulting from rural exodus and natural demographic growth are among the phenomena that have amplified the human impact on natural environments in recent decades [3–6]. Indeed, in 1850 the proportion of the world's population living in urban areas was 6% [7] compared to 55% in 2020; that proportion is projected to reach 70% by 2050 [8].

In addition to the densification of existing built-up areas, many cities are experiencing reverse migration leading to low-density sprawl on land reserves at the urban–rural interface, an area known as the "peri-urban" zone [5,9–11]. In developing countries, the dynamics of peri-urban zones are characterized by spontaneous and/or anarchic urbanization [12], which constitutes a challenge for urban and landscape planners [6,12]. Thus, many countries in Latin America and the Caribbean have recorded a rapid spatial expansion of urban areas, for example, an urbanization rate of 76.2% in Trinidad has been noted [13]. Mexico City, in Mexico, experienced an annual spatial growth of 0.9% between 2000 and 2010 [14,15]. The Port-au-Prince agglomeration in the Republic of Haiti is no exception to this rule [16].

The uncontrolled peri-urbanization of the Port-au-Prince agglomeration (the capital of Haiti) is the result of changing lifestyles and ineffective land governance, all of which is prompted by galloping and uncontrolled urban population growth. Indeed, from 1982 to 2018, the area's population increased five-fold from approximately 720,000 to 4,000,000 inhabitants [17,18], and is forecasted to house more than five million inhabitants by 2030 [19]. The resulting spatial urban expansion leads to an intensified consumption of agricultural land and pressure on woody vegetation, especially for charcoal production and for the extraction of building materials, etc. [16,20]. Consequently, the green spaces in the Port-au-Prince agglomeration are rapidly disappearing. This, despite their performance as a valuable ecosystem service, which includes moderation of the urban heat island effect, cleansing of air and water, conservation of biodiversity, provision of recreational opportunities, and improvement of physical and psychological well-being for citizens.

However, due to a deficit of over 2.4 million quality housing units in the urban zone of Port-au-Prince [18], about 65% of its population has been relegated to precarious and informal neighborhoods in the peri-urban zone, where access to basic services remains insufficient [16,21]. It should be noted that this situation is also visible in several cities in Latin America and the Caribbean where economic restructuring induced by the process of peri-urbanization has led to significant disparities in development between different neighborhoods [15]. In addition, the growth of the Haitian capital "Port-au-Prince" is also to the detriment of the capital cities, departments, and districts at the country level. Indeed, the centralization of public expenditure and the concentration of the majority of the country's employment in Port-au-Prince favors a steadily increasing rural exodus. Consequently, the population seeks to ensure its housing in a difficult economic context and the absence of territorial development planning, with little concern for the sustainability of resources [16]. This situation is often exacerbated by natural disasters (earthquakes, cyclones, etc.) which lead to changes in the landscape followed by massive displacement of the population towards the capital Haiti. The population allows itself to create new unplanned urban spots wherever space is available [15,16]. This is notably the case regarding the informal district of Canaan, which was created after the 2010 earthquake to house the affected population [16,22].

If the trend continues at the current rate, in which each year more than 10,000 households spontaneously settle in peri-urban zones [16,18], the prosperity of the population could be compromised for many decades to come. It should be noted that most of the spontaneous growth of the peri-urban zones in Port-au-Prince reflects the overall poverty of Haitian society, where 80% of residents subsist on less than USD 1.50 per day [16]. In addition, urban governance in Port-au-Prince is challenged by the growing need for infrastructure provision and land management [21] in an urban core where land for building is becoming increasingly scarce and expensive [18].

Despite this alarming situation, research into quantifying the urban and peri-urban expansion of the Port-au-Prince agglomeration and assessments of the associated ecological consequences still remain limited, including in other Caribbean cities [20]. However, numerous studies establish the importance of understanding the local influence of urban expansion and the various associated anthropogenic activities on landscape dynamics [23] to assess the nature and basis of these changes from the perspective of rational natural

resource management. Given that the urban–rural opposition is completed by accounting for an intermediate zone between both namely, the peri-urban zone [24], it was appropriate for the present study to separately assess the land cover dynamics in the urban, peri-urban, and rural zones of the Port-au-Prince agglomeration. For this reason, the urban–rural gradient approach [6,11,23] was employed.

Accordingly, we characterize the land cover dynamics along the urban–rural gradient of the Port-au-Prince agglomeration in the Republic of Haiti. We hypothesized that the rapid and uncontrolled spatial expansion of the built-up area in urban and peri-urban zones, coupled with the development of shifting agriculture in the rural zone, has led to a landscape dynamic. This dynamic has been marked by the fragmentation and spatial isolation of woody vegetation patches, the extent of which increases in the peri-urban zone of the Port-au-Prince agglomeration

2. Materials and Methods

2.1. Presentation of the Port-au-Prince Agglomeration

The study area represents a group of municipalities that constitute the Port-au-Prince district, namely Port-au-Prince, Delmas, Cité Soleil, Tabarre, Pétion-Ville, Carrefour, Kenscoff, and Gressier, and the municipalities attached to Port-au-Prince district (Croix des Bouquets and Léogane). The 10 municipalities examined by this study form the "Port-au-Prince agglomeration" and cover an acreage of 1755.63 km^2 in the western department of the Republic of Haiti, located between 18°20′–18°50′ north latitude and 72°0′–72°50′ west longitude (Table 1, Figure 1). The relief presents an altitudinal gradient that shifts from low-lying plains to a succession of mountains with peaks exceeding 2000 m [25,26]. According to Köppen's classification, the climate of the study area ranges from tropical savannah in the lowland areas (Aw) to tropical subhumid in the mountainous areas (Cwa), characterized by a total annual rainfall between 1047 mm and 2000 mm and mean annual temperatures between 20 and 26 °C [27]. The natural vegetation largely comprises mangrove forests, shrub savannahs, and stands of pine and hardwood [28]. The economic fabric in the urban zone of the Port-au-Prince agglomeration is dominated by the informal sector (small- and medium-sized enterprises), which accounts for more than two-thirds of GDP and almost 80% of employment [29]. In the surrounding rural zones, the main economic activities are agriculture, livestock, and wood exploitation [30]. The Port-au-Prince agglomeration concentrates the bulk of the country's economic potential, thus attracting large numbers of people from around the country in search of remunerative activities [8,21]. Due to the unprecedented pressure on space of this poorly educated population (the literacy rate in Haiti is 61%), the city limits were extended to the entire southern fringe of the Cul-de-Sac Plain and the foothills of Morne l'Hôpital [16,22]. As a result, there are many threats to the environment in the Port-au-Prince agglomeration, including destruction of vegetation, gully erosion, flooding, and pollution [20,29]

Table 1. Population, area and geographic coordinates of the municipalities in the Port-au-Prince agglomeration [30].

Municipalities	Population	Area (Km^2)	Geographical Coordinates
Port-au-Prince	987,310	36.04	18°32′24″ N–72°20′24″ W
Delmas	395,260	27.74	18°33′00″ N–72°18′00″ W
Cité Soleil	265,072	21.81	18°35′00″ N–72°20′06″ W
Tabarre	130,283	24.47	18°35′00″ N–72°16′00″ W
Croix des Bouquets	249,628	634.62	18°35′00″ N–72°14′00″ W
Pétion-ville	376,834	165.49	18°31′00″ N–72°17′00″ W
Léogane	199,813	385.23	18°30′39″ N–72°38′02″ W
Gressier	36,453	92.31	18°27′00″ N–72°17′00″ W
Kenscoff	57,434	202.76	18°27′00″ N–72°17′00″ W
Carrefour	511,345	165.16	18°32′00″ N–72°24′00″ W
Total	3,209,432	1755.63	

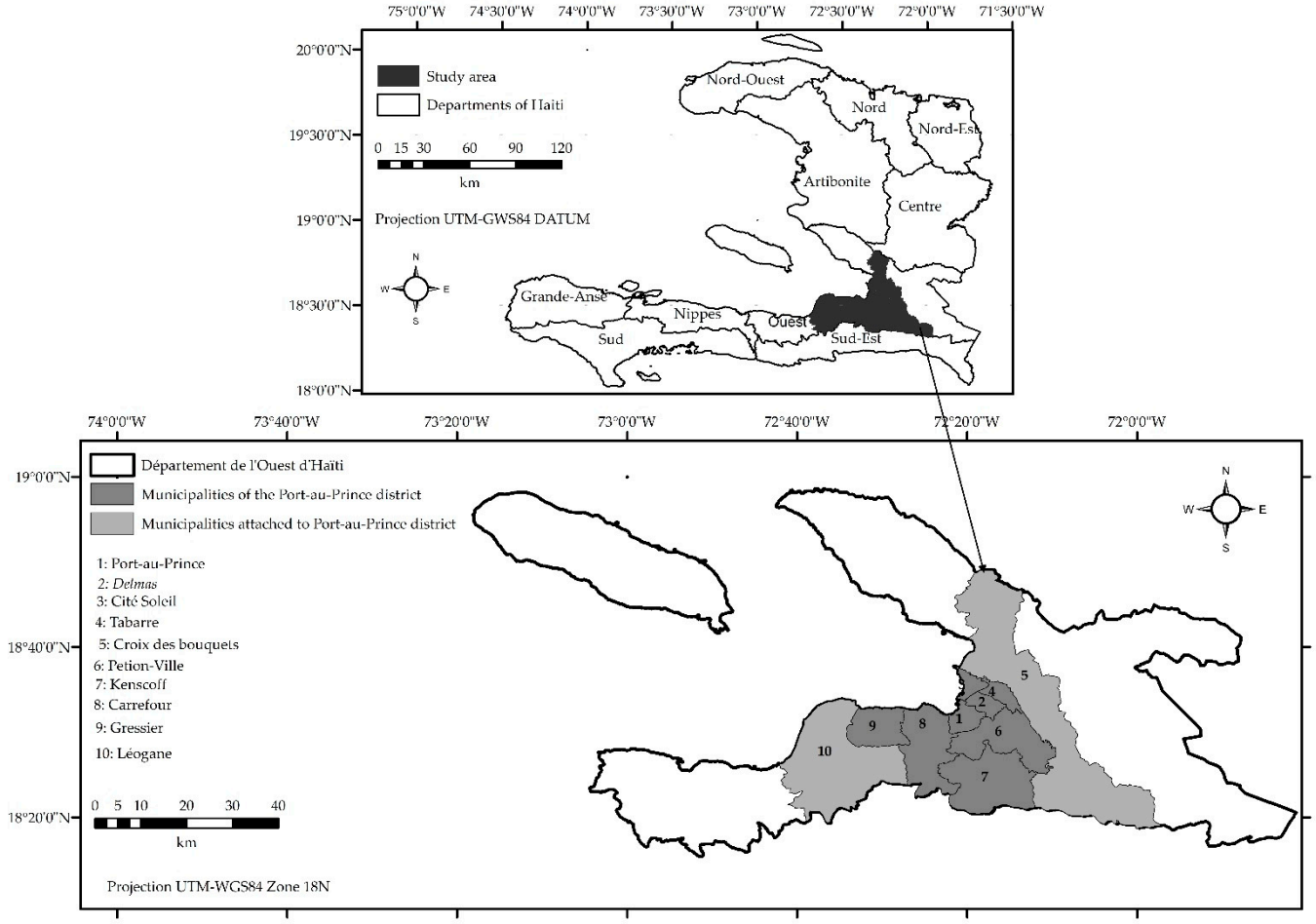

Figure 1. Geographical location of the municipalities of the Port-au-Prince district and attached municipalities in the western department of Haiti.

2.2. Methodology

2.2.1. Choice of Data and Materials Used

Landsat images downloaded from the site "https://earthexplorer.usgs.gov/" accessed on 27 March 2021 via the Multispectral Scanner System (acquired on 6 December 1986/13 December 1986), the Thematic Mapper (acquired on 14 December 1998/1 January 1999 and 22 January 2010/29 January 2010), and the Operational Land Imager (acquired on 4 January 2021/27 January 2021), with a spatial resolution of 30 m, were used to create the mosaics (two images per mosaic) from which the study area was extracted (Table 2). These images were chosen since they are free of charge and recommended for large-scale studies [31,32]. Moreover, they are particularly interesting for data-poor regions lacking recent and reliable spatial information [33]. For these reasons, the images meet the objectives of the study, despite their coarse resolution. All images were acquired during the winter dry season to minimize the effect of haze and clouds and thus facilitating the observation of larger spectral differences among landscape features [34,35]. Furthermore, the dates of acquisition of the Landsat images coincide with key periods marking the sociopolitical and economic life of the country and Port-au-Prince district in particular: (i) the fall of the Duvalier regime in 1986, the overthrow of President Aristide in 1991, and the subsequent embargo; (ii) the socioeconomic instability following the 2000 elections, the 2004–2008 hurricanes, and the 2010 earthquake; and (iii) the post-earthquake period (2010–2021). Additional data such as shapefiles illustrating the boundaries of the municipalities of the Port-au-Prince agglomeration from the Centre Nationale de l'Information Géographique et

de Statistique (CNIGS) were used. ENVI 5.3 and ArcGiS 10.5.1 software was selected for the pre-processing and spatial analysis of the acquired satellite images.

Table 2. Satellite images characteristics.

Sensor	Dates	Path-Row	Spatial Resolution (m)
Landsat MSS	6 December 1986	008-047	30 m
	13 December 1986	009-047	30 m
Landsat TM	14 December 1998	009-047	30 m
	1 January 1999	008-047	30 m
	22 January 2010	008-047	30 m
	29 January 2010	009-047	30 m
Landsat OLI	4 January 2021	008-047	30 m
	27 January 2021	009-047	30 m

2.2.2. Landsat Image Processing and Classification

Pre-Processing

This work involved the development of a mosaic since the extent of the study area exceeded the scope of a remote sensing image [36]. However, a mosaic refers to the assembly of parts of images or contiguous images, preprocessed to be connectable geometrically and radiometrically [37,38]. Thus, the Landsat images used in this study were georeferenced in the UTM (Universal Transverse Mercator)/Zone 18 N, covering the study area, following the WGS 84 (World Geodesic System) reference ellipsoid. The 1986, 1988/1999, and 2010 images were geometrically corrected using 70 ground control points on the 2021 image, which was obtained as a reference. To ensure the efficiency of the change analysis, the geometric accuracy of the registration between the control points and the different Landsat images used was less than one pixel [39].

False Composite Color

A false composite color was created by combining the green, red, and near infrared channels, the last being understood as the most suitable for discriminating vegetation cover [40]. The composite color of the images provides the ability to select the training areas necessary to perform supervised classifications based on visual interpretation of the images supported by GPS data [41,42].

Determination of the Urban, Peri-Urban, and Rural Zones of the Port-au-Prince Agglomeration

To characterize the spatiotemporal dynamics of the different zones of the urban–rural gradient, the land cover was defined in urban, peri-urban, and rural zones according to the decision tree of the definitions of the zones present in the urban–rural gradient [11]. This decision tree, based on morphological characteristics, was preferred owing to its rapidity of execution, simplicity, and closeness to the ground reality, where there is a heterogeneous mix of land cover [6,43]. It should be noted that the urban zone is characterized by the dominance and continuity of the built-up area, which is otherwise dense. The peri-urban zone is characterized by the dominance of a discontinuous and less dense built-up area, while the dominance of vegetation indicates a rural zone [6,11].

The aforementioned decision tree was applied to map the different land cover (urban, peri-urban and rural) on each of the composite Landsat images by a supervised classification employing the maximum likelihood algorithm. This algorithm uses training sites to calculate the probability of each pixel belonging to one of the classes [44]. It should be noted that the urban zone is characterized by the dominance and continuity of the built-up area, which is otherwise dense. The peri-urban zone is characterized by the dominance of discontinuous and less dense built-up area, while the dominance of vegetation indicates a rural zone [6,11]. Thus, the training samples used for this classification were delineated through 219 fixed points acquired with a Garmin 66s GPS (accuracy 3 m) during November and December 2020. The classification accuracy was assessed using the Kappa coefficient

and the overall accuracy, based on the confusion matrix generated with 387 validation points. The Kappa coefficient provides a more accurate estimate (which takes into account well-classified pixels) of the quality of the classification. The overall classification accuracy represents the average of the percentages of correctly classified pixels. The percentage of landscape, which indicates the relative abundance of each urban–rural gradient zone, was calculated.

Qualification of the Port-au-Prince Agglomeration's Municipalities in Urban, Peri-Urban, and Rural Zones

Subsequently, the morphological status of the municipalities along the urban–rural gradient of the Port-au-Prince agglomeration was defined according to the proportions of the different zones (urban, peri-urban, and rural) resulting from the supervised classification of the urban–rural gradient zones from the Landsat image of 2021. If the proportion of the built-up area dominates the landscape, a distinction is drawn between the urban and the peri-urban: if the urban dominates, the area is urban and if the peri-urban dominates, the area is peri-urban. If the co-dominance of urban and peri-urban is less than rural, the area is recognized as rural. Finally, if the co-dominance of urban and peri-urban is higher than rural, the area is considered peri-urban [43].

Classification and Assessment of Land Cover Changes along the Urban–Rural Gradient Zones

Based on knowledge of morphological status, the municipalities of the Port-au-Prince agglomeration were grouped into urban, peri-urban, and rural zones. In each group of municipalities, the land cover dynamics from 1986 to 2021 were assessed based on a second supervised classification. For this reason, the following land cover types were defined: built-up and bare soil (built-up area, bare ground, road), field (mono- or multi-crop agricultural areas, agroforestry systems), woody vegetation (wooded savannah, forest, mangrove) and grassy vegetation (grass, young fallow land, pastures). A total of 206 fixed points and plots obtained from these different land cover types were used in the definition of training samples for supervised classification, based on the maximum likelihood algorithm [45]. Finally, a confusion matrix generated from 497 ground points was employed to verify the classification accuracy, based on the Kappa coefficient and the overall accuracy—two appropriate indices for verifying the reliability of a supervised classification [46].

To assess the impact of peri-urbanization on land cover changes along the urban–rural gradient, the proportion of land cover types in each type of municipality (urban, peri-urban, and rural) was calculated based on the patch area. This index often indicates human impact on landscape morphology [47]. It may provide information on the fragmentation of a land cover type between two periods, particularly through its decrease (Equation (1)).

Rate of land cover change (Rc):

$$(\mathrm{Rc}) = \frac{(\mathrm{UA_{i+n}} - \mathrm{UA_i})}{\mathrm{UA_i}} \quad (1)$$

where $\mathrm{UA_i}$ is the extent occupied by a class in the initial year of a period, n is the interval between two evaluated years, and $\mathrm{UA_{i+n}}$ is the extent occupied by the same class in year i + n [48].

3. Results

3.1. Accuracy of Supervised Classifications

The overall accuracy values obtained were above 90% (Table 3), and the Kappa coefficient indicated values between 92 and 99%, thus suggesting a better distinction between land cover types.

Table 3. Overall accuracy and Kappa coefficient values from supervised classifications of Landsat image mosaics of the Port-au-Prince agglomeration from 1986, 1998–1999, 2010 and 2021 based on the maximum likelihood algorithm.

	Classification 1		Classification 2	
Image Mosaics Classified	**Overall Accuracy (%)**	**Kappa (%)**	**Overall Accuracy(%)**	**Kappa (%)**
1986	94.08	97.04	95.36	98.78
1998–1999	98.11	94.08	98.44	97.66
2010	94.52	96.38	96.46	97.36
2021	95.09	92.52	94.35	92.43

Classification 1 refers to the segmentation and qualification of the urban–rural gradient zones, and classification 2 to the land cover types classifications within the urban, peri-urban and rural zones.

3.2. Mapping and Quantification of the Spatial Changes in the Urban, Peri-Urban, and Rural Zones in the Port-au-Prince Agglomeration

A total of four land cover maps were produced following the supervised classification of Landsat images, illustrating the dynamics of the urban, peri-urban, and rural zones of the Port-au-Prince agglomeration in 1986, 1998–1999, 2010, and 2021 (Figure 2). The visual analysis of the spatial dynamics shows that the urban and peri-urban zones are in constant spatial progression between 1986 and 2021 in the north and east of the study area on a rural matrix that has registered a regressive dynamic (Figure 2).

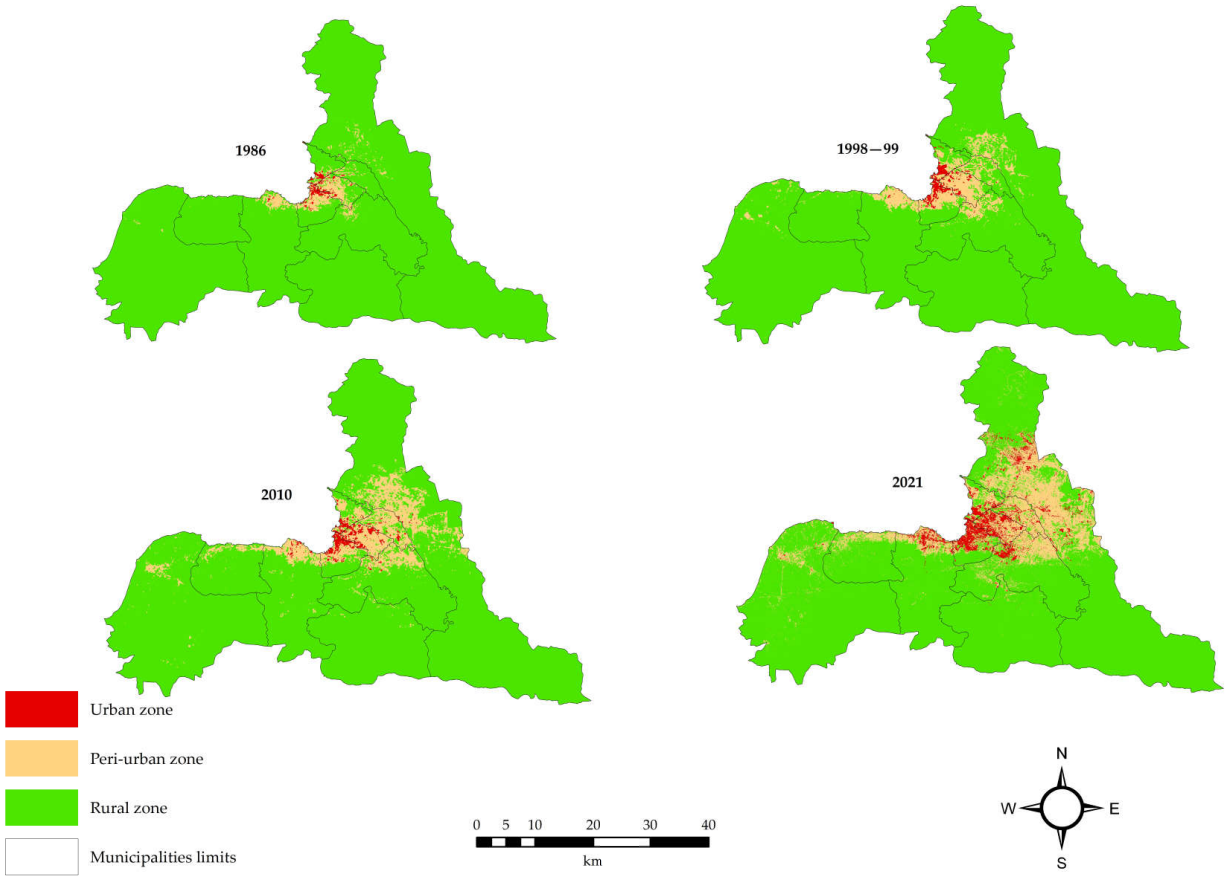

Figure 2. Land cover maps of the Port-au-Prince agglomeration obtained from supervised classification of Landsat images from 1986, 1998–1999, 2010 and 2021 based on the maximum likelihood algorithm. The black lines correspond to the boundaries of the municipalities.

The urban zone experienced a net increase of 612.33% in the landscape between 1986 and 2021, with its area increasing from 8.19 km^2 to 58.34 km^2. However, it should be

noted that the most dramatic spatial increase in the urban zone occurred between 2010 and 2021, with a net increase of 229.42%. The peri-urban zone also increased in acreage from 45.57 km^2 in 1986 to 242.93 km^2 in 2021, with a rate of change of 433.09%. In contrast to the urban and peri-urban zones, the rural zone experienced a regression in acreage from 1697.47 km^2 in 1986 to 1449.82 km^2 in 2021, a net loss of 14.59% compared to 1986 (Table 4).

Table 4. Net area increase between 1986–1998/1999, 1998/1999–2010, 2010–2021 and 1986–2021 of the different zones (urban, peri-urban, rural) corresponding to the agglomeration of Port-au-Prince.

	Area 1986–1998/1999 (km^2)	**Area 1998/1999 (km^2)**	**Net Increase/Decrease(%)**
Urban zone	8.19	12.37	51.04
Peri-urban zone	45.57	102.52	124.97
Rural zone	1701.87	1640.74	−3.59
	Area 1998/1999 (km^2)	**Area 2010 (km^2)**	**Net Increase/Decrease (%)**
Urban zone	12.37	17.71	43.17
Peri-urban zone	102.52	165.1	61.04
Rural zone	1640.74	1572.82	−4.14
	Area 2010 (km^2)	**Area 2021 (km^2)**	**Net Increase/Decrease (%)**
Urban zone	17.71	58.34	229.42
Peri-urban zone	165.1	242.93	47.14
Rural zone	1572.82	1454.36	−7.53
	Area 1986 (km^2)	**Area 2021 (km^2)**	**Net Increase/Decrease (%)**
Urban zone	8.19	58.34	612.33
Peri-urban zone	45.57	242.93	433.09
Rural zone	1701.87	1454.36	−14.54

3.3. Mapping and Quantification of Land Use Dynamics along the Urban–Rural Gradient of the Port-au-Prince Agglomeration

Table 5 displays the morphological urbanization status of the 10 municipalities within the Port-au-Prince agglomeration and the land cover change that occurred within each morphological type of municipality. First, four municipalities exhibit a dominance of built-up area, notably Port-au-Prince and Delmas, which bear an urban zone status, as opposed to Cité Soleil and Tabarre, which have a peri-urban status. In the municipalities with an urban zone status, the "built-up and bare soil" class increased to become the landscape matrix (dominant land cover type) in 2021, while the proportion of fields (the dominant land cover type in 1986), woody vegetation, and grassy vegetation decreased (Figures 3 and 4). This seems to suggest the replacement of vegetation under the influence of expansion and built-up densification. Regarding the municipalities with peri-urban morphological status, the evolution of land cover shows a transition marked by the replacement of fields, which constituted the landscape matrix in 1986, 1998–1999, and 2010, by the built-up area and bare soil that became the dominant land cover type of the peri-urban zone in 2021. During the same period, the proportion of woody and grassy vegetation decreased in the peri-urban zone between 1986 and 2021 (Figures 3 and 4).

In contrast, the municipalities of Croix des Bouquets, Pétion-Ville, Léogane, Gressier, Kenscoff and Carrefour are characteristic of rural zones (Table 5). Within these municipalities, a degradation of woody vegetation (the dominant land cover type in 1986) and grassy vegetation was noted, marked by their replacement with fields, which increased in proportion to become the new landscape matrix in 1998–1999, 2010, and 2021. In these municipalities with a rural morphological status, the area of "built-up and bare soil" increased three-fold in the landscape over the entire study period, with a more marked evolution between 1998–1999 and 2021 (Figures 3 and 4).

Table 5. Morphological status of the municipalities along the urban–rural gradient of the Port-au-Prince agglomeration according to [43] typology. These results are derived from the supervised classification of the Landsat image mosaics of 2021 based on the maximum likelihood algorithm.

Municipalities	Urban Area in km^2 (%)	Peri-Urban Areain km^2 (%)	Rural Area in km^2 (%)	Zone Status
Port-au-Prince	12.7 (35.2)	7.94 (22.0)	15.4 (39.9)	Urban
Delmas	14.2 (51.9)	11.7 (42.9)	2.37 (8.5)	Urban
Cité Soleil	5.8 (26.6)	11.1 (51.3)	4.8 (22.)	peri-urban
Tabarre	2.8 (11.4)	17.1 (69.9)	4.6 (18.8)	peri-urban
Croix des Bouquets	13.9 (2.2)	115.9 (18.3)	504.8 (79.5)	Rural
Pétion-ville	5.5 (3.3)	36.9 (22.4)	123.5 (74.6)	Rural
Léogane	0.9 (0.2)	17.8 (4.6)	366.5 (95.1)	Rural
Gressier	0.4 (0.5)	12.9 (13.2)	78.3 (86.3)	Rural
Kenscoff	0.2 (0.1)	2.0 (1.0)	200.0 (98.6)	Rural
Carrefour	6.0 (3.7)	16.3 (10.0)	142.2 (86.4)	Rural

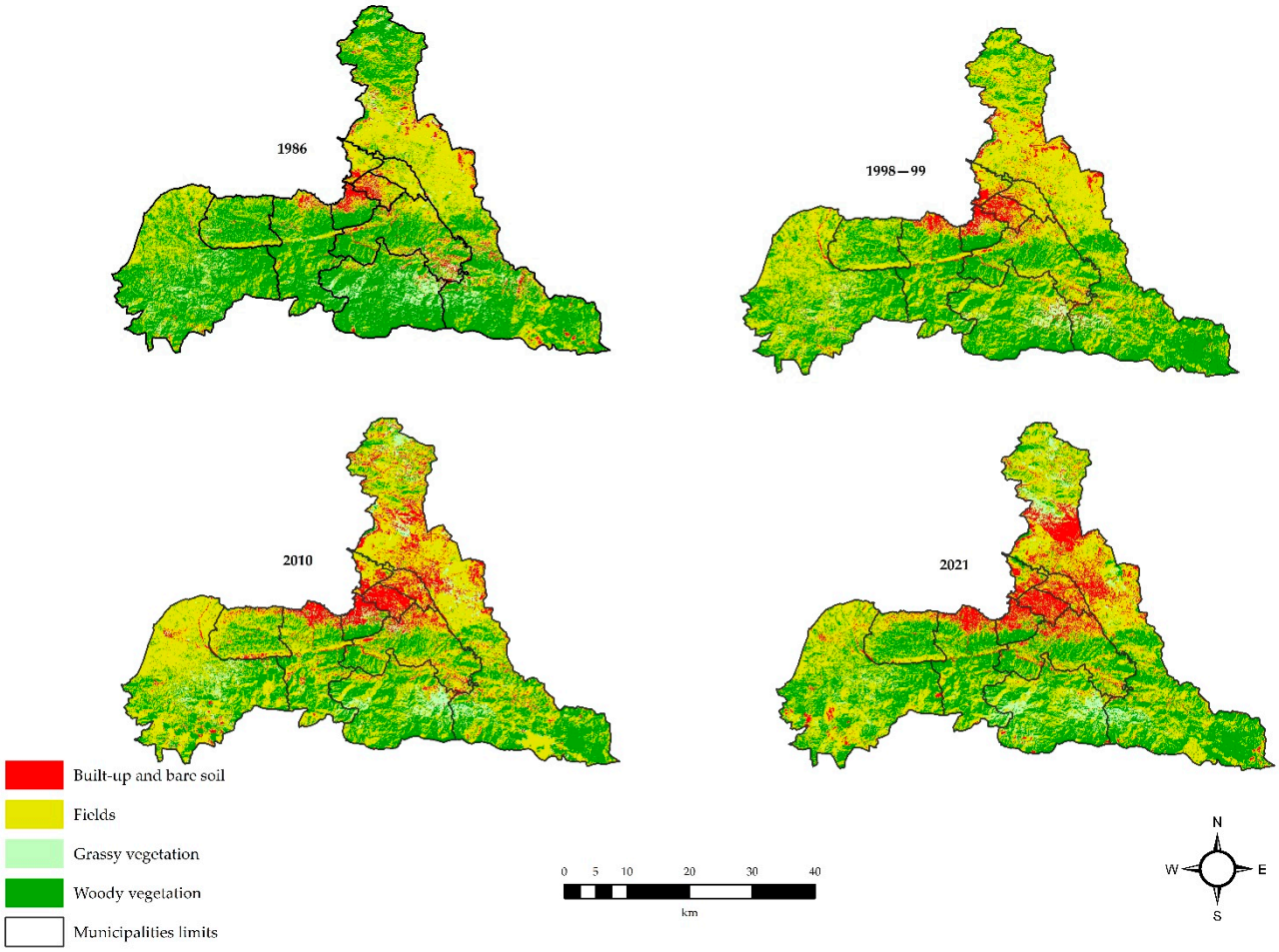

Figure 3. Land cover maps of the Port-au-Prince agglomeration from supervised classification of Landsat image mosaics from 1986, 1998–1999, 2010 and 2021 based on the maximum likelihood algorithm. The black lines correspond to the boundaries of the municipalities.

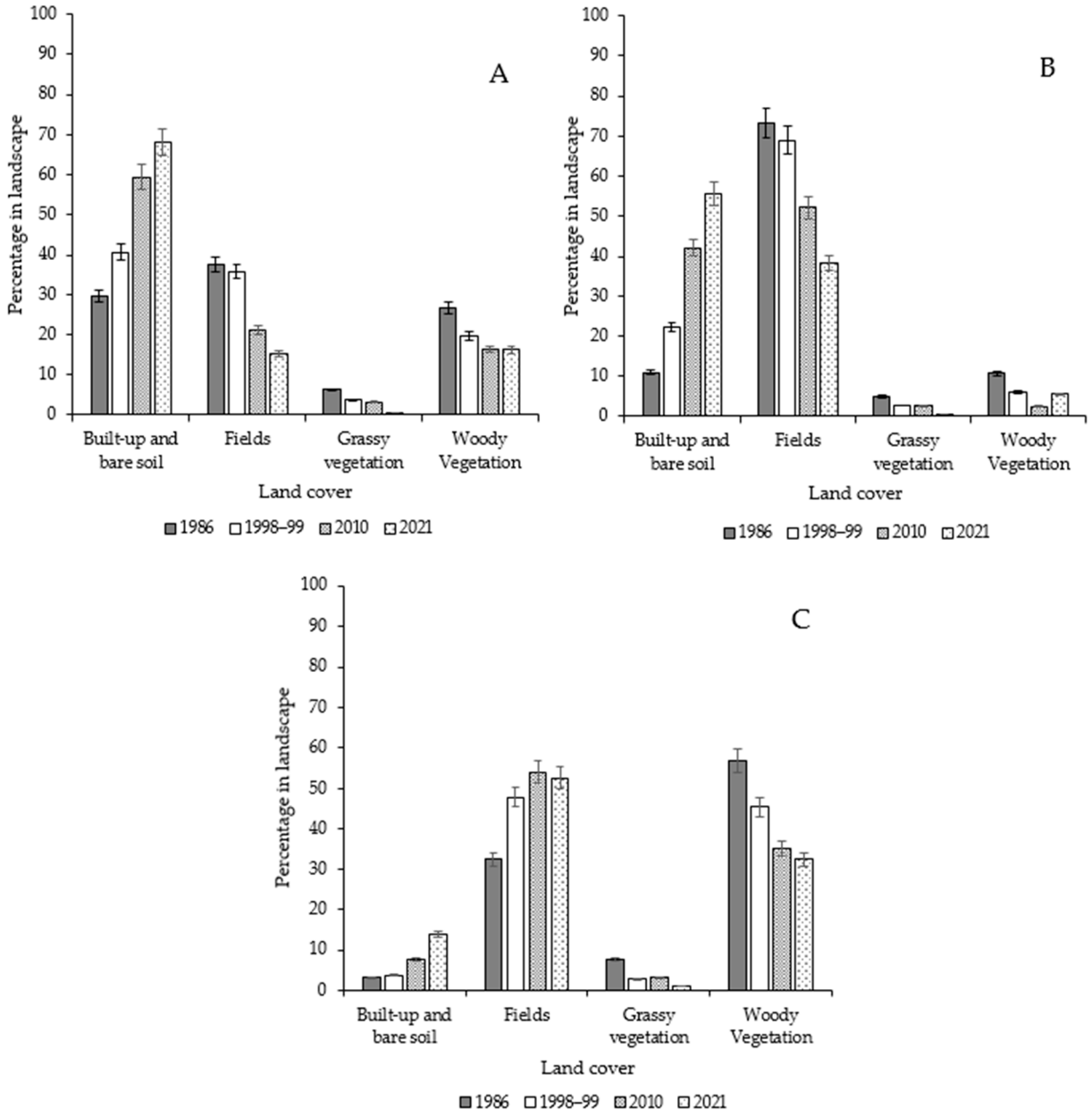

Figure 4. Evolution of the percentage of landscape of different land cover types in municipalities with urban (**A**), peri-urban (**B**) and rural (**C**) zones morphological status. These results were obtained on the basis of supervised classification of Landsat image mosaics from 1986, 1998–1999, 2010 and 2021 based on the maximum likelihood algorithm. The vertical bars represent the standard deviation.

4. Discussion

4.1. Dynamics of the Urban-Rural Gradient Zones of the Port-au-Prince Agglomeration

Since 1986, the various sociopolitical crises that have occurred in Haiti have led to a massive influx of rural populations into the Port-au-Prince agglomeration. In addition, the rapid population growth of the Port-au-Prince agglomeration is largely dependent on unplanned and informal urbanization to meet its housing needs [16]. As a result, the Port-au-Prince agglomeration has experienced rapid spatial urban expansion, particularly towards the north-east, and densification of preexisting built-up areas. The significant spatial expansion of the urban zone in the Port-au-Prince agglomeration seems to indicate a spatial densification of the built-up area in the urban core. These findings should be viewed within the context of an increase in built-up density closer in proximity to the

otherwise more densely populated urban core [16]. This exacerbates the vulnerability of this disadvantaged population due to the mixing of highly densified marginal and risky urban and peri-urban spaces [22,28].

Furthermore, to meet the additional need for housing, the Port-au-Prince agglomeration tends to connect with peripheral municipalities [16], thus justifying the regressive dynamics of the rural zone to the benefit of the peri-urban zone. The rapid spatial urban expansion of Port-au-Prince city towards peripheral areas leads to the discontinuity of urban patches, further suggesting that the geographical space represents a limited resource [6].

The current pattern of urban expansion seems to be influenced by a more favorable topography (the Cul-de-Sac Plain). It has been recognized that topography could influence the expansion of urban areas [31,49]. However, in recent years, urbanization continues to progress, particularly in the south of the study area, in the foothills of the Massif de la Selle, especially on Morne l'Hôpital, despite its status as a reserved area [28]. Indeed, within a context of buildable land becoming scarce and relatively expensive and where the cost of living does not allow for the rental of flats in the urban zone, poor populations settle in risky areas, which lack urban planning infrastructure, and construct houses with salvaged materials [18]. These observations are similar to those of [50] in Cap-Haitian (the second largest city in Haiti), which shows the settlement of the poor population in risky areas such as mangrove forests and mountainsides. Moreover, urban growth is linked to the occurrence of natural disasters in the country (hurricanes and earthquakes), which have led the population to relocate to spaces reserved for agricultural use, mostly unsuitable for building, etc. [51]. Thus, it was revealed that the decade of 2010–2021 was characterized by a stronger urban expansion than other periods studied. Indeed, the urban dynamic during this period seems to have been determined by the 2010 earthquake, which pushed residents without housing and those coming from rural zones to occupy vacant spaces without basic infrastructure [18]. Indeed, new townships, including Canaan with nearly 250,000 inhabitants, emerged after the 2010 earthquake in the municipality of Croix des Bouquets, which bears a rural morphological status [16,18].

4.2. Landscape Dynamics of the Urban Core towards the Rural Areas Adjacent to the Port-au-Prince Agglomeration

The rapid evolution of the peri-urbanization process in the Port-au-Prince agglomeration between 1986 and 2021 is manifested by the anarchic expansion of built-up land to the detriment of the fields. Indeed, in recent decades, agricultural areas have been increasingly transformed into housing and roads [51]. This trend is similar to the findings of [50] on the city of Cap-Haitian (Haiti) and [52] in the French Antilles (Guadeloupe and Martinique), according to which agricultural land in peri-urban areas is constantly being invaded by anarchic buildings. However, agricultural activity is essential to boost the economy of the city and the peri-urban area, to regreen it, and to protect against food insecurity [53].

Moreover, the process of peri-urbanization contributes to the regression of woody vegetation, which is becoming scarcer in both lowland and mountain areas due to their accessibility [28]. This situation risks creating an imbalance between rainwater infiltration and groundwater exploitation in the Cul de Sac Plain, given that the quantity of water drawn from the aquifer is estimated between 63 and 86% of the annual recharge for a growing population [54]. It should be noted that, with an increasingly low poverty line, the population of the Port-au-Prince agglomeration is exploiting and destroying vegetation in favor of subsistent farming activities.

The landscape dynamics of the municipalities located in the rural zone of the Port-au-Prince agglomeration are marked by a decrease in woody vegetation in favor of fields. Indeed, the socioeconomic situation of the rural population, characterized by increasing poverty, has pushed a large proportion of the population into agriculture, particularly slash-and-burn agriculture. Despite the low average productivity of the agricultural sector and the low economic surplus generated, it remains the refuge sector *par excellence* for the population in the rural zone [55]. In addition, due to the increasing demand for charcoal by

the urban and peri-urban population [56], pressure on vegetation in the rural zone is intensifying, especially since charcoal accounts for more than 70% of the country's energy needs. The degradation of vegetation in the Port-au-Prince agglomeration leads to a reduction in its resilience and could thus lead to an increase in flooding in the (peri-)urban zone and an increase in the risk of landslides and rockfalls [28]. In addition, this anthropization of the Port-au-Prince landscape could also lead to runoff and silting of the drainage networks during each rainfall event in the urban sectors located downstream of the mountain, thus obstructing the city's drainage infrastructure, which causes recurrent damage in the lowest areas [20,28].

4.3. Proposals and Perspectives

4.3.1. For the Government and Planners

The current spatial challenge of peri-urbanization in Port-au-Prince consists of adapting or readapting human settlements in such a way as to respond sustainably to the socio-spatial needs of city dwellers and thus to reduce environmental degradation as much as possible. It thus requires efficient planning and settlement policies coupled with a better understanding of the spatial and temporal evolution of the (peri-)urban areas of the Port-au-Prince agglomeration provided by this study. Our results deliver a basis for promoting better planning and efficient spatial organization of the (peri-)urban areas of the Port-au-Prince agglomeration aiming at sustainable development. Moreover, it would be important to anticipate peri-urbanization in currently rural areas that are destined to become potential peri-urban areas within the framework of a territorial development plan, in order to ensure the food security of the population. Indeed, agricultural land continues to be invaded by housing, according to our results. Conversely, for the preexisting urbanized spaces, there is an urgent need to reverse the current socio-spatial imbalance from the perspective of establishing dynamic balances of the mid-place, especially concerning vegetation [57]. Finally, it would be necessary to address the land issue, corruption and also the establishment and enforcement of legal frameworks appropriate to urbanization and the implementation of peri-urban agriculture in the design of a development plan.

It is necessary to delay the growth rate of the Port-au-Prince agglomeration and to reduce the demographic and economic gap between it and other chief towns of the departments and districts of Haiti. This implies the elaboration and application of a true spatially-balanced growth strategy and to work towards decentralization, economic and political deconcentration through the development of different departmental cities.

4.3.2. For Scientific Research Institutions

This study has rendered it possible to characterize (peri-)urban growth in the Port-au-Prince agglomeration and to evaluate its consequences along the urbanization gradient. However, there remain many aspects to be investigated in order to identify a sustainable solution that will enable reconciliation of the conservation of biodiversity and the satisfaction of the spatial needs of an ever-growing population. In this sense, it is up to scientific research institutions to contribute, among other things, to the evaluation of the impact of the degree of urbanization on the ecosystem services mainly provided by green spaces in the Port-au-Prince agglomeration; to develop indicators for monitoring the health of (semi-)natural ecosystems; to integrate the notion of ecosystem services in the planning of territorial development; and to provide scientific assistance to the conservation and development of green spaces.

4.3.3. For the Public

An integrated and sustainable management of the landscape is therefore a very important issue. To achieve this, the populations will have to become involved in the conservation of (semi-)natural ecosystems in the urban and peri-urban landscape of the Port-au-Prince agglomeration, as vegetation directly influences the urban soil and climate while providing beneficial ecosystem services to city dwellers [9,42]. It is important to diversify energy

sources and to adopt new techniques and practices to reduce the collection of wood for energy production, as wood resources tend to decrease along the urban–rural gradient of Port-au-Prince. The scarcity of wood resources bears socioeconomic consequences: the lack of wood energy limits the amount of food cooked and therefore has consequences for nutrition and health, loss of jobs, and income for charcoal producers. It should be noted that the rapid development of the charcoal network is a popular reaction to the lack of alternative energy sources, particularly electricity, in Haitian cities [58]. Participatory land use mapping is urgently needed and the population should be made aware of the preservation of agricultural and (semi-)natural areas in view of the various socio-ecological benefits they provide. Urban fragmentation through building densification should be controlled in urban areas, as it could pose a threat to the preservation of vegetation in the plots.

5. Conclusions

This study sought to highlight the spatial dynamics of land use that prevails along the urban–rural gradient of the Port-au-Prince agglomeration. Our results confirm a change in the spatial pattern along the urban–rural gradient, characterized over 35 years by a rapid progression of built-up and bare soil in urban and peri-urban zones, and of fields in the rural zone. The expansion of these anthropogenic land cover types leads to a regression in the patch area of woody and grassy vegetation among the landscape. This represents an indication of the anthropogenic impact on landscape dynamics along the urban–rural gradient of the Port-au-Prince agglomeration, the extent of which has intensified over the years in the peri-urban zone. This study provides basic information that should lead to an improved understanding of the spatial urban and peri-urban growth of the Port-au-Prince agglomeration and its impact on the different land cover types along the urban–rural gradient. This information remains crucial for the implementation of territorial development planning measures through an integrated and participatory approach.

Author Contributions: Conceptualization, W.S., Y.U.S., K.R.S. and J.B.; Methodology, W.S., Y.U.S., K.R.S., A.T.M.K., Y.S.S.B. and J.B.; Software, W.S.; Validation, W.S., Y.U.S., K.R.S., A.T.M.K., Y.S.S.B., J.M.T. and J.B.; Formal Analysis, W.S., Y.U.S., K.R.S., A.T.M.K., Y.S.S.B. and J.B.; Investigation, W.S.; Resources, W.S., Y.U.S. and J.B.; Data Curation, W.S.; Writing—Original Draft Preparation, W.S.; Writing—Review & Editing W.S., Y.U.S., K.R.S., A.T.M.K., Y.S.S.B., J.M.T. and J.B.; Visualization, W.S., Y.U.S., K.R.S., A.T.M.K., Y.S.S.B. and J.B.; Supervision, W.S., Y.U.S., K.R.S., A.T.M.K., J.M.T. and J.B.; Project Administration, W.S., Y.U.S., J.M.T. and J.B.; Funding Acquisition, J.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Académie de Recherche et d'Enseignement Supérieur-Commission de la Coopération au Développement (ARES-CCD. Exceptional scholarship program) and the Agence Universitaire de la Francophonie (AUF, Antenor Firmin Scholarship) and Fédération Wallonie Bruxelles (FWB, Exceptional Covid-19 measures).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mazoyer, M.; Roudart, L. *Histoire des Agricultures du Monde: Du Néolithique à la Crise Contemporaine*; Histoire; Éditions du Seuil: Paris, France, 2002.
2. Bogaert, J.; Vranken, I.; André, M. Anthropogenic Effects in Landscapes: Historical Context and Spatial Pattern. In *Biocultural Landscapes*; Hong, S.-K., Bogaert, J., Min, Q., Eds.; Springer: Dordrecht, The Netherlands, 2014; pp. 89–112. [CrossRef]
3. Nguimalet, C.R. Population et Croissance Spatiale: Diagnostic et Implications Pour Une Gestion Urbaine de Bangui (République Centrafricaine). In Proceedings of the PRIPODE Workshop on Urban Population, Development and Environment Dynamics in Developing Countries, Cicred, Aphrc, Pern, Ciesin, Nairobi, Kenya, 11–13 June 2007. [CrossRef]

4. Weeks, J.R. Defining Urban Areas. In *Remote Sensing of Urban and Suburban Areas*; Remote Sensing and Digital Image Processing; Rashed, T., Jürgens, C., Eds.; Springer: Dordrecht, The Netherlands, 2010; Volume 10, pp. 33–45. [CrossRef]
5. Besussi, E.; Chin, N.; Batty, M.; Longley, P. The Structure and Form of Urban Settlements. In *Remote Sensing of Urban and Suburban Areas*; Remote Sensing and Digital Image, Processing; Rashed, T., Jürgens, C., Eds.; Springer: Dordrecht, The Netherlands, 2010; Volume 10, pp. 13–31. [CrossRef]
6. Bogaert, J.; Biloso, A.; Vranken, I.; André, M. Peri-urban dynamics: Landscape ecology perspectives. In *Territoires Périurbains: Développement, Enjeux et Perspectives Dans les Pays du Sud*; Bogaert, J., Halleux, J.M., Eds.; Les presses agronomiques de Gembloux: Gembloux, Belgique, 2015; pp. 63–73. Available online: http://hdl.handle.net/2268/188554 (accessed on 18 January 2022).
7. The World Bank. *World Development Report. 1984: Recovery or Relapse in the World Economy? Population Change and Development, Population Data Supplement, World Development Indicators*; Oxford University Press: Oxford, UK, 1984. [CrossRef]
8. United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). 2014. Available online: https://population.un.org/wup/publications/files/wup2014-report.pdf (accessed on 18 January 2022).
9. Alberti, M. *Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems*; Springer: New York, NY, USA, 2008.
10. Chapman, R. Urbanism in the Age of Climate Change. *J. Urban Des.* **2014**, *19*, 149. [CrossRef]
11. André, M.; Mahy, G.; Lejeune, P.; Bogaert, J. Vers une synthèse de la conception et d'une définition des zones dans le gradient urbain-rural. *Biotechnol. Agron. Soc. Environ.* **2014**, *18*, 61–74.
12. Tchékoté, H.; Ngouanet, C. Périurbanisation anarchique et problématique de l'aménagement du territoire dans le périurbain de Yaoundé. In *Territoires Périurbains: Développement, Enjeux et Perspectives Dans les Pays du Sud*; Bogaert, J., Halleux, J.M., Eds.; Les Presses Agronomiques de Gembloux: Gembloux, Belgique, 2015; pp. 259–270.
13. Moullet, D.; Saffache, P.; Transler, A.-L. L'urbanisation Caribeenne: Effets et Contrastes. *Etudes Caribeennes* **2007**, *7*. [CrossRef]
14. Souchaud, S.; Prévôt-Schapira, M.-F. Introduction: Transitions métropolitaines en Amérique latine: Densification, verticalisation, étalement. *Problèmes D'amérique Lat.* **2013**, *90*, 5. [CrossRef]
15. Darbouze, J.; Simonneau, C.; Hanin, Y. Précisions sémantiques, état des lieux dans les pays du Sud et introduction à l'aire métropolitaine de Port-au-Prince. In *Rapport du Programme de Recherche Dans le Champ de L'Urbain FED/2015/360-478, Perspectives de Développement de L'Aire Métropolitaine de Port-au-Prince, Horizon 2030*; Rapport; UQAM: Montréal, QC, Canada, 2018; pp. 41–57.
16. Théodat, J.-M. Port-au-Prince en sept lieues. *Outre-Terre* **2013**, *1*, 123. [CrossRef]
17. Persée, Le Recensement Haitien de 1982. *Population* **1983**, *38*, 1055. [CrossRef]
18. Lizarralde, G.; Petter, A.-M.; Julien, O.J.; Bouchereau, K. L'habitat Dans la Zone Métropolitaine de Port-au-Prince: Principales Représentations, Défis, Opportunités et Prospectives. 2018. Available online: https://www.researchgate.net/publication/326876764 (accessed on 30 December 2021).
19. Bodson, P.; Benoît, J.; Duval, C.J.; Thérasmé, K. la Population de l'aire métropolitaine de port-au-prince 2009–2030. In *Rapport du Programme de Recherche Dans le Champ de L'Urbain FED/2015/360-478, Perspectives de Développement de L'Aire Métropolitaine de Port-au-Prince, Horizon 2030*; Rapport; UQAM: Montréal, QC, Canada, 2018; pp. 89–118.
20. Dehoorne, O.; Cao, H.; Ilies, D. Étudier La Ville Caribéenne. *Etudes Caribeennes* **2018**, 39–40. [CrossRef]
21. Belvert, A. Etude de L'urbanisation du Secteur Sud du Littoral de Port-au-Prince: Cas des Quartiers de Cite Michel et de Ruelle Assade. Faculté des Sciences Économiques, Sociales, Politiques et de Communication, Université Catholique de Louvain. Prom: Emmanuelle PICCOLI; Claire SIMONNEAU. 2019. Available online: http://hdl.handle.net/2078.1/thesis:22484 (accessed on 18 January 2022).
22. Herrera, J.; Lamaute-Brisson, N.; Milbin, D.; Roubaud, F.; Saint-Macary, C.; Torelli, C.; Zanuso, C. L'Evolution des Conditions de vie en Haïti Entre 2007 et 2012. La Réplique Sociale du Séisme. IHSI, DIAL, Paris, Port-au-Prince. 2014. Available online: https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers14-08/010062827.pdf (accessed on 11 November 2021).
23. Mcdonald, R.I.; Kareiva, P.; Forman, R.T.T. The Implications of Current and Future Urbanization for Global Protected Areas and Biodiversity Conservation. *Biol. Conserv.* **2008**, *141*, 1695–1703. [CrossRef]
24. Useni, S.Y.; Sambiéni, K.R.; Maréchal, J.; Ilunga wa Ilunga, E.; Malaisse, F.; Bogaert, J.; Munyemba, K.F. Changes in the Spatial Pattern and Ecological Functionalities of Green Spaces in Lubumbashi (the Democratic Republic of Congo) in Relation with the Degree of Urbanization. *Trop. Conserv. Sci.* **2018**, *11*, 194008291877132. [CrossRef]
25. Moise, P. Etude de Marché de l'aire Métropolitaine de Port-au-Prince: Première étape à la Mise en Place d'une Ferme de Production Maraîchère à Dume (Croix-des-Bouquets), Travail de Fin d'étude en Master de Spécialisation en Production Intégrée et Préservation des Ressources Naturelles en Milieu Urbain et Péri-Urbain, ULiège Gembloux Agro-Bio Tech (Belgique). 2017. Available online: http://hdl.handle.net/2268.2/3087 (accessed on 22 July 2021).
26. MDE. Sixième Rapport National sur la Biodiversité d'Haïti. gef/CBD/6NR/UNDP. Ministère de L'Environnement. Direction de La Biodiversité. 2019. Available online: https://www.cbd.int/doc/nr/nr-06/ht-nr-06-fr.pdf (accessed on 6 May 2021).
27. Climate-Data.org. Available online: https://fr.climate-data.org/amerique-du-nord/haiti/departement-de-l-ouest/port-au-prince-3571/ (accessed on 23 January 2022).
28. Fifi, U. Impacts des Eaux Pluviales Urbaines Sur les Eaux Souterraines dans les Pays en Développement Mécanismes de Transfert des Métaux Lourds à Travers un sol Modèle de Port-au-Prince, Haïti. Ph.D. Thesis, L'Institut National des Sciences Appliquées de Lyon, Lyon, France, 2010.

29. MDE, DDC, HSI. Plan de gestion 2017–2022 du Parc National Naturel de l'Unité 2 de la Forêt des Pins, Rapport d'étude élaboré dans le cadre du Projet Valorisation de la Biodiversité à l'Unité II du Parc National Naturel de la Forêt des Pins, 2017.
30. IHSI. Population Totale, de 18 Ans et plus. Ménages et Densités Estimés en 2015. Port-au-Prince. 2015. Available online: https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/documents/files/estimat_poptotal_18ans_menag2015.pdf (accessed on 20 July 2021).
31. Bamba, I.; Yedmel, M.S.; Bogaert, J. Effets des routes et des villes sur la forêt dense dans la province orientale de la République Démocratique du Congo. *Eur. J. Sci. Res.* **2010**, *43*, 417–429.
32. Mama, A.; Sinsin, B.; De Canniere, C.; Bogaert, J. Anthropisation et dynamique des paysages en zone soudanienne au nord du Benin. *Tropicultura* **2013**, *31*, 78–88.
33. Pham, H.M.; Yamaguchi, Y.; Bui, T.Q.A. Case Study on the Relation between City Planning and Urban Growth Using Remote Sensing and Spatial Metrics. *Landsc. Urban Plan.* **2011**, *100*, 223–230. [CrossRef]
34. Clerici, M.; Mantiero, D.; Lucchini, G.; Longhese, M.P. The Saccharomyces cerevisiae Sae2 protein negatively regulates DNA damage checkpoint signalling. *EMBO Rep.* **2006**, *7*, 212–218. [CrossRef]
35. Oszwald, J.; Gond, V.; Dolédec, S.; Lavelle, P. Identification d'indicateurs de Changement d'occupation Du Sol Pour Le Suivi Des Mosaïques Paysagères. *Bois For. Trop.* **2011**, *307*, 7. [CrossRef]
36. Ouattara, G.; Koffi, G.B.; Kouakou, Y.K.A. Contribution des images satellitales Landsat 7 ETM+ a la cartographie lithostructurale du Centre-Est de la Côte d'Ivoire (Afrique de l'Ouest). *IJIAS* **2012**, *1*, 61–75.
37. Leruth, F. Les mosaïques d'images. *Bull. Soc. Géogr. Liège* **2000**, *38*, 95–106.
38. Girard, M.-C.; Girard, C.M. *Traitement des Données de Télédétection: Environnement et Ressources Naturelles*, 2nd ed.; Technique et Ingénierie: Paris, France, 2017.
39. Mas, J.F. Une Revue Des Méthodes et Des Techniques de Télédétection Du Changement. *Can. J. Remote Sens.* **2000**, *26*, 349–362. [CrossRef]
40. Vital, J.A. Land Use/Cover Change Using Remote Sensing and Geographic Information Systems: Pic Macaya National Park, Haiti. Master's Thesis, Michigan Technological University, Houghton, MI, USA, 2008. [CrossRef]
41. Koné, M.; Aman, A.; Adou Ayo, C.Y.; Coulibaly, L.; N'Guessan, K.E. Suivi diachronique par télédétection spatiale de la couverture ligneuse en milieu de savane soudanienne en Côte d'Ivoire. *Télédétection* **2007**, *7*, 433–446.
42. Useni, S.Y.; Cabala, K.S.; Malaisse, F.; Nkuku, K.C.; Amisi, M.Y.; Bogaert, J.; Munyemba, K.F. Vingt-cinq ans de monitoring de la dynamique spatiale des espaces verts en réponse à l'urbanisation dans les communes de la ville de Lubumbashi (Haut-Katanga, R.D. Congo). *Tropicultura* **2017**, *4*, 300–311. [CrossRef]
43. Sambieni, K.R.; Messina Ndzomo, J.-P.; Biloso Moyenne, A.; Halleux, J.-M.; Occhiuto, R.; Bogaert, J. Les statuts morphologiques d'urbanisation des communes de Kinshasa en République Démocratique du Congo. *Tropicultura* **2018**, *3*, 520–530. [CrossRef]
44. Bonn, F.J.; Rochon, G. *Précis de Télédétection*; Universités francophones; Presses de l'Université du Québec: Sillery, QC, Canada, 1992.
45. Inoussa, M.M.; Mahamane, A.; Mbow, C.; Saadou, M.; Yvonne, B. Dynamique spatio-temporelle des forêts claires dans le Parc national du W du Niger (Afrique de l'Ouest). *Sci. Chang. Planét. Sécher.* **2011**, *22*, 108–116. [CrossRef]
46. Skupinski, G.; BinhTran, D.; Weber, C. Les Images Satellites Spot Multi-Dates et La Métrique Spatiale Dans l'étude Du Changement Urbain et Suburbain—Le Cas de La Basse Vallée de La Bruche (Bas-Rhin, France). *Cybergeo* **2009**. [CrossRef]
47. Krummel, J.R.; Gardner, R.H.; Sugihara, G.; O'Neill, R.V.; Coleman, P.R. Landscape Patterns in a Disturbed Environment. *Oikos* **1987**, *48*, 321. [CrossRef]
48. Barima, Y.S.S.; Barbier, N.; Bamba, I.; Traoré, D.; Lejoly, J.; Bogaert, J. Dynamique Paysagère En Milieu de Transition Forêt-Savane Ivoirienne. *Bois For. Trop.* **2009**, *299*, 15. [CrossRef]
49. Useni, S.Y.; Andre, M.; Mahy, G.; Cabala, K.S.; Malaisse, F.; Munyemba, K.F.; Bogaert, J. Interpretation paysagere du processus d'urbanisation à Lubumbashi (RD Congo): Dynamique de la structure spatiale et suivi des indicateurs ecologiques entre 2002 et 2008. In *Anthropisation des Paysages Katangais*; Bogaert, J., Colinet, G., Mahy, G., Eds.; Presses Agronomique de Gembloux: Gembloux, Belgique, 2018; pp. 281–296.
50. Salomon, W.; Useni, S.Y.; Kouakou, A.T.M.; Barima, Y.S.S.; Kaleba, S.C.; Barthelemy, J.-P.; Bogaert, J. Caractérisation de la dynamique de l'occupation du sol en zone urbaine et périurbaine de la ville du Cap-Haïtien (Haïti) de 1986 à 2017. *Tropicultura* **2020**, *38*, 1438. [CrossRef]
51. Milian, J.; Tamru, B. Port-Au-Prince, Ville Du Risque? Un Mythe Au Prisme d'une Urbanisation Vulnérable. *Etudescaribeennes* **2018**, 39–40. [CrossRef]
52. Audebert, C. Les Antilles françaises à la croisée des chemins: De nouveaux enjeux de développement pour des sociétés en crise. *Les Cah. D'Outre-Mer. Rev. De Géographie De Bordx.* **2011**, *64*, 523–549. [CrossRef]
53. Tambwe, N.A. Urban agriculture, land sustainability. The case of Lubumbashi. In *Territoires Périurbains: Développement, Enjeux et Perspectives dans les Pays du Sud*; Bogaert, J., Halleux, J.M., Eds.; Les Presses Agronomiques de Gembloux: Gembloux, Belgique, 2015; pp. 153–162.
54. Chérubin, D.C.; Jébrak, Y.; Isabelle, T. Infrastructures et Grands Équipements, Vulnérabilité et Constats. In *Rapport du Programme de Recherche Dans le Champ de l'urbain FED/2015/360-478, Perspectives de Développement de L'Aire Métropolitaine de Port-au-Prince, Horizon 2030*; rapport; UQAM: Montréal, QC, Canada, 2018; pp. 227–228.

55. Montas, R. Estimation du poids relatif de l'économie informelle dans l'économie haïtienne en 2016. In *Rapport du Programme de Recherche Dans le Champ de L'Urbain FED/2015/360-478, Perspectives de Développement de l'Aire Métropolitaine de Port-au-Prince, Horizon 2030*; rapport; UQAM: Montréal, QC, Canada, 2018; pp. 141–144.
56. Angelier, J.P. Analyse de la Substitution Entre Combustibles Dans le Secteur Résidentiel en Haïti. 2005. Available online: https://halshs.archives-ouvertes.fr/halshs-00120739/fr/ (accessed on 18 January 2022).
57. Sambieni, K.R. Dynamique du Paysage de la Ville province de Kinshasa sous la Pression de la Périurbanisation: L'Infrastructure Verte Comme Moteur d'Aménagement, Thèse de Doctorat en Cotutelle, École Régionale Post-Universitaire d'Aménagement et de Gestion Integrés des Forêts et Territoires tropicaux (ÉRAIFT) et Université de Liège (ULIEGE). 2020. Available online: http://hdl.handle.net/2268/234317 (accessed on 23 January 2022).
58. Salomon, W.; Sikuzani, Y.U.; Kouakou, A.T.M.; Barima, S.S.; Théodat, J.-M.; Bogaert, J. Monitoring of Anthropogenic Effects on Forest Ecosystems within the Municipality of Vallières in the Republic of Haiti from 1984 to 2019. *Trees For. People* **2021**, *6*, 100135. [CrossRef]