Analysis of Landscape Evolution and Fragmentation in Valencia/Matura, Trinidad and Tobago (1994-2022)

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Abstract

The Valencia/Matura region of Trinidad and Tobago is an ecologically significant area, characterised by a range of habitats. However, increasing anthropogenic activity has resulted in significant land use/land cover change in the region. The purpose of this study is to assess the spatiotemporal changes in landscape configuration and fragmentation in this region from 1994 to 2022 using landscape metrics. Forest/non-forest classes were derived from Google Earth satellite imagery and aerial photography and fragmentation was assessed using landscape metrics in RStudio for both classes. Class Area, Largest Patch Index, Number of Patches, Patch Density, Percentage of Landscape, Mean Patch Area, Edge Density, Patch Cohesion and Effective Mesh Size at the class level were quantified in this study. The results from this analysis indicate that the region is becoming increasingly fragmented primarily due to quarrying activities and urbanisation and the use of these metrics proved to be an effective means for monitoring this region.

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1.0 Introduction

Rapid population growth and the expansion of industrialisation in recent times have resulted in a considerable surge in the consumption of Earth's natural resources, resulting in extensive land use changes as well as habitat and biodiversity loss. Landscape ecology is a field of study that aims to investigate the complex interactions between landscape patterns and the underlying ecological processes (Fan and Myint 2014). Thus, due to its effects on the functioning of ecosystems and their populations, landscape fragmentation has captured scientific interest beyond landscape alterations. Landscape ecology operates on the fundamental premise that a landscape can be regarded as a collection of patches within a larger background matrix, which together make up a diverse landscape mosaic (Simmons 2004).

Landscape fragmentation is a clear indication of the profound impact that humans have had on ecosystems at various levels, ranging from local to global. Landscape fragmentation involves the breaking apart of continuous habitat into smaller, isolated patches. Thus, fragmentation can be seen as a physical process that reduces the overall quantity of original vegetation, divides and isolates habitat patches, and introduces new land-use types (Bennett and Saunders 2011). The remaining size and arrangement of fragments have been found to have a significant impact on the population dynamics of species. Thus, the quantitative characterisation of spatial patterns is a critical step in understanding the interaction between ecological processes and landscape structure (Buyantuyev and Wu 2009). Several factors contribute to forest fragmentation.

Several studies note that urban expansion and infrastructure development, such as housing developments and road networks, are major drivers of fragmentation that create physical barriers and impede wildlife movement (Fan and Myint 2014; Inostroza, Baur, and Csaplovics 2013; Reis, Silva, and Pinho 2015). In agricultural landscapes, fragmentation can arise from creating small, isolated fields surrounded by barriers such as roads, which can hinder the movement of wildlife (Narmada, Gogoi, and Dhanusree 2021; Gestich et al. 2021). Logging and other forms of land-use change can also lead to fragmentation by removing large tracts of forest and replacing them with smaller, isolated patches (Mullu 2016). Fragmentation can have a ripple effect on ecological processes, disrupting species interactions, nutrient cycling, and ecosystem functioning, ultimately leading to biodiversity loss and ecosystem degradation (Flowers, Huang, and Aldana 2020). According to Parker and Nally (2002), one of the primary effects is increased isolation of populations, which can result in decreased genetic diversity and increased risk of extirpation or extinction due to catastrophic events and edge effects can potentially increase predation and competition (Mullu 2016).

There are several methods that can be used to study the consequences of land use and cover changes and fragmentation on a specific habitat; including the utilisation of remote sensing data and landscape metrics (Southworth, Munroe, and Nagendra 2004). Landscape metrics are algorithms that quantify the spatial structure of a landscape, evaluating them as a mosaic of patches of different size, shape and spatial arrangements. By providing a quantitative description of landscape features, landscape metrics can provide a comprehensive understanding of landscape patterns and their influence on ecological processes (McGarigal and Cushman 2002). The increased complexity of calculations used to analyse ecological phenomena has led to a corresponding increase in the complexity of their interpretation and behaviour in response to changes in the environment. Therefore, a metric that is effective in analysing fragmentation in one context may not be appropriate for studying fragmentation within another context. The nature of the process and the characteristics of the disturbing agent must be taken into account when selecting appropriate metrics for analysing ecological phenomena (Llausàs and Nogué 2012).

The choice of appropriate landscape metrics for fragmentation analysis is crucial to accurately interpret the ecological consequences of changes in the environment. Narmada et al. (2021) focused on six class level indices to determine patterns of landscape change as a result of economic development within a forested area. While a variety of metrics were utilised, Narmada, Gogoi, and Dhanusree (2021) concluded that the forest landscape has fragmented due to increase in the number of patches, mean patch size and patch density and correlated these changes with a decrease in biodiversity and species richness. Singh, Pandey, and Singh (2014) utilised four landscape level metrics and four class level metrics to characterise landscape changes. Similarly, they concluded that the gradual increase in the number of patches and patch density as well as the reduction in the total area and area mean indicate increasing fragmentation attributed to anthropogenic activity. Therefore, it can be noted that landscape metrics for fragmentation analysis vary contextually but have common characteristics such as: mean patch area, patch density, number of patches and percentage of landscape (Linh, Erasmi, and Kappas 2012; Nurwanda, Zain, and Rustiadi 2016; Ololade and Annegarn 2015; Yan et al. 2022).

Few studies on fragmentation are focused within developing countries and none within Trinidad and Tobago. The Valencia/Matura region of Trinidad and Tobago is an ecologically significant area, characterised by a range of habitats. However, rapid population growth and urbanisation, along with agricultural and industrial development, particularly quarrying activities, have resulted in significant habitat loss and fragmentation in the region. Despite the importance of this region, there is a significant gap in the understanding of how fragmentation affects tropical species and landscapes and much remains to be learned about how best to conserve and manage these unique ecosystems. Therefore, the purpose of this study is to assess the spatiotemporal changes in landscape configuration and fragmentation in Valencia/Matura, Trinidad and Tobago from 1994 to 2022 using landscape metrics. The findings of this study will have significant implications for conservation and management strategies in Valencia/Matura and other tropical regions facing similar challenges.

2.0 Methodology

The research methodology can be divided into the following major components: (i) data acquisition and pre-processing; (ii) Image classification and accuracy assessment; and (iii) selection and computation of landscape metrics.

2.1 Study Area

The Valencia/Matura region is situated in the eastern part of Trinidad and Tobago, extending between 10° 41’ to 10° 43’ N latitudes and 61° 10’ and 61° 20’ W longitudes. The area is renowned for its tropical climate with two distinct seasons, a dry season from January to May, and a rainy season from June to December, characterised by an annual rainfall of approximately 2,000 mm. The temperature remains relatively constant throughout the year, averaging around 27°C (Trinidad and Tobago Meteorological Service 2023).

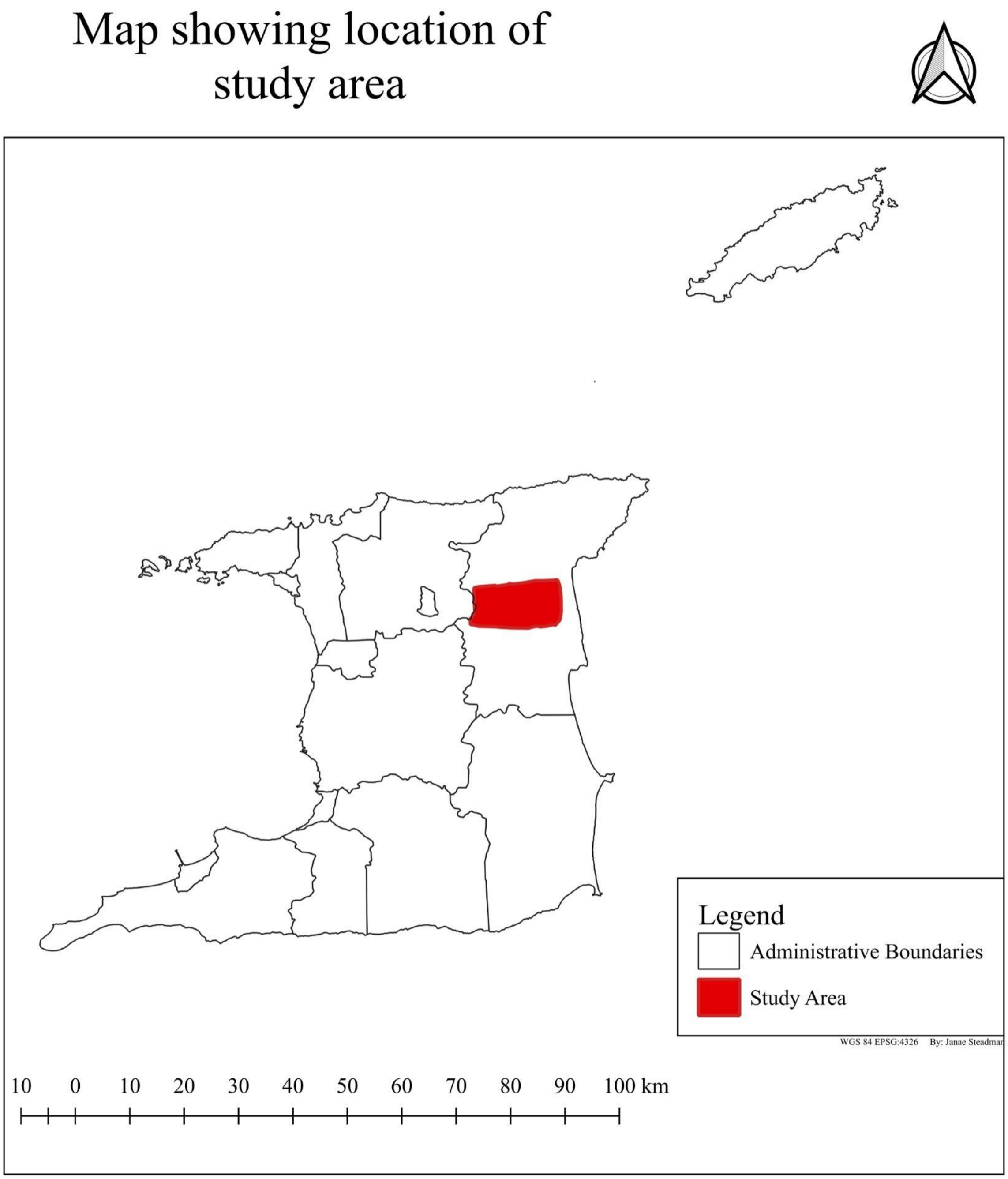

Figure 1. Location of study area

The study area exhibits relatively flat topography with undulations ranging from 10 to 100 metres above sea level, and an imperfect drainage system. It is primarily covered by terrace deposits of fine sand, consisting of a loose sand layer of approximately one quarter to one metre in thickness overlaying cemented gravel that forms an undulated pan. The area encompasses the

Valencia Wildlife Sanctuary, which serves primarily as a research and recreational ground and is managed for timber production. It is also renowned for its natural mineral resources, such as limestone and gypsum, with quarrying serving as a significant economic activity. However, the region is currently facing environmental degradation due to detrimental agricultural practices, excessive logging, squatting, and indiscriminate quarrying activities. Sand and gravel mining in the region have also resulted in the loss of aquatic species, as silt-laden discharge from washing plants enters the Oropouche, Turure, and Quare Rivers (Al-Tahir and Oatham 2005).

2.2 Data Acquisition and Pre-processing

Google Earth satellite imagery and aerial photographs are used as a source for the study. Aerial photographs from 1994 covering the study area were obtained and high resolution images of 15 September 2022 were downloaded at 10 km eye altitude from Google Earth Pro archives. Two images were required to cover the whole study area. The 2022 image was georeferenced using QGIS with a root mean square error (RMSE) of less than 10 m by using the nearest neighbour resampling method. Both images were then mosaicked and the study area was extracted. The 1994 aerial photograph was then georeferenced to the 2022 image (image to image registration), with an RMSE of less than 30 m. For each photo, between 6 and 10 ground control points were selected. The selected points were: Road crosses, building corners and small isolated trees. The accuracy of the georeferencing process has been verified by the RMSE which provides an assessment of the deviation between observed and expected values.

2.3 Image Classification and Accuracy Assessment

This study depends upon human photo interpretation to identify and delineate land cover classes, which were divided into two categories; forest and non-forest. The high resolution of the digital photographs ensured that the two classes of land cover types could be distinguished with a satisfactory degree of certainty, using criteria such as size, texture, colour, shape, and location. To achieve this, specific areas of land cover were identified, and their boundaries were manually delineated on-screen in the QGIS environment. Manual interpretation was necessary in this study due to the nature of the data sources, which typically have high spatial resolution but may not be suitable for automated classification methods. Automated methods rely on spectral properties of the data to identify and classify land cover classes. However, these methods may not be effective in cases where the spectral differences between classes are not well defined. Manual interpretation allows for a more nuanced assessment of land cover patterns and the ability to account for subtle variations in land cover that may not be distinguishable using automated techniques (Hu et al. 2013; Franklin, Montgomery, and Stenhouse 2005).

One crucial step in the classification process is the accuracy assessment, which aims to evaluate how effectively pixels were classified into their respective land cover classes (Nasehi and Imanpour Namin 2020). To perform the accuracy assessment, the error matrix was used, which is one of the most widely used methods for assessing classification accuracy. To create the reference data for the error matrix, 20 polygons representing the two land cover classes (forest and non-forest) were delineated across the study area using Google Earth Satellite Imagery. The classified image and the reference data were loaded into the r.kappa algorithm in QGIS. The output file contained the Kappa coefficient, errors of commission, errors of omission and overall accuracy which were then used to calculate the user's accuracy, and producer's accuracy where :

$$\text{Producer's accuracy} = 100 - \text{Error of Omission}$$

$$\text{User's accuracy} = 100 - \text{Error of Commission}$$

These measures were used to evaluate the quality of the classification and identify areas where the classification accuracy could be improved.

2.4 Selection and Calculation of Landscape Metrics

To analyse changes in spatial and temporal patterns in the study area, landscape metrics were calculated using the packages 'landscapemetrics' (Hesselbarth et al 2019) and 'SDMtools' (VanDerWal et al. 2014) in RStudio (R Core Team, 2021). Various indices, including contagion, juxtaposition and patchiness, can be used to measure fragmentation mechanisms (Madarasinghe, Yapa, and Jayatissa 2020). However, selecting an appropriate metric or suite of metrics for a particular situation can be challenging due to the diversity and redundancy of available metrics and the complexity of habitat loss and fragmentation effects. Therefore, in this study, 9 class level metrics of land cover pattern between forest and non-forest classes were selected to avoid redundancy complying with FRAGSTATS v4 definitions (Hesselbarth 2022):

Table 1. Selected Landscape Metrics

Name	Definition	Formula
Class Area (CA)	Indicates the total area covered by a land cover class in hectares.	CA = sum(AREA[$patch_{ij}$]) where AREA[$patch_{ij}$] is the area of each patch in hectares.
Percentage of Landscape (PLAND)	Quantifies the proportional ratio of each patch type in the landscape.	$\text{PLAND} = (\sum_{j=1}^{n} a_{aj} \div A) * 100$ where a_{ij} is the area of each patch and A is the total landscape area.
Number of Patches (NP)	A measure of landscape fragmentation that represents the total number of discrete patches of a given land cover class.	$NP = \sum n_i$ where n_i is the number of patches
Patch Density (PD)	A measure of patch abundance and distribution in the landscape.	$PD = n_i / A * 10000 * 100$ where n_i is the number of patches and A is the total landscape area.
Largest Patch Index (LPI)	A measure of landscape dominance and patch size distribution.	$LPI = (max(a_{ij})/A)*100$ where $max(a_{ij})$ is the area of the patch in square metres and A is the total landscape area in square metres.
Mean Patch Area (MPA)	The average area of patches of a given land cover class in the landscape.	MPA = mean(AREA[$patch_{ij}$]) where AREA[$patch_{ij}$] is the area of each patch in hectares.
Edge Density (ED):	Represents the length of edge per unit area of a given land cover class.	$ED = \sum_{k=1}^{m} e_{ik} / A \; * \; 10000$ where e_{ik} is the total edge length in metres and A is the total landscape area in square metres.
Patch Cohesion (PC):	A measure of patch connectivity and shape complexity, representing the degree of connectedness among patches of a given land cover class.	PC = $1 - (\sum_{J=1}^{n} p_{ij} / \sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}) * (1 - 1/\sqrt{Z})^{-1} * 100$ where p_{ij} is the perimeter in metres, a_{ij} is the area in square metres and Z is the number of cells.
Effective Mesh Size (EMS):	A measure of landscape connectivity and fragmentation, representing the size of gaps in the landscape that would impede movement of organisms or ecological processes.	$EMS = (\sum_{j=1}^{n} a_{ij}^{2} / A) \; * \; 1 / 10000$ where aij is the patch area in square metres and A is the total landscape area in square metres.

3.0 Results

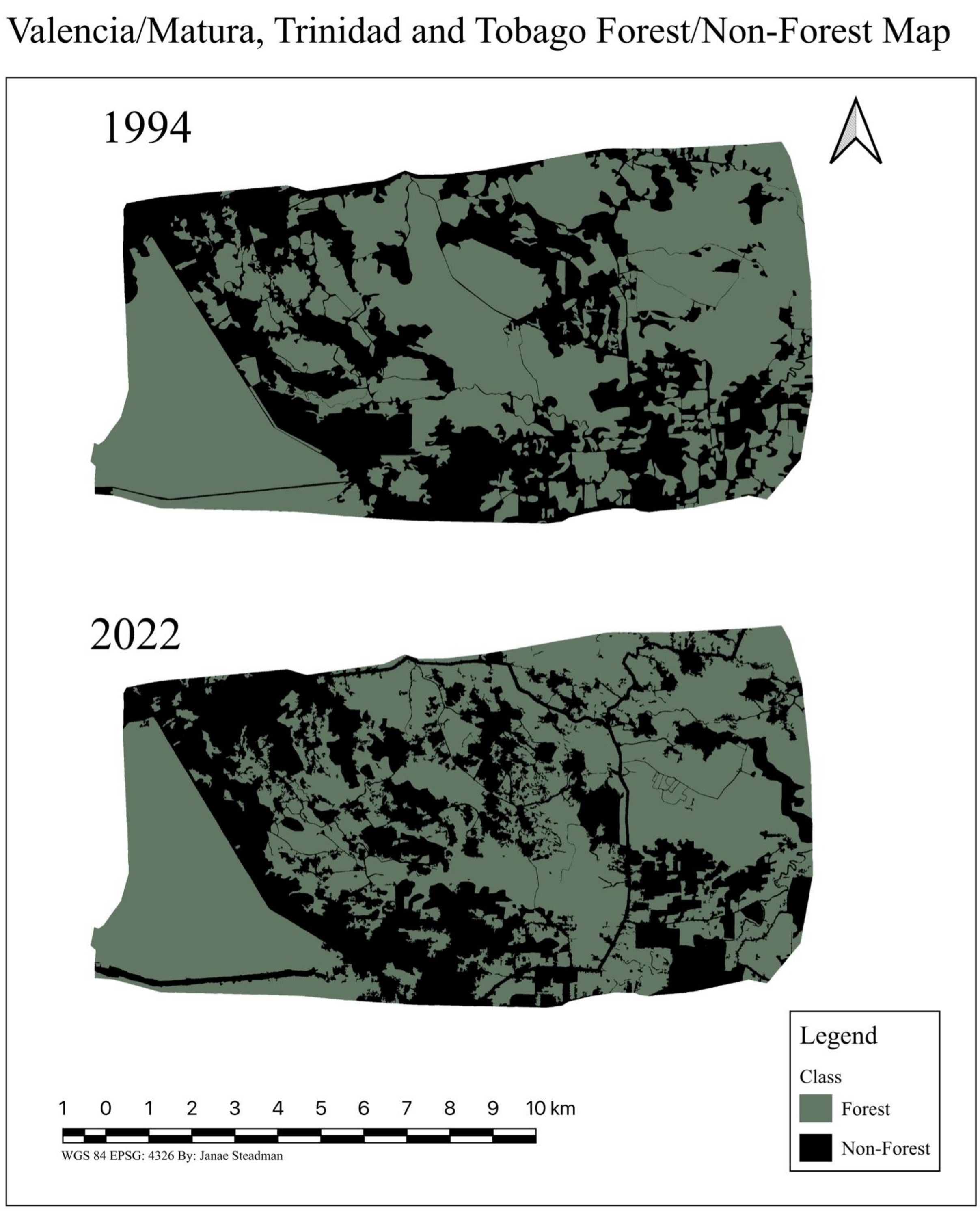

Figure 2. Forest/Non-Forest Classification for Valencia/Matura, Trinidad and Tobago

Table 2. Accuracy Assessment of Forest/Non-Forest Classification

Class Name	1994		2022	
	Producer's Accuracy	User Accuracy	Producer's Accuracy	User Accuracy
Forest	100	98.21	99.87	89.17
Non-Forest	97.19	100	93.1	99.92
Overall Classification Accuracy		98.9		95.56
Kappa Statistics		0.98		0.91

According to table 2, Kappa statistics of 0.98 and 0.91 and an overall accuracy of 98.9% and 95.56% were derived from the classified images of 1994 and 2022. By meeting the minimum accuracy requirement of 85% set by the Anderson classification scheme for satellite-derived LULC maps, these statistics were deemed suitable for conducting continuous studies (Linh, Erasmi, and Kappas 2012).

Table 3. Values of Landscape Metrics obtained from standard analysis in RStudio.

Classes	Class Area (hectares)		Largest Patch Index (%)		Number of Patches	
	1994	2022	1994	2022	1994	2022
Forest	8154	7901	17.2	14.6	171	310
Non-Forest	4690	4941	35.9	36.7	227	476
Classes	**Patch Density (number per 100 hectares)**		**Percentage of Landscape (%)**		**Mean Patch Area (hectares)**	
	1994	**2022**	**1994**	**2022**	**1994**	**2022**
Forest	1.33	2.41	63.5	61.5	47.7	25.5
Non-Forest	1.77	3.71	36.5	38.5	20.7	10.4
Classes	**Edge Density (metres per hectare)**		**Patch Cohesion (%)**		**Effective Mesh Size (hectares)**	
	1994	**2022**	**1994**	**2022**	**1994**	**2022**
Forest	49.5	88.3	99.8	99.8	856	654
Non-Forest	49.5	88.3	100	100	1657	1727

Discussion

4.1 Factors driving landscape change

Most studies on landscape change have focused on the increasing influence of human activity, primarily through urbanisation, intensified agriculture, and forest fragmentation. Socioeconomic factors have been identified as key drivers of landscape change, as exemplified by the Valencia/Matura region in Trinidad and Tobago. The transformation of this landscape has been driven by the economic need for natural resources, which has been facilitated by advances in quarry and agricultural technology.

The negative impacts of forest fragmentation on ecosystems and the environment are well-documented. In Trinidad and Tobago, during the period of 1973-1982, the rapid growth of the construction sector, with a 9% annual increase, led to a surge in demand for building materials. This resulted in a significant increase in quarrying activity, where the total area of quarries increased from 40.04 hectares in 1969 to 203.36 hectares in 1994. The aftermath of this expansion was two-fold: the production of low quality materials at exorbitant prices, and the prevalence of illegal quarrying practices, which not only encroached on state-owned lands but also threatened the fauna and flora of the Aripo Savannas Scientific Reserve. Furthermore, it almost decimated a naturally occurring forest in Manzanilla, which served as a windbreaker against the North-East Trade Winds. The careless disposal of effluent, in enormous quantities, into the environment from quarrying sites resulted in the pollution of the Caroni River on a massive scale (Al-Tahir and Oatham 2005).

Despite these negative impacts, the quarry industry in the study area still persists, as it remains an important source of construction materials and revenue for the country. However, quarrying activities have been severely reduced, causing a decline in the country's economy. According to Al-Tahir and Oatham (2005), abandoned quarries and agriculture have led to increased natural vegetation in the Valencia Forest, as compared to 1969 when such activities were located on the forest edges or close to roads. After lands have been abandoned, natural re-vegetation occurs gradually from weeds to shrubs to native plants, although the rate of recovery may vary depending on the degree of degradation.

4.2 Analysis of Landscape Metrics

The Valencia/Matura region of Trinidad and Tobago experienced significant changes in land cover from 1994 to 2022. Class Area and Percentage of Landscape are critical metrics for understanding the spatial distribution and extent of land cover classes within a landscape. The Class Area metric indicates the total area covered by each land cover type while the percentage of landscape represents the proportion of the total landscape covered by a particular land cover class and these changes can provide valuable insights into land use dynamics and their ecological implications. Forested area decreased from 8154 hectares in 1994 to 7901 hectares in 2022. Representing a reduction in the forested area by 253 hectares or approximately 3.1% over the study period. In contrast, the Class Area metric increased in the non-forested area from 4690 hectares in 1994 to 4941 hectares in 2022, representing an increase in the non-forested area by 251 hectares or approximately 5.3%. Consequently, the percentage of landscape of forested area decreased from 63.5% in 1994 to 61.5% in 2022, with a corresponding increase in non-forest percentage of landscape from 36.5% to 38.5%.

These changes in Class Area and Percentage of Landscape are noteworthy because they reflect alterations in land use patterns, which can have significant ecological and socio-economic impacts. The decrease in forest percentage of landscape and an increase in non-forest percentage of landscape can indicate the conversion of forested areas into non-forest land uses, such as agriculture, urbanisation or quarrying activities. Such land use changes can result in habitat loss for biodiversity, degradation of ecosystem services, and reduction in carbon sequestration capacity. Moreover, in the forested area, the number of patches increased from 171 to 310. This increase in patch number suggests that the larger forested areas have broken up into smaller, isolated patches. Similarly, in the non-forested area, the number of patches increased from 227 to 476, indicating a similar trend of fragmentation. The decrease in the forested area and the increase in the non-forested area as well as the increase in the number of patches suggests that there has been an expansion of anthropogenic land use activities.

Herzog and Lausch (2001) found that the Number of Patches within a landscape is inversely proportional to the Mean Patch Area. The inverse relationship between the number of patches and the mean patch area is due to the underlying principles of landscape ecology. In fragmented landscapes, the creation of smaller patches inevitably leads to an increase in the number of patches, while also reducing the mean patch area. As the number of patches increases, the spatial arrangement of patches also becomes increasingly complex, with greater edge-to-area ratios and greater distances between patches, further exacerbating edge effects and reducing habitat connectivity. This is validated within this study, as the Number of Patches within the study area increased and while the Mean Patch Area decreased. The mean patch area measures the average size of patches within a given land cover class and can be used to infer the level of interspersion of different land cover classes and their spatial configuration. The reduction of this metric can indicate a decrease in the level of interspersion and an increase in fragmentation. Table 3 shows that the mean patch area for the forest class decreased from 47.7 hectares in 1994 to 25.5 hectares in 2022, while for the non-forest class, it decreased from 20.7 hectares to 10.4 hectares during the same time period.

The largest patch index represents the proportion of the landscape that is occupied by the largest patch of a particular land cover type. A high value of the largest patch index indicates that the majority of the landscape is dominated by a contiguous patch of a particular land cover type, whereas a low value indicates that the landscape is more fragmented, with smaller and dispersed patches of the same land cover type. In the forested area, the largest patch index decreased from 17.2% in 1994 to 14.6% in 2022. The reduction in the largest patch index in the forested area indicates that forested areas are becoming more fragmented and disconnected, which is consistent with the observed increase in the number of patches.

In contrast, the largest patch index in the non-forested area increased from 35.9% in 1994 to 36.7% in 2022. Despite the increase in the number of patches, this suggests that the non-forested areas are becoming more connected and less fragmented, likely due to land use changes that result in larger patches, such as the expansion of road networks. These findings are consistent with previous research (Narmada et al. 2021) showing that land use activities such as urbanisation and agriculture can lead to increased fragmentation and loss of biodiversity in forested areas, while non-forested areas may become more connected due to land use changes that result in larger patches.

Patch density is a commonly used metric to measure landscape fragmentation and refers to the number of patches per unit area. The increased patch density observed in both forested and non-forested areas in the Valencia/Matura region indicates a significant trend of fragmentation, characterised by the breaking up of larger areas into smaller, isolated patches. The observed increase in patch density from 1.33 patches per hectare in 1994 to 2.41 patches per hectare in 2022 for the forest class and from 1.77 patches per hectare in 1994 to 3.71 patches per hectare in 2022 for the non-forested area demonstrates that landscape fragmentation has intensified over time. These findings suggest that fragmentation is increasingly affecting the connectivity and ecological functioning of the landscape and could have negative consequences for the biodiversity and ecosystem services provided by the Valencia/Matura region.

Edge Density is a measure of the amount of edge habitat in a given area, and it is an important indicator of landscape heterogeneity. The results show that both forest and non-forest classes have experienced a significant increase in edge density over the study period. In 1994, the edge density for both forest and non-forest classes was 49.5. By 2022, the edge density for both classes had increased to 88.3. The increase in the number of patches is accompanied by an increase in the number of smaller, isolated patches, which leads to an increase in the amount of edge habitat between them, as indicated by the increase in edge density and is consistent with previous studies noting a positive correlation between the number of patches and edge density.

The Patch Cohesion metric is an indicator of the degree to which the landscape is composed of contiguous patches versus isolated patches. A higher value of this metric indicates a more cohesive landscape, where the patches are more connected. For both classes, no change was observed from 1994 to 2022, with both classes having a high Patch Cohesion value of 99.8 and 100. The results show that Patch Cohesion remained stable for both forest and non-forest classes over the study period, indicating a relatively cohesive landscape that did not experience significant fragmentation. However, the limitations of Patch Cohesion as a metric for fragmentation analysis are acknowledged, as it does not account for other factors such as patch size, shape, and distribution (Wang, Blanchet, and Koper 2014).

To address the limitations of using varied metrics for fragmentation analysis, effective mesh size has emerged as a useful tool to measure landscape connectivity and fragmentation in a more standardised way. The concept of effective mesh size was proposed by Jaeger (2000) as a landscape metric representative of the probability of any two points in the landscape being connected and not separated by barriers. The adaptability of this metric to various ecological contexts has made it highly valuable for quantifying landscape change (Jaeger 2000; Moser et al. 2006).

Effective Mesh Size (EMS) is a landscape metric that measures the degree of fragmentation and connectivity of patches in a landscape. In the study area, the EMS of forest patches in 1994 was 856 and decreased to 654 in 2022, indicating a reduction in landscape connectivity and an increase in fragmentation of forest patches. However, the EMS of non-forest patches increased from 1657 in 1994 to 1727 in 2022, suggesting an increase in connectivity of these patches. This increase in the EMS of non-forest patches could be due to land-use changes such as urbanisation or increase in transport networks which have led to the consolidation of non-forest patches and a reduction in their fragmentation. The decrease in the EMS of forest patches could be attributed to factors such as deforestation, forest degradation, or forest fragmentation due to human activities or natural processes.

4.3 Conservation and Management

In order to maintain biodiversity in fragmented landscapes, it is essential to implement effective measures. One such strategy is the inclusion of wildlife corridors, which play a critical role in managing landscape fragmentation. The establishment of wildlife corridors has been one of the most controversial topics in conservation biology (Simberloff et al. 1992). Corridors serve as pathways between isolated and fragmented patches, allowing for the movement of individuals, such as breeding, feeding, and birthing, as well as promoting immigration and emigration (Xu, Plieninger, and Primdahl 2019; Beier and Noss 1998). Properly designed corridors can also enhance the population viability in both isolated and fragmented landscapes (Beier and Noss 1998). However, Hannon and Schmiegelow (2002) have noted that edge-sensitive biota or poor dispersers may not be able to use most kinds of corridors whereas edge-tolerant taxa, and generalists may not need them to survive. While corridors can play an important role in managing landscape fragmentation and maintaining biodiversity, their effectiveness may depend on the specific characteristics of the species and ecosystems involved. Therefore, it is important to carefully consider the design and implementation of corridors, as well as to explore other management strategies that may be more appropriate for certain contexts.

Additionally, to minimise the negative effects of fragmentation on native ecosystems, creating buffer zones around ecologically sensitive areas can be an effective strategy for reducing the contrast between isolated habitats and surrounding areas (Hylander et al. 2004). Recommended buffer widths vary depending on the location, context, and species involved. To maintain bird species richness in logged Canadian boreal forests, Darveau et al. (1995) recommended buffers of at least 60 m, whereas in the United States, Spackman and Hughes (1995) recommended buffers of almost three times this width to maintain bird species richness along streams and Kilgo et al. (1998) recommended buffer widths of 100 m to maintain species richness and abundance of migratory neotropical songbirds in the United States. Evidently, the recommended buffer widths vary depending on the geographic location, context and species involved, but they can be crucial for maintaining species richness and abundance in fragmented landscapes. While buffers may not serve the same function as corridors in promoting movement between isolated patches, they can help to reduce edge effects and provide a more suitable habitat for certain species. Therefore, incorporating buffer zones into management plans alongside other strategies, such as the inclusion of wildlife corridors, can contribute to the maintenance of biodiversity in fragmented landscapes.

4.4 Limitations

Despite providing a general understanding of the effects of landscape fragmentation in Valencia/Matura, Trinidad and Tobago, the present study does not investigate the specific impacts of fragmentation on individual species. As different species exhibit unique responses to fragmentation contingent on an array of factors, a more detailed investigation of the effects of fragmentation on individual species is necessary to develop effective conservation and management strategies that can mitigate these impacts. Some of these factors include:

1) The mobility of a species: Highly mobile species such as birds exhibit greater adaptability to fragmented habitats compared to less mobile ones such as small mammals.

2) The size of the habitat patches: This has a decisive role in determining the impact of fragmentation on biodiversity. Smaller patches have lower levels of biodiversity due to decreased habitat availability, while larger patches support a more diverse range of species.
3) The extent of fragmentation: Moderate fragmentation may have fewer adverse effects as some species may persist in small fragments or move between patches. However, extensive fragmentation may lead to a loss of habitat connectivity, reducing species' mobility and potentially causing local extinctions (Ewers and Didham 2005).
4) Species-specific habitat requirements: Landscape fragmentation can disturb these specific habitat requirements, such as vegetation structure and food resources, leading to changes in species composition, abundance, and diversity. For example, some species may require open areas with sparse vegetation, while others may need dense vegetation cover for shelter or foraging.
5) The ecological roles of species: Some species play a critical role in maintaining ecosystem function. The loss of these species due to fragmentation can have cascading effects on the entire ecosystem, leading to declines in ecosystem services such as pollination, pest control, or nutrient cycling (Wilson et al. 2015).

The lack of specific information on individual species limits the practical implications of the present study and its usefulness for conservation efforts. Thus, future research should aim to investigate the specific impacts of fragmentation on individual species to gain a more comprehensive understanding of the ecosystem's response to fragmentation and develop effective conservation strategies.

Another limitation is the temporal coverage of the study. Increasing the temporal coverage of the study would enable researchers to capture a more comprehensive understanding of the landscape changes that have occurred in the study area. By including additional time periods, researchers can identify trends and patterns in the landscape changes, such as the rate and direction of land use changes and assess the effectiveness of policies and management strategies implemented over time. Moreover, longer temporal coverage would provide a more robust dataset for predictive modelling of future landscape changes. By analysing the trends and patterns in landscape changes over a longer period of time, researchers can develop more accurate and reliable models that can help predict the impacts of future land-use changes and inform policy and management decisions.

4.5 Implications

Despite the limitations, the findings of this study are expected to provide significant contributions to the scientific community's understanding of landscape evolution and fragmentation in Valencia/Matura, Trinidad and Tobago. By highlighting the drivers of fragmentation and their implications, the study can contribute to policy and decision-making aimed at mitigating fragmentation and promoting sustainable landscape management in the study area. This information can be useful for land-use planners, conservationists, and policymakers, as they seek to make informed decisions about managing Trinidad and Tobago's unique landscapes. Effective land use planning and management strategies that prioritise the conservation of forested areas and promote the restoration of degraded lands can help mitigate the negative impacts of land use changes on biodiversity and ecosystem services.

5.0 Conclusion

From the analysis, the Valencia/Matura region of Trinidad and Tobago experienced significant changes in land cover from 1994 to 2022, with both classes increasing in fragmentation. The factors driving these changes include human activities, primarily quarrying and urbanisation, driven by socioeconomic factors, such as economic need for natural resources. The negative impacts of forest fragmentation on ecosystems and the environment are well-documented, and these changes in land use patterns can result in habitat loss for biodiversity, degradation of ecosystem services, and reduction in carbon sequestration capacity. These findings suggest that there has been an expansion of anthropogenic land use activities, highlighting the need for sustainable land management practices that balance economic growth and ecological conservation. Landscape metrics provide valuable insights into land use dynamics and their ecological implications, and the understanding of these metrics is crucial for effective landscape planning and management.

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