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Research Application Summary

Assessment of spatio-temporal dynamics of land use/cover change in the Fresco Lagoon Landscape, Cote d'Ivoire

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Abstract

Climate-change and/or climate-variability is affecting the temporal and spatial distribution of ecosystems and human activities at the landscape scale. There are implications of land use/cover change on ecosystems as well as human activities at the landscape scale, because of the combined actions of climate variability and human activities remains scant. Understanding these variations might improve our understanding of how to address ecosystems and human communities' resilience to extreme climate events. The present study seeks to understand the historical dynamics in the landscape by reviewing the combined influence of nature and anthropogenic activities in the Fresco lagoon landscape (FLL). This present study employed fused layers of Normalized Difference Vegetation Index (NDVI), Tasseled cap indices (greenness, brightness and wetness) and Land Surface Water Index (LSWI) derived from Landsat 5 (thematic mapper) and 8 (Operational Land Imager (OLI) /Thermal Infrared Sensor (TIRS)) for 1990 and 2017 respectively to map and detect variations in land use/cover in the 27 years period. Annual rates of change of the land use/cover types in the landscape were computed. The baseline year 1990 was dominated by closed forest (43%), followed by food crops and tree crops of equal proportions (20% each). In 2017, tree crops and open forest coverage had expanded by 15% and 7% respectively while closed forest dwindled to 22% and food crops lands stabilized. Within this same period, mangrove forest areas in the landscape reduced. The FLL is faced with degradation and depletion of forests and mangroves to make way for tree crops expansion. Meanwhile human livelihoods have over the years continued to center around food crops, mangrove and forest products. There is the need to enforce forest and mangrove protection for sustainable resource landscape services delivery particular for the poor.

Key words: Climate change, Cote D'Ivoire, Fresco Lagoon, Land use, mangroves

Résumé

Le changement et la variabilité climatique affectent la distribution temporelle et spatiale des écosystèmes et des activités humaines à l'échelle du paysage. Il y a des implications du changement d'utilisation/couverture des terres sur les écosystèmes ainsi que les activités humaines à l'échelle du paysage, en raison des actions combinées de la variabilité du climat et des activités humaines. La compréhension de ces variations pourrait améliorer notre compréhension de la manière d'aborder la résilience des écosystèmes et des communautés humaines aux événements climatiques extrêmes. La présente étude cherche à comprendre la dynamique historique du paysage en examinant

l'influence combinée de la nature et des activités anthropiques dans le paysage de la lagune de Fresco (FLL). Cette étude a utilisé des couches fusionnées de l'Indice de Différence de Végétation Normalisé (NDVI), des indices de la couverture végétale (verdure, luminosité et humidité) et de l'Indice d'Eau de Surface (LSWI) dérivés de Landsat 5 (thematic mapper) et 8 (Operational Land Imager (OLI) /Thermal Infrared Sensor (TIRS)) pour 1990 et 2017, respectivement, afin de cartographier et de détecter les variations de l'utilisation et de la couverture des sols sur une période de 27 ans. Les taux annuels de changement des types d'utilisation et de couverture des sols dans le paysage ont été calculés. L'année de référence 1990 était dominée par la forêt fermée (43%), suivie par les cultures vivrières et les cultures arboricoles en proportions égales (20% chacune). En 2017, la couverture des cultures d'arbres et des forêts ouvertes s'est accrue de 15 % et 7 %, respectivement, tandis que les forêts fermées ont diminué à 22 % et que les cultures vivrières se sont stabilisées. Au cours de cette même période, les zones de forêt de mangrove dans le paysage ont diminué. Le FLL est confronté à la dégradation et à l'épuisement des forêts et des mangroves pour faire place à l'expansion des cultures arboricoles. Pendant ce temps, les moyens de subsistance de l'homme ont continué au fil des ans à se concentrer sur les cultures vivrières, les mangroves et les produits forestiers. Il est nécessaire de mettre en œuvre la protection des forêts et des mangroves pour assurer la prestation de services durables dans le paysage des ressources, en particulier pour les pauvres.

Mots clés : Changement climatique, Côte d'Ivoire, lagune de Fresco, utilisation des terres, mangroves

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Introduction

Landscape change in tropical forest-agriculture frontiers have received increased attention from both the scientific and policy communities in recent times (Geist and Lambin 2001; Meyfroidt *et al.,* 2010; van Vliet *et al*., 2012; Smith *et al.,* 2014). The renewed interest in landscape management is because of synergistic impacts of climatic and anthropogenic stressors that operate at this scale. For instance, increase in temperature, coupled with variability in the amount of precipitation have been identified to affect the provision of ecosystem services (Tang *et al.,* 2018). At the same time, the exploitation, use and commercialization of ecosystem resources by humans is also degrading the landscape as well as contributing greenhouse gases such as carbon dioxide, nitrous oxide, and methane into the atmosphere, hence to the climate change phenomenon. These parallel processes form synergies that could influence the composition of the environment and spatio-temporal changes at the landscape level.

Studies reinforcing interlinkages between ecosystems and climate change occurrences might help to diagnose the level of vulnerability of society and ecosystems, and to identify specific adaptation and mitigation measures in the landscape scale and beyond. Comprehensive understanding of the landscape changes is crucial for interlinkages between ecosystems and climate change; and this is normally based on accurate monitoring of trends in land cover change over an extended period. Different methodologies, including mathematical models and satellite sensors, are employed to investigate the connection between ecosystems and the climate change (Bonan, 2008). By mapping changes at the landscape scale, it will be possible to classify the different habitats that constitute the landscape at different spatial and temporal scales. Such classifications provide critical knowledge resource about the state of the landscape and the factors driving the change. Trends in landscape dynamics provides insights into exposure to vulnerabilities and resilience

capacities to extreme events at landscape level. A detailed understanding of the context changes and driving forces are needed for meaningful policy intervention (Lambin *et al.,* 2001; Geist and Lambin 2002). Satellite remote sensing provides a good information development tool for large area monitoring of the environment. It helps to understand how anthropogenic actions drive changes in the long term within landscapes (Castella *et al.,* 2013; Asubonteng *et al.,* 2018). Trends in landscape dynamics provides insights into exposure to vulnerabilities and resilience capacities to extreme events at landscape level.

Despite the data opportunities offered by remote sensing on the evolution of ecosystem changes at the landscape scale, exposed to multiple change drivers, this information continues to elude decision makers for guided developmental planning. Like other coastal landscapes, the Fresco lagoon landscape is changing rapidly, partly as a result of improved access, in-migration and expansive tree crop development fueled by favorable market and government policies (TetraTech, 2016). At the same time, it is possible that the effects of climate change effects are already manifesting in this landscape and exacerbating the vulnerabilities of communities and ecosystems (from field report). Understanding the changing trends in land use/cover and their underlying drivers is not only important for the landscape planning but also understanding for vulnerabilities, particularly in rural agrarian landscapes. However spatial information on the changes in the landscape to guide the departure from the business as usual developmental is not readily available from this region. This study seeks to assess trends in land use/ cover change and link them drivers to inform resilience planning in the Fresco landscape.

Materials and Methods

Study area. The study was conducted in the Fresco lagoon landscape (FLL), defined as the region between latitude 5°18'0''N - 5°3'0''N and longitude 5°50'0''W - 5°30'0''W. Fresco is in the region of Bas-Sassandra in Southwest Cote d'Ivoire in the forest zone (Figure 1). Bas-Sassandra's capital San-Pedro (San-Pédro) is approximately 124 km / 77 mile away from Fresco (as the crow flies). The distances from Fresco to Ivory Coast's economic and capitals Yamoussoukro and Abidjan are approximately 195 km and 171.5 km respectively (as the crow flies). This landscape has been classified as a RAMSAR site due to the richness of its flora and fauna, and presence of several endangered species, in particular the manatees. In recent times this predominantly rural-forest landscape has seen enhancement in road infrastructure connecting Fresco the region to mainland Cote d'Ivoire. The population of the whole region is estimated at 60,700 with an average density of 137 habitant/km2 (INS, 2014). The dominant ethnic group in the region is Godié with secondary groups Aka, Mandé and Gours and immigrant populations from Liberia, Ghana, Togo, Benin and Guinea. Christianity, Islam and Animism are all present.

In addition to the Landsat satellite images, field data collection was conducted between 22 – 23 February 2018. The purpose of the field data exercise was to sample real life representatives of the main land cover categories in the FLL which are of monitoring interest for the period 1990 - 2017. With handheld Global Positioning Systems (GPSs), polygons and point coordinates (731 points) were collected in cover types of interest and their description and where possible photographs were snapped in addition as attributes of the location. The edges of the cover types were consciously avoided to reduce edge effect of mislabeling of land cover categories in other to enhance reliability of the data.

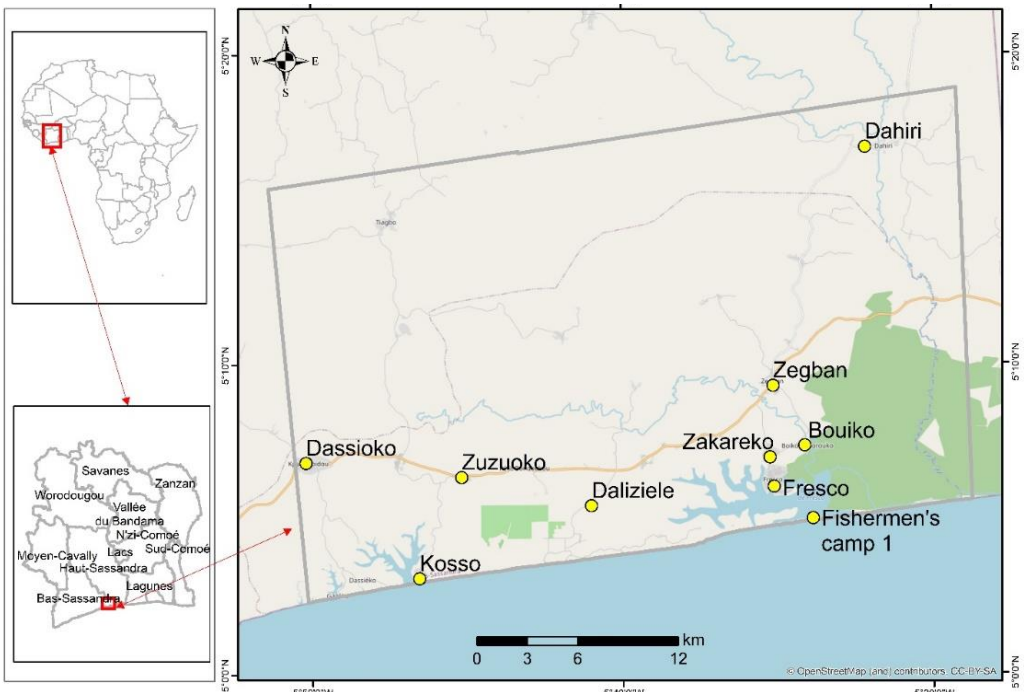

Figure 1. Fresco Lagoon Landscape shown by the tasselled cap image of Landsat 1990

Data and data sources

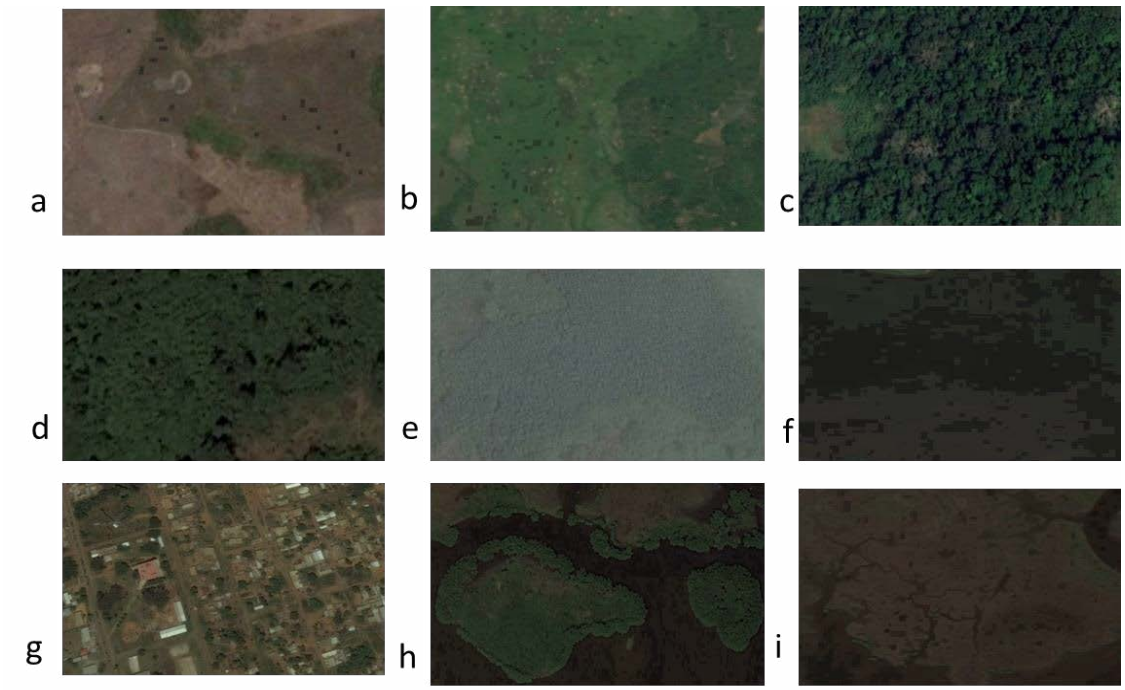

Figure 2. a) Cropland, b) opened forest c) closed forest d) cocoa, e) rubber, f) water g) built-up area, h) mangrove and i) wetlands

Secondary maps focusing on mangrove areas (not based on satellite) within the landscape for the years 1985 and1991 (unpublished maps by Egnankou) were also acquired to provide insights on the nature of the landscape in the 80s and 90s. In addition to the field data, recognizable land cover categories from Google Earth historical and current high-resolution data were also extracted to improve the image classification and for accuracy assessment processes. Identifiable scenes from Google Earth are shown in Figure 2.

Satellite image classification. Image classification constitute an important part of detecting changes in a landscape. It refers to an interlinked process of clustering image pixels based on similarities into predetermined meaningful land cover classes. The greater fresco landscape is a highly fragmented tropical landscape composed of heterogeneous land cover types. For example, agriculture land area is smallholder of varying sizes under different management regimes. The complexity of such landscapes makes the use of a traditional algorithm challenging in achieving a representative classification. A hybrid version unsupervised and supervised classification was employed in the classification (Wondrade *et al.,* 2014).

Classification and change detection. The images were segmented spectrally into 50 classes each using the K-means unsupervised classification algorithm in ENVI software. Unsupervised classification algorithm statistically groups pixel of an image into a specified number of spectral classes based pixel values rather than comparing it to a reference data (Lu and Weng, 2007). The larger number of spectral classes allowed for the separation classes, which are spectrally similar but are physically different. The final map classes were arrived at subsequently by manually merging similar classes. The merging of the 1990 map were informed by historical maps from Egnankou (1991), features which have not changed, and are present in the landscape in 2019. The 2019 final map classes were arrived at based on field observations and google earth extracted data. Change detection was executed to generate a transition matrix, which shows the transfers of land area across the different land cover types. The diagonal of the matrix are the lands that persisted and off-diagonal areas constitute the portion of the landscape that participated in change.

Results and Discussion

Our analysis delineates the FLL into closed forest, open forest, tree crop, croplands, water, mangrove forest, wetland and built-up/bare areas for the two time points under study. From the satellite image classification, the composition of the landscape summarily remained unchanged however, their proportional distribution changed immensely between 1990 and 2019.

The land use /cover classes observed on the 1990 image classification has the closed forest dominating 43% (41,944 ha) of the FLL (Figure 3). Closed forests are distributed around north-west and south-east with small patches scattered across the area. The closed forests in the coastal region were mostly found along the course of rivers and lagoons. This result has serious significance to restoration efforts, it also means that river banks and to certain extent lagoons are well preserved. Next in terms of coverage is croplands with 19477.62ha (20%)., mainly located at the central portion of the FLL. This cropland mixes with tree crops found the frontiers of the forest. These tree crops occupied almost same size (20%) as the croplands in 1990 (Figure 4). Tree crops were found to be common near roads, especially near Zuzuoko and Daliziele townships in the south of the FLL. The contiguous tree crop class near Daliziele are mostly coconut trees, an estate established by government to produce oil.

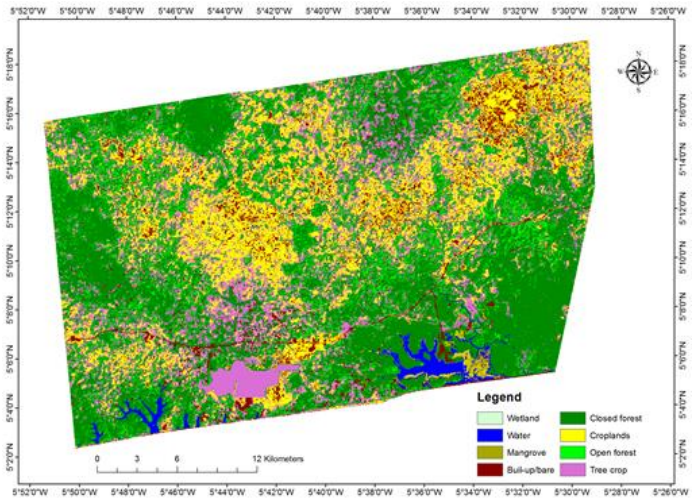

Figure 5. Land cover map of Fresco lagoon landscape in 2019

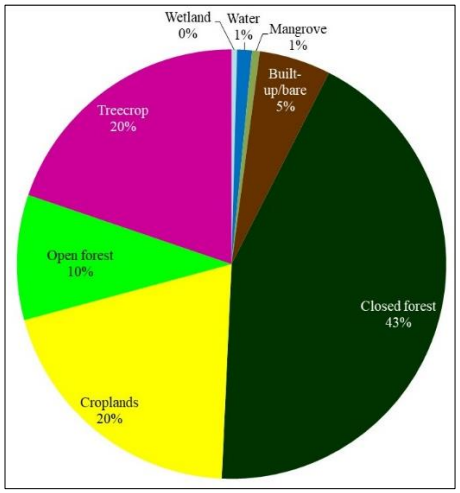

Figure 6. Percentage area distributions on the 2019 map

The closed forest as per 2017 is spatially fragmented with a majority located in the south-eastern corner of the FLL and some small patches interspersing cropland, tree crops and water networks. Similarly, croplands and open forest were also assessed to be scattered covering areas of 20,286 ha and 16,251 ha respectively in the landscape. Agriculture is the dominant economic activity followed by the administrative and fisheries sector (Sankare and Aka, 2016). It is believed that forestlands are fertile and promote the growth and production of cocoa. Today the population of the region are strongly reliant on the exploitation and use of natural resources because of the lack of other economic opportunities. Expansion of cocoa in this area is attributable to favourable market and government policies put in place by the government, who has been supporting cocoa production in this region.

Land cover change and distribution of change. Comparing the state of the landscape in 1990 and 2019 changes have occurred in both composition and spatial properties of the FLL. A comparism of changes to land use for 1990 and 2017 reveal that the closed forest, tree crop, open forest and built- up and bare areas witnessed considerable change dynamics in the landscape. Closed forest declined at an annual rate of 2.5% and accounted for 43% of the change in the landscape (Table 1). This impressive decline of closed forest might be attributed to the improvement in accessibility to the FLL coupled with the development and switching to tree crops farming, by farmers in pursuit for higher economic returns in lieu of food crops. This shift to tree crop has been facilitated by a ready market, coupled with enable policies that the Ivorian government has put in place. Regardless of the loss of about 20392.1ha, closed forests are the most prominent and the second least gainer among the four major land cover types contributing change in the landscape.

Behind the gross gains and losses closed forests have changed areas to the tune 61% of the landscape within which it losses in one place and gain in another location. An examination of land cover change from 1990-2017 reveals that about 13640.5 ha of closed forests transitioned to tree crops (Table 2), while croplands and open forests transitioned by 14,192 ha and 7483.5 ha respectively over a period of 27 years (Table 2).

Table 1. Changes in area (ha) and annual change rates of land-cover types

Land cover	1990 area (ha)	Percentage area	2017 area (ha)	Percentage area	Change (ha)	Annual rate of change (ha)
Wetland	399.96	0. 4%	373.86	0.4%	-26.1	-0.25
Water	1085.67	1.1%	1603.8	1.7%	518.13	1.45
Mangrove	563.04	0.6%	437.85	0.5%	-125.19	-0.93
Built-up/ bare	5232.6	5.4%	2211.48	2.3%	-3021.1	-3.19
Closed forest	41944.59	43.2%	21552.48	22.2%	-20392	-2.47
Croplands	19477.62	20.1%	20286	20.9%	808.38	0.15
Opened forest	9142.74	9.4%	16251.39	16.7%	7108.65	2.13
Tree crop	19194.66	19.8%	34324.02	35.4%	15129.4	2.15

The high conversion of closed forests to tree crops in this region might be linked to improved road network that is facilitating access by outside farmers who seek to exploit the conducive microclimate provided by the forest canopy and the perceived richness of forest soils for rubber and cacao production (WABiCC). However after a few seasons of boom yields, the bust period sets in with declining yields and new frontier deforestation (Clough *et al.,* 2009). This study therefore concurs with Gockowski *et al.,* (2004) that the drivers of forest cover change in the Ivorian landscapes are associated with high rural population growth, and coupled with strong natural resources dependency and utilization, particularly in rural areas due to poverty (Ehuitché, 2015).

Land cover/use changes and community vulnerability

Landscapes and its resources are intrinsically linked to livelihood and socio-economic wellbeing of communities (Castella *et al.* 2013; Pfund *et al.,* 2011). This nexus implies that land cover change directly influence the ecosystems services and land –based livelihood opportunities available to dwellers in such landscapes (Chhabra *et al.* 2006). The afore analysis revealed that closed forest, mangroves, and wetlands are declining at a varying rate, and tree crops are widespread throughout the FLL. Abe *et al.* (2000), corroborated that mangrove are noticeably decreasing in this region, although there is no data to support this observation because of lack of monitoring. Mangroves are excessively exploited for traditional uses such as poles for building, fuel wood, and for commercialization in the local market (Abe *et al.* (2000). From an ecological perspective, it many of the locals confirm that the remaining mangrove relicts provide habitat for fisheries, a main source of livelihood for coastal dwellers. Fish is a main so source of animal protein for most of the vulnerable households in the FLL (EMMA, 2011). Therefore, the nutritional diversity of most rural households will be affected because of the decline in fish

Table 2. Transition table for land cover change between 1990 and 2017 in the Fresco Lagoon Landscape (Area measured in hectares)

	1990							
2017	Wetland	Water	Mangrove	Built-up/ bare	Closed forest	Cropland	Open forest	Tree crop
Wetland	52.7	52.2	143.0	32.6	88.8	0.0	4.2	0.4
Water	269.5	885.6	242.0	10.2	189.1	0.3	3.9	3.3
Mangrove	35.4	42.0	78.4	23.7	238.1	2.2	13.7	4.4
Built-up/ bare	2.5	6.5	18.9	600.2	442.8	705.4	77.3	357.8
Closed forest	35.0	74.5	47.2	674.5	12328.6	2881.4	2298.6	3212.8
Cropland	1.1	6.3	18.5	1545.0	7518.3	5285.7	1716.3	4194.7
Open forest	2.9	11.7	8.3	671.6	7498.4	3060.1	1659.2	3339.3
Tree crop	1.0	6.8	6.8	1674.9	13640.5	7542.6	3369.5	8081.9

population, resulting from mangrove destruction. The fish sector in Cote d'Ivoire also provides huge employment opportunities through fishing and associated activities (EMMA, 2011). In recent times, the decreasing availability of fish in the local markets has resulted in ripple effects on price, and thus affects purchasing power of vulnerable households (EMMA, 2011).

Besides reducing current and future revenue streams to households, forests and mangroves destruction lowers coastal communities' resilience and expose them to adverse weather effects such as flood during high tides (Tetra Tech, 2017. The observed declining wetlands is alleged to be caused by coastal sand winning activities exposes the coastal regions to sea-water intrusion, soil erosion, and flooding. Such drastic changes in natural systems endangers communities' natural, socio-economic, and physical resiliencies (Antwi et al, 2015). Tree crops especially cocoa benefit from the microclimate and natural disease and pest control mechanism offered by the diverse forests and water systems of the FLL. Communities are also known to depend on forest for products which are of medicinal and nutritive value that contribute to household incomes. However, with current deforestation rates, as observed by this study, remnant forest tress left on farm to mimic forest canopy play this significant role (Gockowski, et al, 2004). However, as deforestation increases it leads to soil erosion, and soil nutrient loss; thereby reducing overall agricultural productivity and eventually the abandonment of land for new closed forest clearing.

Conclusion

The prime objective was to assess trends in land use/ cover change and link them to drivers to inform resilience

planning in the Fresco landscape. As elucidated by this study, the sizes of closed forest, mangrove forests, and wetland decreased in the 27 years. Declines in forest have negative implications for the long-term suitability of cocoa production, and provisioning of ecosystem services essential for the livelihoods of communities. Moreover, this decline comes with the loss of favorable environmental conditions for the spawning of fish because of the reduction of mangrove forest area. These infractions in the landscapes constraints resilience to social and environmental shocks, hence undermining current and prospective sustainable socio-economic development. To mitigate further degradation of the landscape beyond sustainable levels, farmers must engage in tree-crop agroforestry systems and the government should enforce forest protection. Similarly, the management of mangroves should be assigned to a specific institution, and the participation of the landscape dwellers is in the management of the FLL resources in their landscape should be prioritized.

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