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Journal of Ecology and The Natural Environment

January - March 2022
ISSN 2006-9847
DOI: 10.5897/JENE
www.academicjournals.org

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Vol. 14(1), pp. 1-14, January-March 2022
DOI: 10.5897/JENE2021.0921
Article Number: 2F8466968514
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and The Natural Environment

Full Length Research Paper

Detection and predictive modeling of land use changes by CA-Markov in the northern part of the Southern rivers: From Lower Casamance to Gêba river (Guinea Bissau)

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Received 01 December, 2021; Accepted 04 January, 2022

The northern part of the Southern rivers, which is the subject of this study, lies between 18° 54' and 14° 48' north latitude and 11° 30' and 12° 54' west longitude. It is characterized by a dense hydrographic network dominated by maritime marshes and expanses of salty lands and mangrove mudflats that have developed on a vast coastal plain. The objective of this study is to analyze spatio-temporal changes of the geomorphological units and to simulate their spatial behavior in 2035. The methodology is based on the processing of Landsat TM and Landsat OLI satellite images acquired in 1986 and 2018, respectively. Change detection is performed by post-classification comparison of the two previously validated land cover states with overall accuracies of 91% for the 1986 image and 97% for the 2018 image. The prediction made using the CA-Markov model yielded a result with 88% agreement. This made it possible to understand the spatio-temporal evolution of land use and changes in the near future (2035). The results of the land use prediction in 2035 show that bare land will have the highest gain with 93% probability while tans will decrease by 60% to other land use categories. Vegetation and mangroves will lose 47 and 44% of their areas respectively to bare soil and mudflats. A strong degradation of vegetation cover is predicted by the Markov chain by 2035. The probability of change in the area covered by water is the lowest during this period.

Key words: CA-Markov, landsat, land use change, predictive modeling, Southern rivers.

INTRODUCTION

Land, which is not elastic is definitely one of the most important natural resources, since life and developmental activities are based on it. Land use and land cover is an important component in understanding the interactions of the human activities with the environment and thus it is necessary to be able to simulate changes (Baboo et al., 2017; Padalia et al., 2018; Karki et al., 2021a,b). Land use refers to the type of utilization to which man has put the land. It also refers to evaluation of the land with respect to various natural characteristics. Land use and land cover data are essential for planners, decision makers and those concerned with land resource management (Pande et al., 2002; Bargali et al., 2019). The variations of the vegetation in an area constitute an important parameter affecting the slope failures, as slope stability is very sensitive to changes in vegetation (Rozos et al., 2011; Bargali et al., 2018; Manral et al., 2020). Poverty, population pressure, agricultural expansion and intensification and development of infrastructure have been are the major activities to change the land use pattern and land cover which adversely affect the nutrient status of soil and biodiversity (Bargali et al., 1993, 2015; Davidar et al., 2010; Vibhuti et al., 2018, Padalia et al., 2022).

Studies of land use land cover change are of an importance because they allow us to know the current trends in the processes of deforestation, degradation, desertification and loss of biodiversity in a given region (Lambin et al., 2001). The detection of land cover changes allows to estimate the nature of the natural and anthropogenic processes that is involved and to evaluate the risks and the issues of natural resources and territories management (Serradj, 2007). In sub-Saharan Africa, the majority of the population depends on natural resources to satisfy its basic needs. Thus, it is essential to preserve them in order to ensure resilience sustainable development. Land use and land cover changes can affect regional and global climates in terms of car emission or sequestration and can alter the global reflection properties of the Earth's surface (Feddema et al., 2005; Pan et al., 2011 in FAO, 2012). They are the result of anthropogenic phenomena and impact environmental quality, availability and use of natural resources (Serradj, 2007). The Intergovernmental Panel on Climate Change (IPCC) reports of 2007 and 2014 predict an increase of temperature between 2 and 6°C by 2035-2100, climate variability and rising sea levels. These climate changes impact coastal environments and control ecosystem dynamics. These effects make coastal areas dynamic entities with regard to coastal erosion that affect the world's coastal regions (Leclerc, 2010).

Thus it is essential to monitor the dynamics of current surface conditions to better understand its future evolution, for a sustainable management of the environment. Indeed, the rational management of natural resources become an imperative, especially with climate change which is causing profound changes and may be severe in the coming decades. However, resource management requires better knowledge, and if possible, accurate measurements, of the natural resources used, usable, degraded or disappearing on the surface of the globe (Kpedenou, 2016). It is therefore necessary to have sufficient information about the factors that govern its dynamics evolution, whether natural or anthropogenic. In this sense spatial remote sensing, which offers a global and diachronic vision of the environment, has become today, an essential tool in environmental management.

Predictive or prospective modeling provides information on the future of spatial behavior of land use units. It is not intended to predict reality but can help us to better understand complex environmental and/or social spatio-temporal changes. Land use modeling means a simulation of what reality might be, a reasoned and quantifiable scenario in the context of decision support (Paegelow et al., 2004). However, the literature has shown that the models for predicting land use and land cover changes are numerous and varied. Among others we can mention the Markov chain (CA-Markov), Cellular Automata that model spatial interrelationships between different land use typology (Debolini, 2014), Land Change Modeller (LCM) that allows to study land cover changes and to predict their future evolution that is one of the models frequently used to predict surface states. The objective of this study is not to test all of these models but to model future land cover changes in a context of climate change in the Southern rivers region using Markov chain. The choice of CA-Markov is based on its flexibility to develop customized models whose changes are based on the proximity effect (areas near the sites of a land use category are more likely to change towards it).

Study area

The study area (Figure 1) is located in the northern part of the Southern rivers, particularly from the lower Casamance to the Gêba river. The name "Southern rivers" refers to the south trading posts of Gorée which depended on its administration in colonial times. The northern part of the Southern rivers, which is the subject of this study, lies between 18° 54' and 14° 48' north latitude and 11° 30' and 12° 54' west longitude. It is characterized by a dense hydrographic network dominated by maritime marshes and expanses of salty lands and mangrove mudflats that have developed on a vast coastal plain. This coastal fringe is characterized, from a geological point of view, by the Senegalese-Mauritanian sedimentary basin of Meso-Cenozoic age that extends from Cap Blanc in Mauritania to Cap Roxo in Guinea Bissau and the Bowé basin that occupies the

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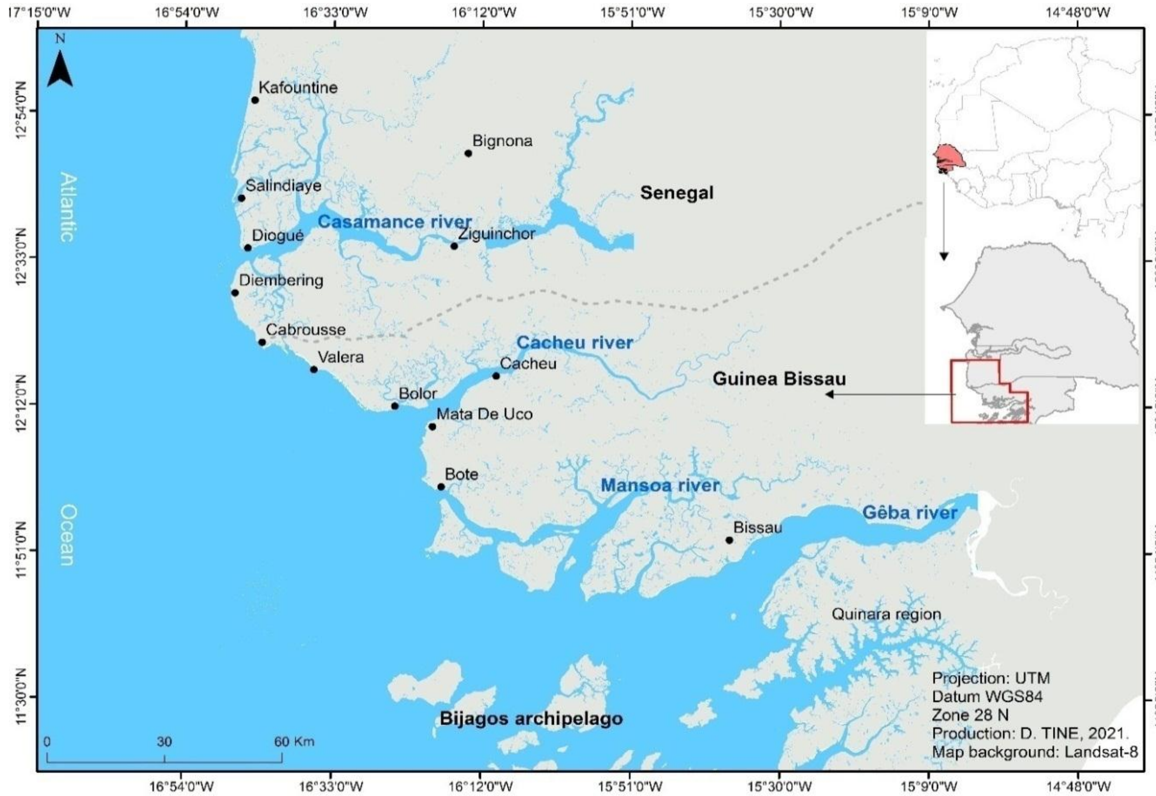

Figure 1. Geographical location of the studied area.

south and southeast of the Gêba river. It is a transitional area between the maritime and continental domains with a relatively low topography along the coastal zone. This relief is dominated by a littoral plain constituted in its natural state by mangrove mudflats, composed essentially of *Rhizophora mangle* and *Avicennia africana* in particular (Diop, 1990). At the limits of the mangrove mudflats, there are expanses of tans that are flooded in places during the rainy season due to the flatness of the relief. The area studied is marked by the density of the hydrographic network composed of rivers constantly invaded by the tides. From a climatic point of view, the area belongs to the Libero-Guinean domain (Leroux, 1983) which is a sub-division of the tropical climate. The region is characterized by two seasons due to the alternating circulation of the trade winds and the monsoon. A dry season from November to April and a rainy season from May to October. Rainfall is relatively abundant (over 1000 mm per year). This abundance is mainly related to the high potential advected rainfall and the relief that conditions the summer translation of the intertropical convergence zone (Pennober, 2009).

MATERIALS AND METHODS

The Landsat images selected for this study were chosen on the basis of their availability, their free and open access, and their age, covering a period from 1972 to the present. The dry season images (February and April) are selected to better discriminate the vegetation cover from the grass cover whose reflectance are confused when the images are acquired in the rainy season or just at the end of it. A series of corrections is applied to these images in order to increase the quality of the information and minimize the uncertainty in the data, which is often linked to atmospheric disturbances.

The satellite images (Table 1) were obtained from the Google Earth Engine (GEE) platform and Climat Engine. The GEE platform allows the analysis and visualization of satellite images of our planet. This cloud platform groups an archive of more than 40 years of satellite imagery, as well as tools with the computational power to analyze and exploit this huge geospatial data warehouse or big data. It also stores a set of geospatial data such as land use, vegetation cover etc. Change detection is done by post-classification comparison which involves using two previous land cover states to produce change information. The results describe the transition from one morphological unit to another depending on the characteristics of the environment.

CA-Markov Model

The Markov chain model is used to simulate temporal changes in land use. The spatial dimension is taken into account by cellular automata models that simulate spatial distributions. The principle of the cellular automaton consists in taking into account the state of the neighboring cells in the definition of the future state of the considered cell (Ladet et al., 2004). The CA-Markov model then simulates the spatio-temporal changes of the landscape based on the principle that the future state of a cell depends on the state of its

Table 1. Characteristics of the Landsat image that used.

Sensors	Bands	Wavelengths (µm)	Resolution	Date of acquisition
TM	1-Blue	0.45-0.52	30 m	April-May 1986
	2-Green	0.52-0.6		
	3-Reed	0.63-0.69		
	4- NIR	0.76-0.9		
	5-SWIR 1	1.55-1.75		
	7- SWIR 2	2.08-2.35		
Sensors	**Bands**	**Wavelengths**	**Resolution**	**Date of acquisition**
OLI	2- Bleu	0.45-0.52	30 m	April-May 2018
	3- Vert	0.53-0.60		
	4- Rouge	0.63-0.68		
	5- PIR	0.85-0.89		
	6- SWIR 1	1.56-1.66		
	7- SWIR 2	2.10-2.30		

neighbors and at the same time on its previous state. A Markov chain corresponds to "a process whose transition probabilities are conditional on the past" (Berchtold, 1998).

Validation of the model

The statistical approach was chosen, at the expense of the visual comparison of land cover states. The Kappa index was chosen for this purpose to compare predicted data with observed data (references) using the CROSSTAB module of IDRISI software. For all Kappa statistics, 0% indicates that the level of agreement is equal to the agreement due to chance and 100% indicates perfect agreement. If the Kappa index is less than or equal to 0.4 (40%), then the land cover has changed significantly and with poor consistency between the two images. If the Kappa index is between 0.4 (40%) and 0.75 (75%), then there are general consistencies and obvious changes between the two images otherwise there is high consistency between two images (Yousheng, 2011). The composite rule was chosen because of its many attractive features such as the identity matrix with a 5×5 adjacency filter.

Treatment procedure with IDRISI software

Several predicting models of spatio-temporal behavior of land use units are implemented in the IDRISI software. However, their use is not easy because of the complexity of IDRISI software. The procedure of change detection and prediction is described in Figure 2, which consists of producing two land cover maps (1986 and 2018) and detecting changes. Then, use the 2018 land use as a benchmark for the Markov chain simulation and validate it before predicting the 2035 land use. The results of this processing are composed of a transition matrix, a transition probability matrix, a change image, an inter-class change images and a change trend images.

RESULTS

Reflectance analysis of coastal morphological units

The reflectance of geomorphic units depends on their intrinsic characteristics as well as their surface condition. Moisture, roughness and other time-varying elements influence the reflectance of land cover features. In the coastal environment, difficulties often noted in the evaluation of geomorphological units are related to confusions due to reflected mixing signal, spatial and radiometric resolution.

Estimating and mapping salted lands is a real problem related to their typology, degree of salinity and reflectance. Salted lands reflect differently depending on the season and surface conditions. In the dry season, under the effect of strong evaporation, salt tends to be concentrated in the soil surface layers. Depending on their salinity degree, some saline soils are generally covered with herbaceous or shrubby vegetation, so their signal is mixed with that of the vegetation and this causes confusion with sparsely wooded land on images acquired in the dry season. Only bare saline soils, commonly referred to as light Salty lands, are identifiable in the visible and near-infrared spectral bands. The mapping of light Salty lands by remote sensing does not pose any difficulties. In contrast, sodic horizon soils, little salted soils or in the process of salinization without specific surface manifestations, are poorly identified and their surface areas underestimated (Mougenot et al., 1990). Figure 3 shows that the water contained in the salts, reflects the short wavelengths of blue and is at the origin of the absorption peaks observed at the level of the green wavelengths and the near infrared.

The appearance of spectral signatures in the visible range justifies the confusion noted in the classifications. These curves have the same appearance in the visible and separate from the near infrared, hence the choice of these one in the false color compositions. The water content of mudflats sometimes gives them a spectral signature identical to that of water. The differentiation of these land use units is in the shortwave infrared (SWIR 1) where Salty lands and lightly wooded land reflect strongly.

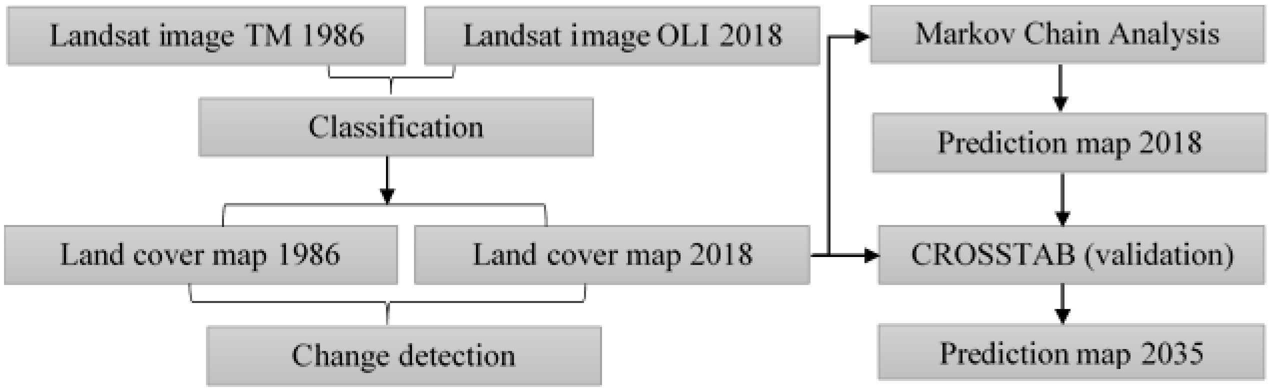

Figure 2. Methodological flowchart of satellite image processing.

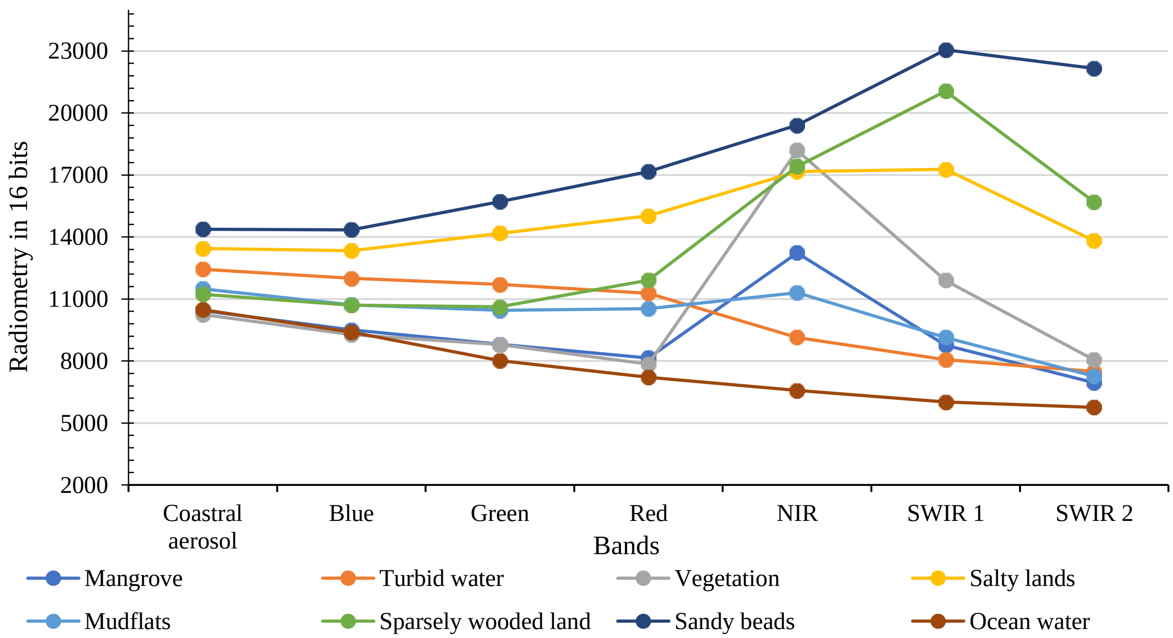

Figure 3. Reflectance of land cover units in the visible and near-infrared bands.

Oceanic waters and turbid waters (those of the bolongs) are separated in order to observe the variation of reflectance in the visible and near infrared spectrum (Figure 3). The variation of the reflectance of the two entities is due to the content of suspended solids (SS) in the continental waters. Mudflats and mangroves have a strong signal in the blue channel due to the water content. Vegetation always shows a peak in the near infrared, which is also the appropriate channel for estimating vegetation cover. The mixing of signals between sandy strips and salty lands may be related to their white color which is difficult to discriminate by photo-interpretation. This color is found in some places in lightly wooded land, hence the confusion noted with Salty lands. In the near-infrared, the reflectance of lightly wooded land, salty lands and vegetation is somewhat similar, which can impact the accuracy of classifications and lead to an underestimation of these units. The use of short-wave infrared allows, in this case, to better discriminate the land use units except for mudflats which are mixed but with a small shift in the near infrared.

Land use dynamics

The change detection operations are based on a prior mapping of the land cover (Figure 4). The accuracy of the two land cover states is evaluated by a confusion matrix from which the performance of the classifications is evaluated and results in a Kappa coefficient of 91% for

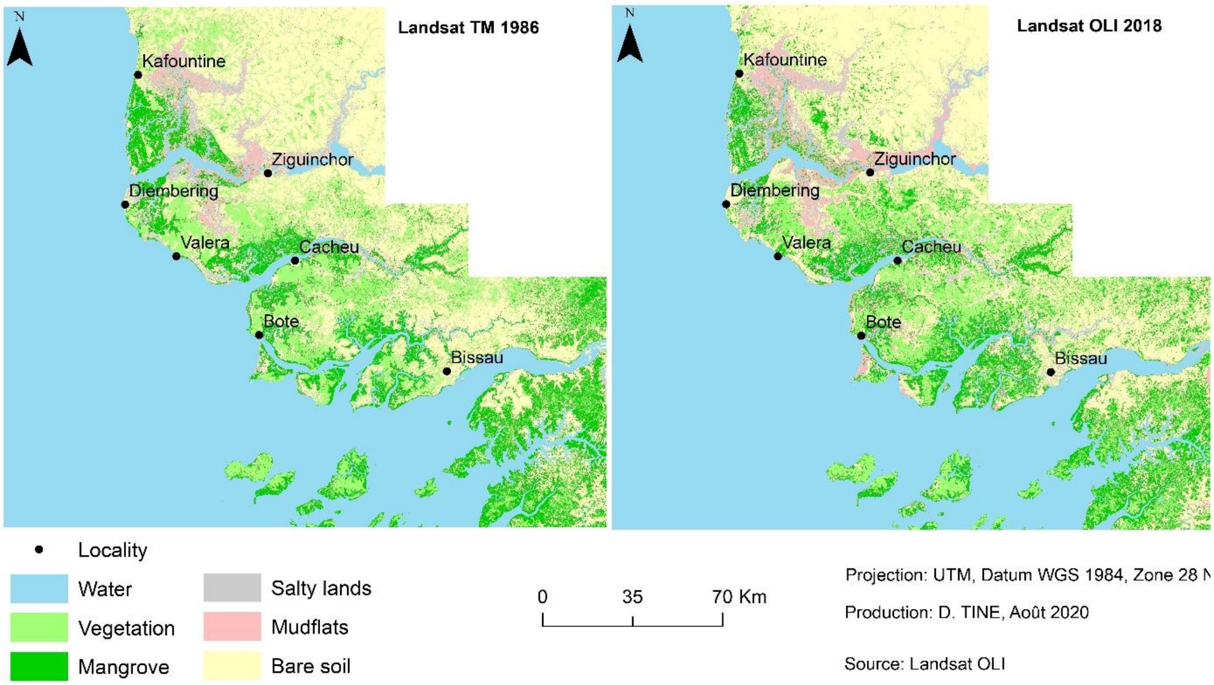

Figure 4. Land use in 1986 and 2018 in the study area.

Figure 5. Rice growing area affected by rising salt water in Enxale, Guinea Bissau.

the 1986 image and 97% for 2018. Bare soil and sparsely forested areas were grouped into a single class (bare soil) since they are difficult to separate. Oceanic, estuarine and rivers are also grouped in one class (water) because of the complexity of their identification. The spatial and radiometric resolution of the images used does not provide sufficient information on the nature of the water.

Land use status

Land use has undergone a slight evolution compared to the 1970s, which justifies the fact that we are so far in the periods of drought that West Africa has experienced. The mangrove and the salty lands, whose extension is dependent on the rainfall conditions, have experienced a slight change from respectively 6.93 and 2.89% in 1986 to 7.06 and 4.37% in 2018.These changes correspond to an extension of 20107.26 ha for the mangrove or 0.13% and 59409.63 ha for the salt land or 1.48% compared to their areas in 1986. The vegetation has increased by 5.28% of the total area which represents a total of211982.22 ha. The increase in mangrove area can be linked to the rainfall conditions that characterize this part of the Southern rivers. The annual rainfall totals exceed on average 1200 mm of precipitation. This positive evolution of the mangrove and the vegetation cover can also be due to the numerous reforestation campaigns that the region has experienced, especially in Lower Casamance.

Salted area was more developed in Lower Casamance but is beginning to occupy large areas in the Guinean region (Figure 5). This is explained by climatic variability

Table 2. Land use statistics between 1986 and 2018.

Classes	1986		2018	
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
Water	2097997.11	52.25	2044990.98	50.93
Vegetation	266606.91	6.64	478589.13	11.92
Mangrove	263563.38	6.56	283670.64	7.06
Salty lands	116171.73	2.89	175581.36	4.37
Mudflats	202976.91	5.05	192737.88	4.80
Bare soil	1061448.03	26.43	807552.27	20.11

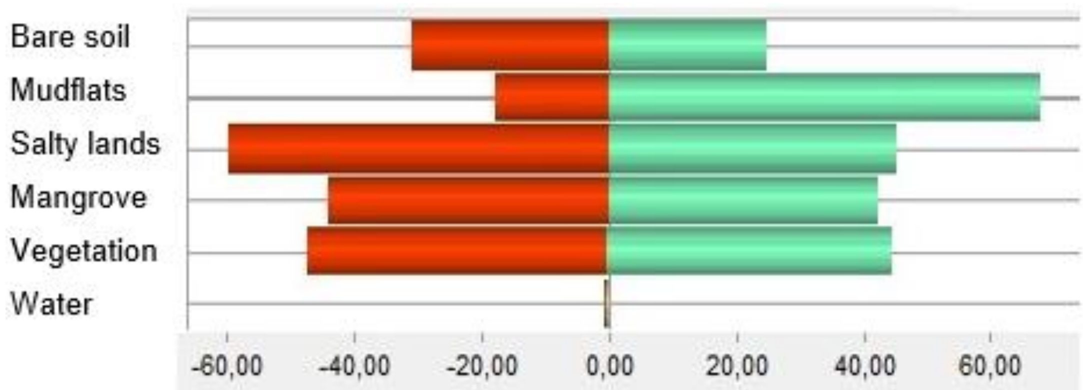

Figure 6. Gains and losses of land use units between 1986 and 2018.

along a south-north gradient that results in a decrease in precipitation and an increase in temperatures that can reach 38°C in the dry season. This situation induces strong evaporation that contributes to the increase in salt content in marine and estuarine waters and to the effervescence of salt at the surface level of the soil. In Lower Casamance, many rice fields have been lost in recent decades due to the expansion of saline lands. They represent 4.4% of the total area or 175581.36 ha in 2018 (Table 2). These areas are lost because so far, no sufficiently effective method has been developed to restore the salt lands. To these extents are added 192737.88 ha of mudflats in 2018, or 4.8% of the studied area. These are constantly flooded salt lands that in some places harbor mangrove formations.

Detection of land use changes

Analysis of the morphological units changes between these two dates shows that the landscape of the area studied has undergone changes often linked to the variation in climatic conditions and the influences of marine hydrodynamic actions. The tides and the regular submergence of the low-lying areas such as salty lands, mudflats and mangrove areas influence the hydrological regime. The rise of the saltwater wedge, the low freshwater input, the increase in temperature and evaporation, and the capillary rise of the saltwater constitute a dynamic system that generates changes (progression or regression) in land use units. The post classification comparison provides in terms of gains and losses (Figure 6), the evolution of land cover between 1986 and 2018. The analysis of Figure 6 shows that only the water class remained almost stable during the whole period studied (from 1986 to 2018). Mangrove and vegetation appear stable as well if losses are subtracted from gains. An expansion of mudflats is observed while salt land has experienced a regression although it is spatially developed in some places in the region.

Spatialization of changes (Figure 7) revealed a north-south gradient of vegetation cover and mangroves. These two land use units remain sparse in the lower Casamance, leaving place to bare soil and mudflats. In the Guinean region, which seems to be a very dynamic environment, vegetation has strongly gained space. This situation can be explained by the good rainfall conditions noted in this region. However, some pockets of bare soil appear, particularly north of the Gêba river. The extension of mudflats is noted in estuarine environments and their immediate edges and can be linked to marine dynamics.

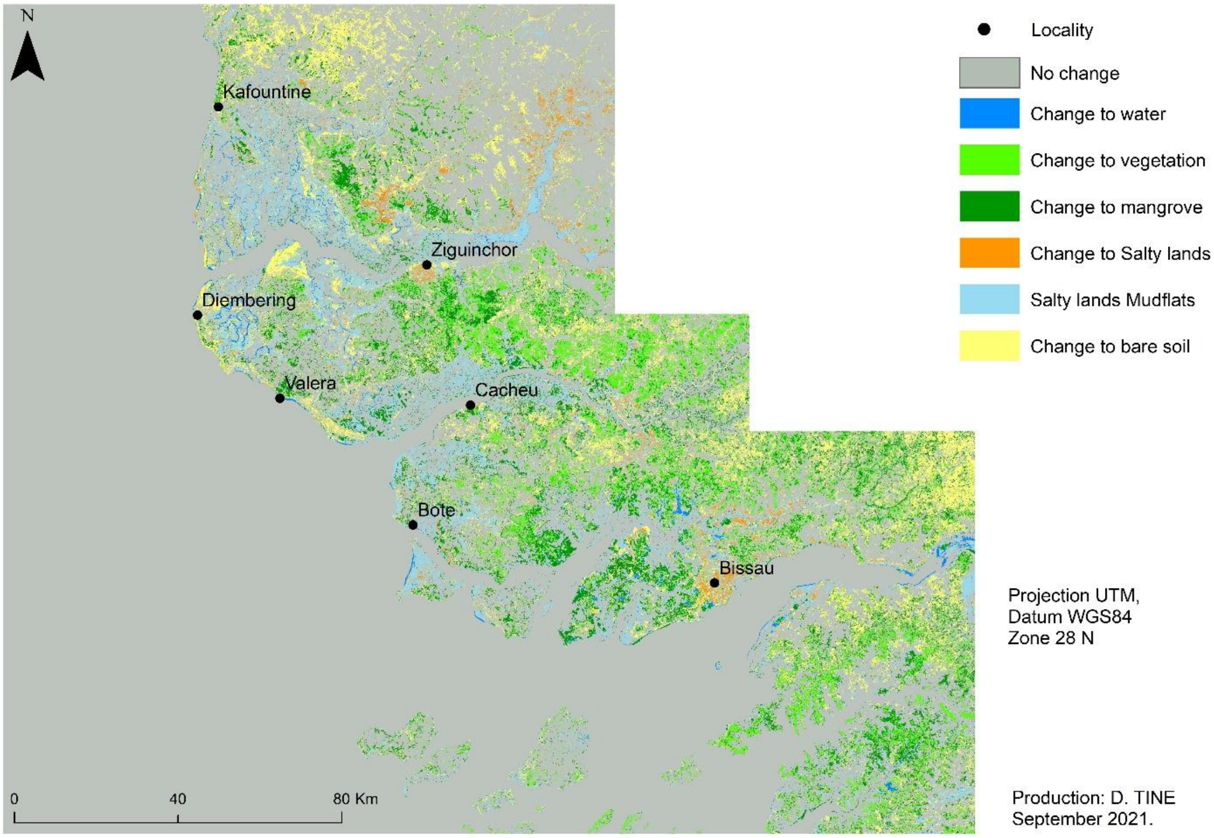

Figure 7. Spatial analysis of land use changes between 1986 and 2018.

Table 3. Transition probability matrix in % obtained from observed and simulated land use in 2018.

Observation 2018	Simulation 2018					
	Water	**Vegetation**	**Mangrove**	**Salty lands**	**Mudflats**	**Bare soil**
Water	**0.9901**	0.0000	0.0028	0.0003	0.0058	0.0010
Vegetation	0.0003	**0.5259**	0.1829	0.0020	0.0013	0.2877
Mangrove	0.0041	0.1098	**0.5604**	0.0011	0.1430	0.1817
Salty lands	0.0144	0.0023	0.0210	**0.4043**	0.1532	0.4048
Mudflats	0.0415	0.0002	0.0606	0.0231	**0.8215**	0.0532
Bare soil	0.0115	0.1184	0.0917	0.0251	0.0631	**0.6901**

Predictive land use modeling

Predictive land use in 2018

The transition matrix from the CA-Markov model shows in percentage the dynamics of each land use unit between 1986 and 2018. Table 3 shows a remarkable stability of the spaces covered by water followed by mudflats and bare soil. However, more pronounced transition probabilities are observed for salted land, mangrove and vegetation. The transition matrix shows that there is a higher probability (45%) that salty lands become bare soil or that they become mudflats (14%). This means that salty lands still remain as saline soils but their reflectance may change depending on their surface condition to the point of being confused with bare soil. The transition from mangrove to vegetation occurs with a probability of 13%, which may be related to signal confusions, but also to mudflats (13%) and bare soil (30%). For vegetation, the probability of changing to other categories is 49%. It is 17% to change to mangrove and 32% to bare soil. This shows a considerable loss of forest and mangrove vegetation. It is followed by a change in salted land which may be the cause of the degradation of the vegetation

Table 4. Transition matrix of areas (in ha) calculated from observed and simulated land use in 2018.

Observation 2018	Simulation 2018					
	Water	Vegetation	Mangrove	Salty lands	Mudflats	Bare soil
Water	**16801440**	649	48258	5108	97581	17044
Vegetation	1030	**2062803**	717575	7706	4929	1128514
Mangrove	17884	479092	**2444861**	4609	623748	792861
Salty lands	9740	1577	14196	**273495**	103615	273820
Mudflats	95283	358	139307	53016	**1887943**	122300
Bare soil	112771	1158782	897515	245719	617498	**6750934**

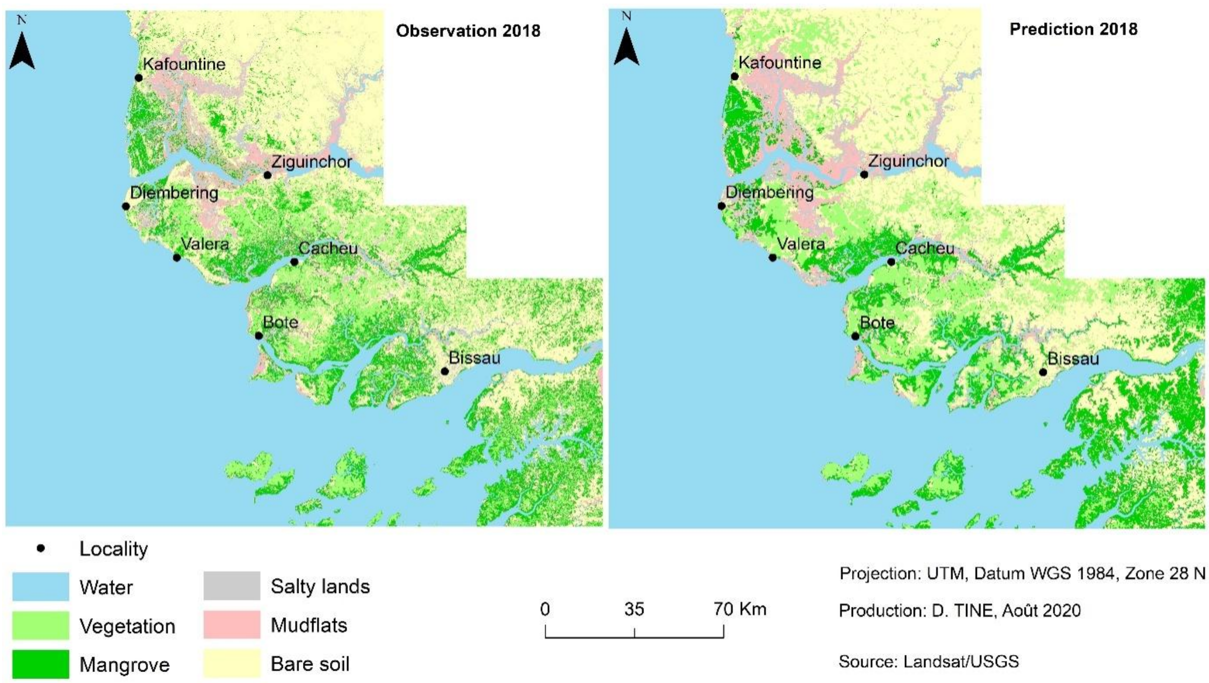

Figure 8. Spatial comparison between observed and predicted changes in 2018.

cover. All these probable changes can be linked to climate variability and its effects on coastal environments in particular.

Area transition matrix analysis (in ha)

The area transition matrix (Table 4) shows, in terms of hectares, which land use categories have changed to which ones. The matrix shows a strong transformation of land use units between 1986 and 2018. 53016 ha of Mudflats have migrated to salty lands while the amount of salted land converted to mudflats is estimated at 103615 ha. The change between these two land use units is dependent on climatic conditions and tidal intensity. A significant regression of forest vegetation is observed between these two dates. These losses amount to 1.2% of its actual area and converted to salted land, 358 ha that became mudflats and 1158782 ha that leaves place to bare soil. There are 479092 ha of mangroves that became vegetation. However, these changes noted between the two classes may be due to the temporal variation of chlorophyll which strongly influences the reflected signal.

Comparison between observed and predicted changes in 2018 and model validation

The simulated and observed 2018 land use maps are presented in Figure 8. A visual interpretation shows a great similarity between land cover categories except for mangrove which appears denser in the prediction. A progression of mangrove is noted in the estuaries, along

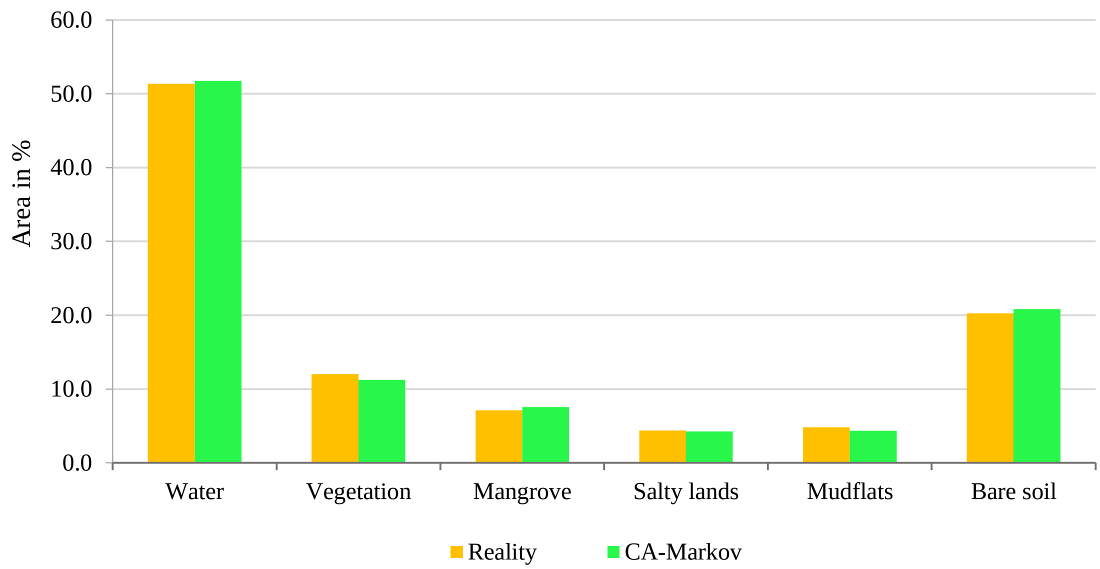

Figure 9. Comparison between measured data (%) and the simulated model in 2018.

the bolongs and south of the Gêba river while bare soil is much more developed in the north of the Casamance River. The spatial distribution of morphological units is correctly simulated.

Comparison of the statistics of predicted and observed changes (Figure 9) shows a slight difference between some categories. The observed and simulated changes show almost the same areas in the water category while vegetation, mangrove, salty lands, mudflats and bare soil show slight difference. The simulated mangrove shows an increase while the vegetation, mudflats and tans show a slight regression compared to the observed model. A small difference is also observed in the bare soil category. This difference in water occupied area represents a gain of 0.4% of occupied space.

Markov chain validation

The Kappa index from the cross between the predicted land cover condition and the observed one in 2018 is 0.88, which is greater than 0.75 and therefore the results are reliable. There is a high consistency between the observed reality and the predicted results. This agreement shows that the land cover changes in 2035 can, for this scenario, be simulated.

Residual analysis

The residuals represent the part of mismatches between simulated and observed land use categories. The bold diagonal (Table 5) represents the match between reality and simulation. The rest of the matrix is the residuals. Water and Salty lands show complete agreement with reality. 61% of observed water areas agree with the simulation while Salty lands were observed and simulated at 1%. Of the 7% vegetation and 8% mangrove simulated, 5% agree with observations. Bare soil represents 14% of consistent in the 17% observed while mudflats are 4% consistent in the 6% observed.

Status of land use in 2035

The land cover prediction for 2035 was performed using the CA-Markov model on the basis of ten iterations, which is sufficient for this study. The probability of land cover change between 2018 and 2035 was analyzed using the Markov transition estimator. Table 6 shows the probability of change matrix of land use classes in 2035. Bare soil will get the highest gain with 93% probability while Salty lands will decrease by 60% to the benefit of other classes like bare soil and mudflats. Vegetation and mangrove will lose 47 and 44% of their areas respectively to bare soil and mudflats. A strong degradation of vegetation cover is predicted by the Markov chain by 2035. The probability of change in the area covered by water is the lowest during this period.

The areas of the different land use categories are also estimated by the Markov transition estimator. The changes between 2018 and 2035 are shown in Table 7 and Figure 10. Although the vegetation statistically loses a large part of its area (3.37%), it is very dense in the estuaries of Cacheu, Mansoa river and in the Quinara region in the south of Gêba river. The mangrove will experience an increase of 2.46% compared to the year 2018. This increase will be observed along the bolongs

Table 5. Comparison of observed and simulated land use (2018).

Observation 2018	Simulation 2018						
	Water	Vegetation	Mangrove	Salty lands	Mudflats	Bare soil	Total Simulated
Water	**0.60**	0.00	0.00	0.00	0.00	0.00	0.61
Vegetation	0.00	**0.05**	0.01	0.00	0.00	0.02	0.07
Mangrove	0.00	0.01	**0.05**	0.00	0.01	0.01	0.08
Salty lands	0.00	0.00	0.00	**0.01**	0.00	0.00	0.01
Mudflats	0.00	0.00	0.00	0.00	**0.04**	0.00	0.04
Bare soil	0.00	0.02	0.01	0.00	0.01	**0.14**	0.18
Total Observed	0.61	0.07	0.08	0.01	0.06	0.17	1.00

Table 6. Transition probability matrix between 2018 and 2035.

2018	2035						
	Water	Vegetation	Mangrove	Salty lands	Mudflats	Bare soil	Lost
Water	**0.990**	0.000	0.003	0.000	0.006	0.001	0.010
Vegetation	0.000	**0.526**	0.183	0.002	0.001	0.288	0.474
Mangrove	0.004	0.110	**0.560**	0.001	0.143	0.182	0.440
Salty lands	0.014	0.002	0.021	**0.404**	0.153	0.405	0.596
Mudflats	0.042	0.000	0.061	0.023	**0.822**	0.053	0.179
Bare soil	0.012	0.118	0.092	0.025	0.063	**0.690**	0.310
Gaine	0.072	0.231	0.359	0.052	0.366	0.928	

Table 7. Land use statistics between 2018 and 2035.

Classes	2018		2035	
	Superficie (ha)	Proportion (%)	Superficie (ha)	Proportion (%)
Water	2044990.98	50.93	2124807.54	52.92
Vegetation	478589.13	11.92	343155.59	8.55
Mangrove	283670.64	7.06	382396.43	9.52
Salty lands	175581.36	4.37	54780.52	1.36
Mudflats	192737.88	4.80	271280.2	6.76
Bare soil	807552.27	20.11	839075.97	20.90

and at the estuarine limits in lower Casamance. The increase of the mudflats is estimated at 78542.32 ha, that is, 1.96% of their area in 2018. Their spatial extension will be more accentuated in the Casamance estuary and its borders, where tidal flats are formed.

Impacts of land use change on the Sustainable Development Goals (SDGs)

Climate change is significantly influencing the spatio-temporal dynamics of land use. Its impact on the physical environment has resulted in the regression of continental vegetation cover and a slowing of the increase in the world's freshwater supply. Preserving and restoring ecosystems to mitigate the effects of climate change is an integral part of the Sustainable Development Goals (SDGs). From 1998 to 2013, nearly one-fifth of the Earth's vegetated surface showed strong downward trends in productivity. Soil and land degradation undermines food security and development in all countries (ODD, 2017). The results of this study showed a regression of vegetation cover and an increase in mudflats and salty lands as a consequence of sea level rise. In the face of these situations, knowledge of changing trends of the surface conditions and natural resources is essential to facilitate the achievement of goals 13 and 15 of the 2030 Agenda for Sustainable Development. The severity of future impacts of climate change on natural resources can be understood through

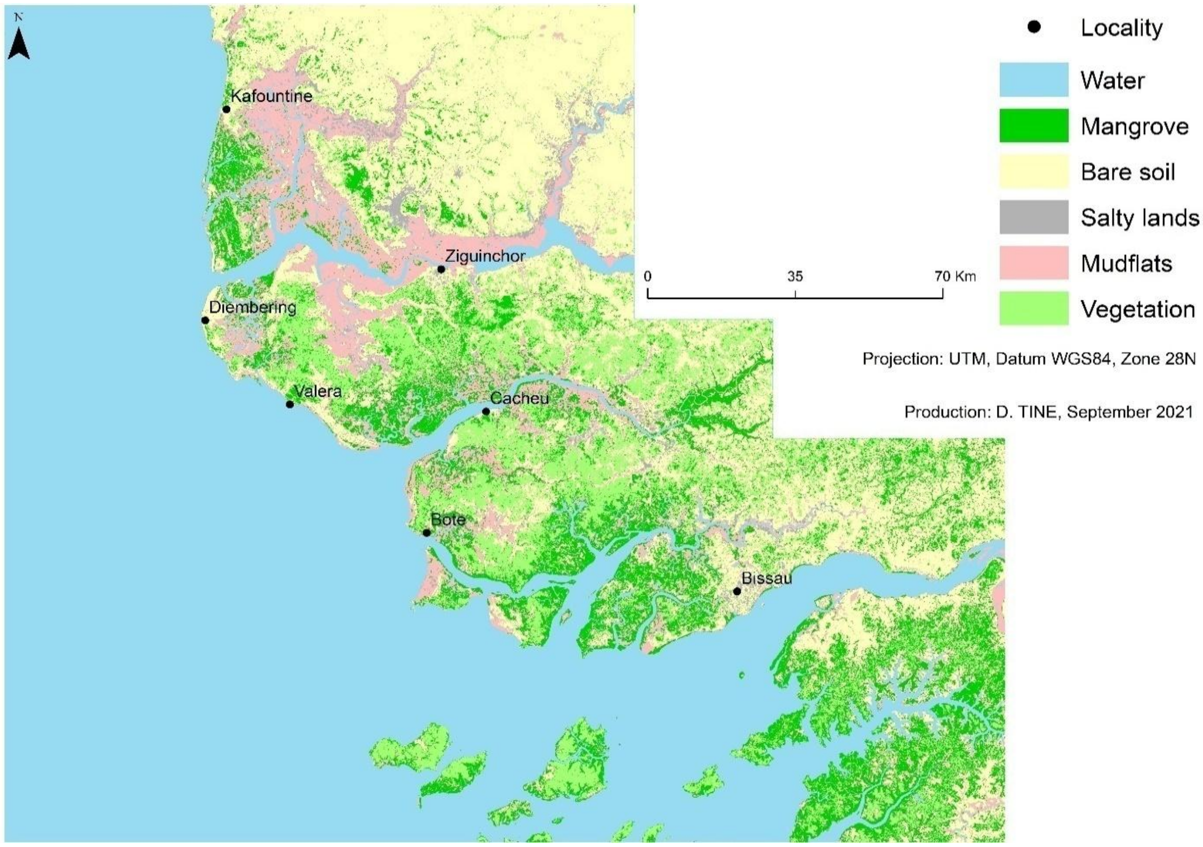

Figure 10. Land use in 2035 simulated by CA-Markov.

the prediction of their spatio-temporal behavior. This is a key source of information for the evaluation of the program. At the rate of land use change observed, the objectives of sustainable development could be compromised in this area.

DISCUSSION

The detection of land use changes in the northern part of the Southern rivers between 1986 and 2018 is made on the basis of prior land use mapping. The classifications are found to be acceptable and allow for the assessment of land use changes from 1986 to 2018, a 33-year period. Confusion errors are noted in the salty lands, mudflats, bare soil classes. The difficulty in visually discriminating these classes may be due to similar spectral signatures, as mudflats are constantly flooded salty lands. The confusion between salty lands and bare soil is that salty lands without salted surface concentration and sometimes grasslands are inseparable from the visual observation (Tine et al., 2020). The change detection results show an increasing trend of mudflats, a regression of salty lands and bare soil, and a slight stability of vegetation and mangrove. The method of comparing classifications demonstrated the utility of a simple approach to detecting land cover change and the ease of creating change maps (Hoang, 2007). The overall accuracies of the classifications give satisfactory results with 91% for 1986 and 97% for 2018.

The validation of the prediction with the 2018 reference image showed a satisfactory result with a Kappa of 88%. These results corroborate with those of Yirsaw et al. (2017) who further assert that Markov chain is an appropriate model for predicting land cover changes. The reliability of the model in predicting land cover changes is confirmed by the work of Maestripieri and Paegelow (2013) who have an accuracy of 86% between observed and simulated changes.

The Markov chain is not too complex to use with IDRISI software. However, problems related to the execution of the model can occur when the reference images, which are used for prediction, are processed by other software. It is often an imbalance related to the size of the images (number of rows over number of columns). Another limitation of predictive models is related to their spatial and statistical validation. Only the opinion of experts constitutes an element of judgment of the simulation. In this work, the results were submitted to the appreciation of several experts. However, the supervised approach (CA-Markov) generates more realistic maps (Maestripieri and Paegelow, 2013).The comparative analysis between the observations and simulation of 2018 showed a similarity of 88%. This accuracy was deemed acceptable and allowed to simulate land cover for 2035. Slight changes in land cover categories will be observed in 2035. Most notable is the 3% regression of saline land from its 2018 footprint. Conversion of salty lands to other categories is possible only if they are mudflats, water and mangroves. Bare soil that encompasses cropland as well as vegetative cover cannot gain space on salty lands due to salinity. This means that saline lands can be modified but remain unsuitable for agriculture. This regression could also be related to model simulation error.

Conclusion

The prediction of land use changes showed an increase of 1.99% in water surfaces, a decrease in continental vegetation from 11.92% in 2018 to 8.55% in 2035. A degradation of the vegetation cover will be observed in 2035 if no preservation measures are taken. Mangrove will occupy more than 2.46% of new space, while 3.01% of the saline land will be converted to other land use categories. Mudflats and bare land will increase slightly in area, with 1.96% and 0.79% respectively by 2035. However, the detection of land use changes and the prediction of their areas is not a perfect representation of the reality on the field. The numerous experiences capitalized in the framework of this work have proven that the temporal horizon should not exceed thirty years. The absence of external data such as population growth, climatic and geomorphological data are the limitations in predicting the state of land cover. However, the Markov chain allows quantifying and mapping the spatial dynamics of future land use changes. The simulation of land use patterns allows the evaluation of actions undertaken within the framework of programs to combat environmental degradation and to adopt sustainable ecosystem management strategies. Despite the methodological problems often encountered in land use simulation, predictive models provide reliable results that are very useful for decision making. A better prediction of morphological units requires taking into account climatic and anthropogenic factors which not considered in this work. The contribution of new sources of information such as urban areas, geology, geomorphology, etc., can improve the quality of the prediction.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Vol. 14(1), pp. 15-27, January-March 2022
DOI: 10.5897/JENE2019.0784
Article Number: 10422E968882
ISSN 2006-9847

http://www.academicjournals.org/JENE

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Full Length Research Paper

The impact of community-based ecotourism program on livelihood of local community: Result of propensity score matching from Adaba- Dodola District, Ethiopia

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Received 11 August, 2019; Accepted 20 May, 2020

Ecotourism is a recently emerged concept described as an ecologically friendly, economically and socially viable form of tourism. Its aims are to conserve the environment and local culture, and to ensure the major beneficiary and participation of local communities. This research aims to analyze the determinants of community based ecotourism and its livelihood impact in local community. 213 sample households consisting 107 program and 106 non-program groups were randomly selected from 5 program and 5 counterfactual kebeles, respectively. Primary data were collected through questionnaires, interviews, field visits and focused group discussions. Results of the impact evaluation model (PSM) after eliminating the difference between the two groups revealed significant difference between program and non-program households in terms of total net household income and tourism service revenue. It can be concluded that the impact of the program intervention among participants have much influence on their livelihood. The result of logistic model regression on the factors influencing livelihood showed that the two were affected by the same set of variables except age and family size which positively affected income and productivity separately and respectively. Whereas, ownership of land and livestock, awareness and being concerned for natural resources and access to credit were found to increase net income significantly. Therefore, ecotourism program policy interventions should consider the aforementioned factors influencing households' tourism income to create positive impact on the livelihood of farm households. The participation and collaboration of different ecotourism stakeholders is suggested to promote community based ecotourism program and its role in the area.

Key words: Ecotourism, livelihood, propensity score matching.

INTRODUCTION

Community-based ecotourism is a way of conservation and tourism development which emerged in the 1980s through escalating protests and subsequent dialogue with local communities affected by international attempts to protect the biodiversity of the earth. This is due to older conservation movements that disregarded the interests of local inhabitants (Brockington, 2002). The essence of classical conservation was to protect wilderness and wildlife areas of pristine wilderness that were largely untouched by humans. All people inhabiting these areas were removed from the land and displaced onto marginal land surrounding or nearby the newly protected land. It is estimated that 20 million people were displaced from their land (Veit and Benson, 2004).

In 1975 the International Union for Conservation of Nature (IUCN) and the World Parks Congress recognized the rights of indigenous people and to recognize their rights to the protected areas (Cholchester, 2004). Understanding people–ecosystem interactions is important in conservation (FairHead and Leach, 1996). In different parts of the world, humans and ecosystems have co-evolved, which has led to the development and refinement of local and traditional knowledge and management strategies through constant adaptation and learning. One strategy of community-based conservation is co-management of a protected area (Child and Jones, 2006)[1].

Local communities' engagement is essential to have a goal and to work together in activities related to ecotourism that promote conservation as well as their benefits. While groups can contain mutual, overlapping and divergent interests and perspectives, the goal binds people together giving them a common identity despite individual differences (Forgie et al., 2001). A wide range of motivations can lead to establishment of community conserved areas; these include: concern for wildlife protection; to secure sustainable access to livelihood resources to obtain sustainable benefits from ecosystem benefits; to sustain religious, identity or cultural needs, to secure collective or community land tenure, to obtain security from threats, and to obtain financial benefits. On the other hand, these areas are critical to an ecological and social perspective in many ways. They help in conservation of threatened species, provide corridors and linkages, offer lessons in integrating customer and statutory laws, help communities in empowering themselves etc (IUCN, 2006).

Concerns over the application of community in natural resource management demonstrate the need to rigorously examine partnering communities to understand how social differentiation shapes the effectiveness of these initiatives. This is made all the more necessary with the rising critique from some sectors as to the social and ecological effectiveness of community conservation.

Public participation in scientific assessments adds local and indigenous perspectives to scientific knowledge (Funtowicz and Ravets, 1990). Assessments with local participation are able to incorporate a more pluralistic, increase public confidence in scientific findings, and ensure representativeness in scientific processes (Backstrand, 2004).

Ecotourism has become one of the fastest growing segments of the tourism industry in the world (UNWTO, 2001). The declaration of the year 2002 as International Year of Ecotourism by the World Tourism Organization reflects the importance of ecotourism in the global industry. It provides better linkages, reduces leakages of benefits out of a country, creates local employment, creates multiplier effects and fosters sustainable development and greater impact on biodiversity conservation (Khan, 1997; Belsky, 1999). However, the roles of community-based ecotourism benefits in Ethiopia are insignificant as compared to the various resources the country has. The tourism industry in Ethiopia is mainly associated with historical and cultural attractions and the contribution to employment opportunities; foreign exchange earnings and improving the welfare of local people (Gezon, 1997; Mbaiwa, 2003) are inadequate. Hence, community-based ecotourism has been given much attention in Ethiopia in general and Adaba-Dodola in particular due to its importance in conservation and local people's livelihood improvement.

The popularity of community ecotourism is largely attributable to the impacts on local people livelihoods and the rise of sustainable development as the guiding discourse for environment and development planning. It has the potential to become a driver of sustainable tourism development providing opportunities for the development of the disadvantaged, marginalized and rural areas. It plays a vital role in poverty alleviation and generating income for local communities without destroying the environment (Ceballos, 1996). It stimulates economic development and social wellbeing of people and at the same time preserving the natural environment and cultural heritage through awareness creation (Isaac et al., 2012). Adaba-Dodola community based ecotourism is, established 1995 with the help of GTZ, one of the ecotourism sites mainly managed by involvement of local communities. Its objective was to improve the local communities' livelihood through ecotourism in which the income was generated from tourists. There is variation in terms of local communities' engagement in this ecotourism project by participants and non-participants.

However, there are local communities that have not yet been involved in ecotourism activities and even the level of household involvement varies from one kebele to another. Moreover, the forest coverage in different kebeles also varies. Hence, the overall perspective of this study is to determine the effect of ecotourism on livelihood of local communities in comparison between participant and non-participant and among households of different kebeles. Hence, understanding the livelihood effect of community based ecotourism between

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[1] Co-management combines local peoples' traditional knowledge of the environment with modern scientific knowledge of scientists [Chiled and Jones, 2006)]. Community-based ecotourism initiatives are bottom-up activities that bring individuals and organizations together to work towards achieving desired goals such as conservation, local peoples livelihood development and improvement of tourists enjoyment (Forgie et al., 2001).

participants and non-participants as well as among different kebeles is essential for better participation and benefit of local communities. Moreover, there was no detailed investigation made to identify the effect of community-based ecotourism on livelihood of local communities. Therefore, this particular study aims to investigate the contribution and impact of community based ecotourism activities on livelihood of local communities in the Adaba-Dodola area.

THEORETICAL FRAMEWORK

One of the fundamental interests of impact studies in adoption of technologies is whether a particular intervention, as designed, is effective in accomplishing its primary objectives. However, the estimation of the impact of adoption of policies or technologies based on non-experimental observations is not an easy task. The main challenge of a credible impact evaluation is the construction of the counterfactual outcome, that is, what would have happened to participants in absence of treatment (Heinrich et al., 2010). Since this counterfactual outcome is never observed, it has to be estimated. In experimental studies, this problem is addressed by randomly assigning improved seeds to treatment and control status, which assures that the welfare outcomes observed on the control households that adopt improved technology are statistically representative of what would have occurred without adoption. However, improved technology is not randomly distributed to the two groups of the households (adopters and non-adopters), but rather the households themselves decide to adopt or not to adopt based on the information they have. Therefore, adopters and non-adopters may be systematically different.

Several methods have been used to study impact of ecological changes in different countries. In Lesotho, Kaliba and Rabele (2004) and in Philippines, Shively (1998a, b) have used linear regression to study impact of short- and long-term soil conservation measures on wheat yield and contour hedge rows on yield, respectively. Shiferaw and Holden (2001) have used cost benefit analysis on experimental trials to study the impact the Soil Conservation Research program in two high rainfall highland sites in Ethiopia. Numerous researchers have used econometric analysis and cross sectional survey data to estimate the impacts of policy measures in the different parts of Ethiopian highlands (Holden et al., 2001; Benin, 2006; Kassie and Holden, 2006; Pender and Gebremedhin, 2006).

These studies, however, suffer from a number of methodological problems, which can either under or overestimate impacts of participatory eco tourism on livelihood. First, comparisons are not based on comparable observations, which can yield biased estimates (Heckman et al., 1998). Second, all studies assume a single equation model where resource use change has only intercept effects and the same set of variables equally affect both participants and non-participants, without testing this assumption empirically. Third, none of the studies account for unobserved heterogeneity that might impact results. For example, in addition to having the limitation of small sample size (50 households), Kaliba and Rabele (2004) did not control for social group characteristics. If there is asymmetric distribution in group change across social groups and households and correlation between livelihood improvement and group attributes, estimation of participatory eco-tourism impacts on livelihood may lead to inconsistent estimates. Other studies also do not consider the effects of important variables, such as group decision making networks and migration characteristics.

The matching approach is one possible solution to the selection problem. It originated from the statistical literature and shows a close link to the experimental context. Matching applies for all situations where one has a treatment, a group of treated individuals and a group of untreated individuals. These include; double difference or difference-in-difference (DID) reflexive comparison and propensity score matching (PSM). Propensity score matching (PSM) has become a popular approach to estimate causal treatment effects and increasingly applied in the policy evaluation community (Baumgartner and Caliendo, 2008; Heinrich et al., 2010). According to matching theory (Rosenbaum and Rubin, 1983; Jalan and Ravallion, 2003; Bryson et al., 2002), the logit model via which the propensity score is generated should include predictor variables that influence the selection procedure or participation in the program and the outcome of interest. Several factors guide selection of predictor variables. In the present study, explanatory variables of the logit model will be identified using findings of previous related empirical studies, project selection criteria, and own field observation.

We will include as many explanatory variables as possible to minimize the problem of unobservable characteristics in our evaluation of the impact of the program. Accordingly, variables that determine households' decision to participate in the participatory Eco-tourism activities that will affect the outcome variable, that is, livelihood index/household income are included. In other word, variables which are not affected by being participant in the program or not or those explanatory variables which are fixed throughout are assumed to be used as explanatory variables. Based on

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economic theory and knowledge about previous research and also information about the institutional settings socioeconomic, demographic, and institutional and household and community level factors are hypothesized to determine participation. Detailed description of the variables-related hypothesis is presented in the Definition of variables and working hypothesis section.

The second stage in the PSM procedure is choosing a matching algorithm that will use the estimated propensity scores to match untreated units to treated units. There are several matching algorithms; however we will present in literature review part the most commonly used for comparison purpose. However we will select the best fitted one for our case. To estimate the impact of program intervention, following the literature of program evaluation, let Y_1 be the livelihood index when the individual *I* is subject to treatment (*C*=1) and Y_0 the same variable when an individual is exposed to the control(*C*=0). The observed outcome is

$$Y = CY_1 + (1 C)Y_0 \tag{1}$$

When (*C*=1) we observe *Y*1; when(*C*=0) we observeY_0. Our goal is to identify the average effect of treatment (ATT) on participant and non-participant households. It is defined as:

$$ATT = E\left(Y_1 - Y_0 \middle| C = 1\right) = E(Y_1 \mid C = 1 - E(Y_0 \mid C = 1) \tag{2}$$

The evaluation problem is that we can only observe $E\left(Y_1 \middle| C = 1\right)$ however$E(Y_0 \mid C = 1)$; does not exist in the data, since it is not observed. A solution to this problem is to create the counterfactual, by matching treatment and control households. Finally, using predicted probabilities of participation in the program (propensity score) matched pairs are constructed using alternative methods of matching estimators. Then the impact estimation is the difference between simple mean of outcome variable of interest for participant and non-participant households. In our case, the mean stands for household livelihood improvement/household income. The difference involvement in Participation in the CBET program between treatment and matched control households is then computed. The ATT is obtained by averaging these differences in adopters' outcomes (Y_i) across the *k* matched pairs of households as follows:

$$ATT = \sum_{j=1}^{p} \left\{ \{Y_{ij\,1} - \sum_{i=1}^{NP} Y_{ij\,0} \middle| \} \quad P \right\}$$

$$\text{ATT} = \tag{3}$$

Where, *ATT* is household livelihood status/household income, $Y_{ij1}$is the post-intervention livelihood status/ income household *j*, Y_{ij0} is the livelihood status/income of household of the i^{th} non-participant matched to the j^{th} participant, *NP* is the total number of non-participants and *P* is the total number of participants. Besides to determine the significant factors affecting participation and impact, Logit and Probit models have extensively been used in the study of households' Participation decision of different programs (Soule et al., 2000; Franzel et al., 2001; Tadesse and Belay, 2004; Fikru, 2009). Both of these models provide the possibility of analyzing the probability of adoption or non-adoption of introduced technologies. The response (dependent) variable is dichotomous taking on two values, 1 if the event occurs and 0 if it does not. In this regard, the linear probability models, logit and probit models are the possible alternatives. Both the logit and probit models yield similar parameter estimates and it is difficult to distinguish them statistically (Aldrich and Nelson, 1984).

METHODOLOGY

Adaba-Dodola is found in the South east part of Ethiopia 310 km from Addis Ababa by road. Adaba-Dodola community based ecotourism development project was initiated in 1995 to develop a replicable model for the conservation and sustainable use of biodiversity in Ethiopia. The project is concerned with the unregulated access to the natural forests. In the past, all attempts to regulate access have failed. The forest priority area of Adaba-Dodola is located on the northern slopes of the Bale Mountains and its size was decreased by 3% per year due to unregulated access by wood collectors and livestock herds. Although the area is among the forest priority areas of the country, overexploitation of timber and firewood as well as increasing demand of farmland and overgrazing endanger the survival of the forest. The area was highly encroached by the surrounding communities and it was on the verge of total degradation when the project was started. With an objective of alternative source of income, five ecotourism lodges which are managed by local communities were established. The project is involved in activities which generate income through eco-tourism management. Towards the fulfillment of this, it has constructed lodges and trekking routes. It also provides camping sites, horses, tents, guides and others. These services are addressed to tourists who are interested in sightseeing, mountain trekking, hunting and looking traditional way of life. Due to the project, the proportion of the natural regeneration has been getting highest attention and the locals are starting to manage the resource properly (Sisay, 2004).

For this specific study, our target groups was the two (Adaba and Dodola) districts, culture and tourism office, Oromia forest and wildlife enterprise, and indigenous local communities. Stratified random sampling technique was employed to select the sample households from the participant and nonparticipant groups. Adaba and Dodola districts comprise 35 kebeles in which 18 of them are from Adaba and 17 of them from Dodola. From these, 6 kebeles are currently involved or they are direct participants in activities of community based ecotourism using legal system and 29 of the kebeles are not involved or non-participants in the community based ecotourism activities. From the 6 kebeles, 5 of them are in Dodola and 1 in Adaba is currently involved in the ecotourism development activity. From these 6 (4 from Dodola and 1 from Adaba) kebeles from the two districts were selected purposely based on coverage of forest area, time of establishment and total number of households involved for better comparison among different kebeles. For the comparison of CBE effect determination on the livelihood of participant with non-participant groups, 5 kebeles from 29 kebeles of non-participant groups were randomly

Table 1. Proportion of sample households from participant and non-participant kebeles.

Participant			Non-Participant		
Sample kebeles	**Total household**	**Sample household heads**	**Sample kebeles**	**Total household**	**Sample household**
Bura Adele	556	50	Berisa	158	15
Denba	150	14	Kechema	248	24
Keta berenda	269	24	Hare genetaa	269	25
Ashena Robe	120	10	Ejersa chumugo	149	14
Bucha	90	9	Weshaa	299	28
Total	**1185**	**107**	**Total**	**1123**	**106**

selected. To maintain higher representativeness of the sample the PPS technique were applied. However, the total sample size will be determined based on a Cochran (1977) formula: The total number of households found in target sample kebeles both in participant and non-participant kebeles were 3362 households (Table 1) (OFWE[2], 2013). The sample size for the participant and non – participant kebeles was determined based on the following equation.

Data collection

Data were gathered using interviews, household survey, and site visits and focused group discussion. Secondary data were obtained from Oromia forest and wildlife enterprise offices of Adaba-Dodola branch, culture and tourism office of Adaba and Dodola districts and other concerned organs. For the sake of getting adequate and relevant information about the impact of community based ecotourism on the livelihood of local communities, observation of people going about their daily activities for their livelihoods, an overview of the local market, shops and any commodities exchange were conducted. Moreover, observations of what people have and do not have, and who does what, local price information (e.g. price of staple foods), exploration of what local people buy and sell, when and for how much, will assessed for livelihood analysis. General interviews were carried out with communities from participants as well as non-participants of community based ecotourism activity. Accordingly, we interviewed the manager of Adaba-Dodola district forest and wild life enterprise, chairman of the tour-guide association, general manager of the farmers union and other stakeholders. General discussion about livelihoods, resources, changes; problems were discussed with these key informants of local communities in both groups. Household surveys were carried out to gain comparable data to allow for quantification, and to reach a representative sample. For this matter semi-structured questionnaire was prepared and one to one interview was used to get important details about livelihood impact from the target respondents and it was administered by 10 interviewers for 213 respondents (106 non participants and 107 Participants).

Financial data were gathered by going through project records, enterprise records, receipt books and discussing incomes or uses of income with household members. Number of members in employment of ecotourism activities was also recorded. Assessment of institutional change, in particular, will be discussed using open-ended conversations with people to identify changes and continuity over time. Subsequently, household survey was also developed for the sake of having the demographic, socio-economic characters of the households to assess the major determinant impact of ecotourism development in the livelihood. Finally, to identify the attitude and perception of participant and non-participant household's Likert scale techniques were employed. Based on Trochim (2003)'s recommendation as a tool two FGDs were conducted on each target groups (Four FGD for the whole study) by selecting respondents from both groups. In each FGD one community leader, four elders of villages, and one officer from the community based ecotourism program, one expert from wildlife and forest enterprise of the districts, one from culture and tourism office of each district, government administrators, one from female association, were selected and discussed on changes, problems, historical perspective and the effects of the ecotourism development on their well-being.

Data analysis

The study used descriptive and inferential statistics, and econometric models to analyze the collected data and address the stated objectives. Descriptive statistics were used to describe community based ecotourism activities, practices and the institutional arrangement followed in the study area. Inferential statistics were important in defining relationships between variables considered to draw relevant conclusions about the population. This method of data analysis refers to the use of percentages, mean, standard deviations and test of significance in the process of comparing socio-economic and institutional characteristics of the participant and non-participant households in the study areas. Before running the PSM or MLR with respect to the study objective data were checked for outliers, collinearity and heteroscedasticity. Accordingly, the existence of outliers was checked using SPSS explore method (Gujarati, 2002). Then, we employed PSM approach to estimate the impact of CBECT in livelihood. In the first step the propensity score was estimated with a simple binary choice model; logit or probit. As described by Rosenbaum and Rubin (1983), matchings were performed conditioning on P(X) alone rather than on X, where P(X) = Prob(D=1|X) is the probability of participating in the program conditional on X. If outcomes without the intervention are independent of participation given X, then they are also independent of participation given P(X). This reduces a multidimensional matching problem to a single dimensional problem. A logit model will be used to estimate propensity scores using a composite of pre-intervention characteristics of the sampled households (Rosenbaum and Rubin, 1983) and matching was then performed using propensity scores of each observation. In estimating the logit model, the dependent variable was participation, which takes the value of 1 if a household participated in the program and 0 otherwise. The mathematical formulation of logit model is as follows:

$$P_i = \frac{e^{z_i}}{1 + e^{z_i}} \quad (4)$$

[2] OFWLE reefers to 'Oromia' Forest and Wild life Enterprises,' Oromia' Region Ethiopia

Table 2. Descriptions of respondents by Districts and Kebele.

Participation	Woreda			Name of Kebele										
	Adaba	Dodola	Total	1	2	3	4	5	6	7	8	9	10	Total
	41	41	82	0	14	0	0	22	5	0	0	22	19	82
Non- participant	50	50	100	0	17	0	0	27	6	0	0	27	23	100
	82	31.54	45.56	0	100	0	0	100	100	0	0	100	100	46
	9	89	98	12	0	46	13	0	0	18	9	0	0	98
Participants	9.18	90.82	100	12	0	47	13	0	0	18	9	0	0	100
	18	68.46	54.44	100	0	100	100	0	0	100	100	0	0	54
	50	130	180	12	14	46	13	22	5	18	9	22	19	180
Total	27.78	72.22	100	7	8	26	7	12	3	10	5	12	11	100
	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Pearson chi2(1)		37.0738***										Pearson chi2(9)		180***
LLR chi2(1)		38.9008***										LLR chi2(9)		248.1089***

Source: Own Survey (2015), Note: *** means significant 1% probability levels.

Where, P_i is the probability of participation,

$$Z_i = \alpha_0 + \sum_{i=1}^{n} \alpha_i X_i + \epsilon_i \quad (5)$$

Where,
i = 1, 2, 3, - --, n
a_0=intercept
a_i= regression coefficients to be estimated
X_i = pre-intervention characteristics.
U_i= a disturbance term, and the probability that a household belongs to non-participant is:

$$1 - \mathrm{P_i} \frac{1}{1 + \mathrm{e}^{\mathrm{z_i}}} \quad (6)$$

Moreover, in this study we used multiple linear regression models because we were interested only in the behavior of matched participant households which results in continuous response. MLR was employed to assess the factors that determine the net effect of CBET among beneficiary groups (factors responsible for determining the variability of the impact were assessed). The outcome variable considered in this study was livelihood status in terms of household income per year.

RESULTS AND DISCUSSION

Overview of the study

The results of the descriptive and inferential analysis of 213 households consisting of 107 CBECT program and 106 non-program households show that there were statistically significant differences between program and non-program households before intervention with regard to the social-demographic characteristics. The sampled groups differ in terms of sex, age, family size and farm size (Table 2). As indicated in our sampling design, and result of the study revealed in Table 3 respondents were selected from both districts of the study area.

Table 4 indicates that there was statistically insignificant association among program and non-program households in terms sex of household head before CBECT program intervention. However, male heads dominate the program non-program group households. There was no statistically significant difference between the two groups in terms of gender. On the other hand we found statistically significant difference (p< 0.01) between the two groups in terms of respondents' religion. The Pearson chi2 (3) value in Table 4 indicates the strong associations between respondents' religion before matching.

Among the continuous variables shown in Table 4 the two groups differed in terms of age, family size and farm size. The CBECT program households were significantly (p<0.1) older than the non-program group. The program group had significant (p<0.01) larger family and farm size. Educational status of the household head (EDUHH): In this part educational status of the household heads in relation to household participation in the program was assessed. Accordingly, 62.5% of total sample respondents were illiterate of which program households represent 37.5%. On the other hand from the total 37.5 literate households the non-program was 25%. The t-Value value (-0.615) for this variable indicates that there is significant difference in educational status of the household head between program and non-program households (Table 5).

Farm characteristics: Land holding and tenure system

The average land cultivated by the sampled CBECT program and non- program households was found to be 2.98 ha and 2.49 ha, respectively (Table 6) and there

Table 3. Demographic characteristics of the sample households (current occupation of respondents).

Participations	Statistics	Occupation						Total
		Gov employee	Merchants	Farmer	Driver	Students	others	
Non Participants	N1	0	9	70	1	2	0	106
	%	0	10.98	85.37	1.22	2.44	0	100
	%	0	90	46.36	6.67	100	0	45.56
Participants	N2	1	1	81	14	0	1	107
	%	1.02	1.02	82.65	14.29	0	1.02	100
	%	100	10	53.64	93.33	0	100	54.44
Total	N	1	10	151	15	2	1	213
	%	0.56	5.56	83.89	8.33	1.11	0.56	100
	%	100	100	100	100	100	100	100
Pearson chi2 (5)= 21.2134***				likelihood-ratio chi2(5) = 25.7309***				

Source: Own survey (2015), Note: *** means significant 1% probability levels.

was significant difference between the two groups in terms of all land tenure systems considered, that is cultivated own, rented and shared land. Cropping pattern has been defined as the list of crops that are produced in a given area and their sequence within a year (Sarker et al., 1997). On the other hand we found statistically significant mean difference of protected land coverage across both groups. On average around 0.05 ha land was found as a protected area in both districts

Household income and livelihood

Table 7 shows the mean difference in outcome variables before matching. Program and non-program households have significant difference in terms of all outcome variables considered, that is, gross and net CBECT income, and gross and net household income as one of the finical component of household livelihood. However, this descriptive result cannot tell us whether the observed difference is exclusive because of the program; as comparisons are not yet restricted to households who have similar characteristics. Hence, further analyses were performed using propensity score matching techniques to address this issue.

Econometric model outputs: Propensity score matching

This section describes the results of econometric analyses. It is divided into two sub-sections. The first part deals with the impact of CBECT program using propensity score matching method. The important analytical steps followed include determination of propensity scores, matching methods, common support region and balancing test and estimation of treatment effect. The second part pertains to the result of a multiple regression model identifying factors affecting the impact of the CBECT program. Propensity score matching is a method that uses information from a pool of units that do not participate in the intervention to identify what would have happened to participating units in the absence of the intervention. The method was used to compare the two groups in terms of CBECT program outcomes. The following procedures were employed to determine the impact of CBECT program with respect to the chosen outcome variables (Livelihood in terms of its financial component, that is, household income).

The first step taken to evaluate impact of CBECT policy net household income was estimation of propensity scores based on the selected covariates. Logistic regression model was employed to estimate propensity scores for matching treatment household with control households. The dependent variable in this model was a dummy variable indicating whether the household has been in the of CBECT program which takes a value of 1 and 0 otherwise. Before and after estimation of the propensity score and the logistic model appropriate diagnostic measures were used on the data and the hypothesized variables. Accordingly the tests for outlying observations, heteroscedasticity, and mullticollinearity and post estimation for model specification, goodness of fit and omitted variables were done. Outlying observations with extreme influence (residual value of >2.5) were removed from analyses. To this effect 10 observations were discarded. Results of multi-collinearity test showed that there was no serious problem of multicollinearity detected (Appendix Table 1).

Similarly, the test for the presence of heteroscedasticity using Breusch-Pagan test showed that there was no heteroscedasticity problem at 5% probability level (p= 0.67) and a further comparison of the standard errors

Table 4. Demographic characteristics of the sample households.

Participation \ Sex and Religion	Male			Female			Total			Orthodox			Muslim			Catholic			Total		
	n	R%	C%	n	R%	C%	n	R%	C%	n	R%	C%	n	R%	C%	n	R%	C%	n	R%	C%
Non	65	46	79	17	43	21	82	46	100	29	80	35	53	37	64	0	0	0	82	46	100
Participants	75	54	76	23	57	23	98	54	100	7	19	7	90	62	91	1	100	1.0	98	54	100
Total	140	100	78	40	100	22	180	100	100	36	100	20	143	100	79	1	100	1	18 0	100	100
		Pearson chi2(1)						0.19						Pearson chi2(3)						22.77***	
		LLR chi2(1)						0.19						LLR chi2(3)						24.08***	

Source: Own survey, 2015. Note: * and *** means significant at 1% probability levels.

Table 5. Demographic characteristics of the sample households (Continuous Variables),

Pre intervention variable	Non Participants(106)					Participants(107)				
	N1	Mean	Std. Dev.	Min	Max	N2	Mean	Std. Dev.	Min	Max
Age	106	42.27	10.57	23	64	107	47.91	10.048	23	69
Education	106	4.44	1.64	0	8	107	3.22	2.213	0	9
Farm Experience	106	17.82	13.36	2	44	107	23.76	10.50	2	50

Source: Own survey (2015). Note: * and *** means significant at 1% and 10% probability levels, respectively STD: Standard Deviation, [a]STD for mean difference = $\sqrt{\left(\frac{STD_1^2}{N_1}+\frac{STD_2^2}{N_2}\right)}$

showed that there was no difference between the two cases. Hence other methods were not needed to correct the problem of heteroscedasticity. Results of post estimation tests showed that the model performed well. The model in general was significant at 1% level of significance showing the appropriateness of the model for estimation. The goodness-of-fit test using Hosmer–Lemeshow also yielded 6.85 and was insignificant (p=0.55), suggesting that the model was fit to explain the relationship well. The model was also checked for model specification using link test and results indicated that there was no such problem (p=0.66).

Before matching logit estimation shows that program participation status has been significantly influenced by six variables (Table 8). Sex of household head, farming experience, family size, and farm size and concern to conserve and social participation level were found to significantly affect the probability of adopting of CBECT program. Sex of household head, farming experience and family size influenced the probability of CBECT participation positively and significantly at 1%; whereas, livestock ownership, off-farm income and age determined participation negatively and significantly at p<0.01. On the other hand ownership of large farm size and livestock affected participation negatively at 5% significance level.

Matching program and non-program households

The estimated propensity scores enable us to define the common support region. Heckman (1997) point out that a violation of the common support condition is a major source of bias as conventionally measured. The basic criterion for determining the common support is to delete all observations whose propensity score is smaller

Table 6. Farm characteristics: Land holding and tenure system.

Pre intervention variable	Non participants					Participants				
	N1	Mean	Std. Dev.	Min	Max	N2	Mean	Std. Dev.	Min	Max
Total farm size	106	2.49	1.24	0.6	7.25	107	2.98	1.07	0	6.75
Self-owned farm size	106	2.20	1.40	0.21	7.25	107	2.89	1.06	0	6
Rent in farm	106	0.73	0.26	0.5	1	107	1.29	0.41	1	2.3
Rent out farm	106	0.67	0.29	0.25	1	107	0.93	0.19	0.5	1
Shared crop land	106	0.65	0.33	0.25	1.04	107	1.96	0.81	0.5	3
Common land	106	0.67	0.29	0.5	1	107	5.53	1.87	2.5	9.75
Cultivated land	106	0.78	0.41	0.25	1.75	107	1.58	0.83	0.5	4
Protected land	106	0.03	0.12	0	0.5	107	0.04	0.14	0	0.75
Fallow land	106	0.37	0.15	0.25	0.6	107	0.46	0.15	0.25	0.6
Grazing land	106	0.25	0.00	0.25	0.25	107	2.13	5.88	0.16	40
Home stead	106	0.42	0.14	0.25	0.5	107	0.42	0.23	0.15	1

Source: Own survey (2015).

Table 7. Household income (ETB).

Pre-intervention variable	Total sample		Program (n=107)		Non-program (n=106)		Differences in mean		t-value
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	
OMEETNG	26.005	6.233	26.336	8.077	25.67	6.233	-.667	0.989	-0.674
NPARTICIPA	2.634	3.377	2.775	3.473	2.491	3.287	-.285	0.463	-0.615
NONPARTICI	6.343	1.908	6.393	1.994	6.292	1.826	6.343	0.262	-0.382
DSPPROTEC	1.469	1.402	1.523	1.383	1.415	1.426	-.108	0.192	-0.562
EXTEN	11.421	5.216	10.977	4.89	11.869	5.504	.892	0.714	1.249
CBETPCH	1733861	2.530	2130756	2.204	2734749	2.815	4371656	3462915	1.2624

Source: Own survey (2014).

than the minimum of the program and larger than the maximum in the opposite group (Caliendo and Kopeining, 2008). The estimated propensity scores as shown in Table 9 vary between 0.144 and 0.937(mean = 0.538) for program households and between 0.114 and 0.858 (mean = 0.385) for non-program households. Therefore our common support region would then lie between 0.144 and 0.858. As a result of this restriction, 8 households (6 program and 2 control households) were dropped from the analysis in estimating the average treatment effect.

Choice of matching algorism

Nearest neighbor, Caliper and Kernel matching estimators were used in matching the treatment and control households in the common support region. The final choice of a matching estimator was guided by three criteria namely: the equal mean test (balancing test), pseudo- R^2 and matched sample size (Caliendo and Kopeining, 2008). The balancing test refers to the test of equality means of covariates after matching (Dehejia and Wahba, 2002), that is before matching differences are expected; but after matching the covariates should be balanced in both groups and significant differences should be found. The pseudo- R^2 indicates how well the regressors explain the participation probability. After matching there should be no systematic differences in the distribution of covariates between both groups and therefore the pseudo- R^2 should be fairly low. In general, a matching estimator which balances all explanatory variables (results in insignificant mean differences between the two groups), bears a low pseudo-R^2 value and also results in large matched sample size is preferable. Table 10 presents the estimated results of tests of matching quality based on the three above-mentioned performance criteria. Based on the criteria set above, caliper matching with tolerance level of 0.25 was found to be the best matching algorithm for the data we have. In what follows estimation results and discussions are the direct outcomes of the caliper radius matching algorithm with tolerance level of 0.25.

Testing the balance of propensity score and covariates

In order to compare two different groups, observations

Table 8. Results of logit estimation on household program participation.

Participation	Coef.	Std. err.	z	[95% Conf.	Interval]
RESPORSHIP	-0.29	0.66	0.4	-0.04	0.06
SEX	0.75	0.7101317	2.5***	0.28	2.50
AGE	0.03	0.03	-3.1***	-0.48	-0.11
RELIGION	1.32	0.53	2.5***	0.29	2.36
EDUCATION	-0.22	0.09	-2.6***	-0.40	-0.05
FARMEXPERI	-0.01	0.02	-1.8*	-6.75	0.32
FAMILYSIZE	-0.09	0.07	-1.7*	-0.27	0.02
FARMSIZ	-0.18	0.43	-0.4	-1.03	0.67
SELFOWN	0.50	0.44	1.2	-0.36	1.36
PERCEPTION	0.48	0.47	1.0	-0.44	1.41
TLUNOW	-0.03	0.07	-0.5	-0.17	0.11
TLUBFBRO	0.08	0.08	1.0	-0.08	0.24
OFFARMI	-0.39	0.51	-0.8	-1.38	0.61
DISTANCE	-0.39	0.51	-0.8	-1.38	0.61
PROTECTED	2.18	1.43	1.5	-0.63	4.99
CONCONSERV	0.13	0.00	1.1***	-1.70	1.10
HCONCERN	5.02e-06-	0.02	0.3**	-0.59	2.43
MCONCERN	0.00	0.00	-0.3	-0.04	0.06
LCONCERN	0.23	0.03	1.4	0.28	2.50
PARTLEVEL	-0.07	0.17	-2.3*	-0.48	-0.11
DECSION	0.12	0.27	-0.4	-0.03	0.08
OPDECSION	0.00	0.00	4.3***	-0.27	0.02
OMEETNG	0.00	0.00	-0.1	-1.01	0.80
CBETPCH	0.30	0.33	-0.5	-0.44	1.41
_CONSTANT	-3.29	1.52	-2.2***	-6.27	-0.31

*** and ** means significant at the 1 and 5% probability level respectively. Number of obs = 213; LR chi2 (17) = 69.90; Prob > chi2 = 0.0000 and Log likelihood = -172.99567; Pseudo R2 = 0.1681.
Source: Own estimation (2012).

Table 9. Distribution of estimated propensity scores.

Variable	Observ.	Mean	Std. deviation	Min	Max
All households	213	0.501	0.196	0.114	0.93
Program households	107	0.538	0.201	0.144	0.937
Non program house holds	106	0.385	0.163	0.114	0.858

Source: Own estimation (2012).

with the same propensity score must have the same distribution of observable (and unobservable) characteristics independently of the treatment status (Becker and Ichino, 2002). Based on this theory the balancing test of propensity scores and covariates was done. The results in Table 10 show that treatment and control households had significant difference for most of the covariates before matching. However, t-tests revealed that most of the covariates became insignificant after matching.

CONCLUSION AND RECOMMENDATIONS

Descriptive and inferential statistics, propensity score matching and multiple linear regression models were used to meet the stated objectives. The results of the descriptive and inferential statistics showed that there was significant difference between program and non-program households in terms of sex and age of household head, family size and farm size. The estimation of the impact of CBECT intervention on

Table 10. Propensity score and covariate balance.

Variable	Before matching (N=213)			After matching(N=203)		
	Program (n=107)	Non-program (n=106)	t-Value	Program (n=107)	Non-program (n=106)	t-value
AGE	0.95	0.95	0.01	1.04	1.05	0.07
EDUC	2.02	1.17	2.66*	2.29	2.51	-0.26
SEX	1.21	1.36	-2.51**	1.14	1.11	0.26
FAMSIZE	6.47	6.22	0.74	6.47	6.34	-0.33
FARMSIZE	1.58	1.71	-1.04	1.61	1.61	-0.05
PERCELD	1.51	1.51	0.00	1.69	1.83	-0.05
PERCPROF	0.21	4.36	2.51**	1.14	1.11	0.86**
LIVESTOCK	3.52	4.32	-2.15**	4.03	3.97	0.11
OFFFARM	21.65	17.25	2.10**	21.26	20.30	0.08
CONCONSERV	1.54	0.58	1.2101	1.04	0.58	1.2101***
HCONCERN	2.02	1.17	2.66*	2.29	2.51	-0.26
MCONCERN	1.21	1.36	-2.51**	1.14	1.11	0.26
LCONCERN	6.47	6.22	0.74	6.47	6.34	-0.33
PARTLEVEL	1.08	0.37	1.54	0.61	0.37	1.54
DECSION	1.92	1.20	0.290	0.59	1.56	-1.805
CBETPCH	27.96	22.34	2.99*	26.28	25.62	-0.21

Source: own estimation.
* **and ***means significant at the 10 and 5% probability level respectively.

livelihood/household income showed that sex of household head, farming experience, family size, farm size and livestock ownership have been the major factors of group difference. The result of the estimation of the impact of CBECT showed that there was statistically significant difference between program and non-program farmers in terms of the outcome variable considered, that is, gross and net household income. This result was not expected as the CBECT interventions were carried out based on the premises of reducing soil and nutrient lose and increasing productivity and income. However, considering the long-term impact of CBECT technologies, the observed positive sign may be taken as good start for the realization of the expected benefits of the CBECT technologies for promoting the livelihood of the poor smallholder farmers. Assessment of the respondents' perception and physical conditions of the area such as participation willingness and Asset profile constitute evidence for the possible contribution of CBECT intervention.

Therefore, it was necessary to identify what other factors were governing farmers' income and productivity. Multiple linear regression models were employed for this purpose. Results indicated that some variables were found to affect only net crop income positively and significantly; whereas ownership of land and livestock and extent of contacts with extension workers were found to increase both annual income and livelihood significantly. However, participation in CBECT activities, ceteris paribus, failed to affect net income and livelihood index. This finding was also supported by result obtained from the PSM model that showed no statistically significant difference between program and non-program in terms of household's income and livelihood status. In general we may conclude that demographic characteristics, ownership of resources, input usage and access to credit affect the outcome variables rather than the adoption of CBECT "technologies".

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Appendix

Appendix Table 1. VIF Value for Explanatory Variables

Variable	VIF	1/VIF
HCONCER	2.24	0.446277
PARTLEVEL	2.23	0.447566
RELIGION	1.45	0.689561
AGE	1.43	0.700803
OFFARM	1.37	0.729662
PERCEPTION	1.32	0.758113
DISTANCE	1.32	0.755576
PROTECTED	1.30	0.767367
FAMILYSIZE	1.23	0.815957
SEX	1.15	0.866107
EDUCATION	1.15	0.867491
FARMEXP	1.14	0.875517
CONCONSERV	1.14	0.875939
CBETPCH	1.12	0.894967
FARMSIZ	1.10	0.909945
DECISION	1.10	0.907263
TLU	1.01	0.988611
AVERAGE	**1.34**	**0.782**

Vol. 14(1), pp. 28-43, January-March 2022
DOI: 10.5897/JENE2021.0919
Article Number: 026860E68910
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and The Natural Environment

Full Length Research Paper

Silvicultural assessment of enrichment planting with commercial tree species after selective logging

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Received 11 November, 2021; Accepted 9 February, 2022

The integrity of forest stands in logging concessions depends on the logging method. Selective logging is the most commonly used method in the tropics, disturbing a considerable proportion of soil and canopy cover creating distinct sites for plant establishment. The objective of this study was to evaluate the silvicultural requirements in terms of light and moisture of seedlings of some commercial tree species used for enrichment planting. This study was carried out in two Forest Management Units in the East Region and a shade house at the University of Buea campus in the South West Region of Cameroon. 15 of the 20 most exploited species were selected for the assessment of their seedling functional performance. Nineteen log yards with their corresponding skid trails were selected randomly for enrichment planting. Monthly height measurements of the seedlings were recorded for 34 months. The shade house experiment had an unbalanced factorial experiment incorporating light and moisture. The growth rate in height was significantly higher in log yards (3.8 cm/month) and least under the forest canopy (1.2 cm/month). The growth rate in height was highest under high light and high moisture in *Pterocarpus soyauxii* (13.3 cm/month) and least under low light and high moisture in *Entandrophragma cylindricum* (0.7 cm/month). Mortality was highest under the forest canopy (11.1%) and least in the skid trails (0%). The results indicated that plant species should be planted according to their light and moisture requirements during enrichment planting at the seedling stage and for a sustainable forest management.

Key words: Enrichment planting, log yards, skid trails, shade house, under forest canopy.

INTRODUCTION

Tropical forests are very diverse in terms of composition, structure and functioning and serve as habitat for heterogeneous animal and plant species (Rhett., 2019). They control the climate, provide hydrological services,

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controls erosion in the area where it is located and provides many timber and non-timber products, that are indispensable to man's livelihood (Dkamela et al., 2009; Blanco and Yueh-Hsin, 2012; Megevand et al., 2013). Forests are thus very essential for life on earth and therefore deserve wise use and conservation for the benefit of rural people in particular who are directly dependent on the forest and for the benefit of humanity in general (Biswas, 1993). However, there has been increasing awareness and concern about the rapid rate of deforestation and forest degradation in developing countries caused by anthropogenic activities like logging, shifting cultivation and urban development.

The integrity of forest stands in logging concessions depends on the method applied in logging. Selective logging is one of the most common forms of forest use in the tropics and in Cameroon in particular with only six logged species accounting for 75% of total timber volume (Ruiz Pérez et al., 2005). This over dependence on some particular species will eventually lead to the extinction of these species in the forest ecosystem altering the natural regeneration of the forest ecosystem dynamics making the ecological and biological complexity of the forest to be profoundly disrupted (Panayotou and Ashton, 1992). This depletion of logged species is of growing concern making some of these species to be listed on the International Union for Conservation of Nature (IUCN) red list (Bourland et al., 2012).

Putz et al. (2012) emphasized in their meta-analysis that although 85-100% of species of mammals, birds, invertebrates, and plants remain after selective logging, the timber volumes decline by about 65% after the first harvest if the same species are again harvested (Deckker and de Graaf, 2003). Thus though logging concessions could be used as a conservation intervention to protect forests (Gaveau, 2014), the timber volume and biodiversity may decline after selective logging To conserve the biodiversity of the forest after selective logging, an enrichment of the forest with exploited species is of outmost importance.

Present forest composition may be largely due to natural selection operating in the past but we can expect major changes to occur in the edaphically extreme sites and those already with limited resources after logging thus hindering regeneration of these species. The main constraint in tropical forests over plant growth and regeneration is the low light intensity at the canopy understory allowing only about 2-3% of the Photosynthetically Active Radiation (PAR) to reach the understorey (Gastellu-Etchegorry et al., 1999). In selectively logged tropical forest, the creation of skid trails and log yards can disturb a considerable proportion of soil and canopy cover during timber harvesting creating distinct sites for plant establishment. Forest recovery in these sites may be substantially retarded due to substrate compaction by heavy machinery use and lack of onsite plant propagules after topsoil disturbance creating a more heterogeneous structure with patches of felling gaps, skid trails, and log yards (Fimbel et al., 2001; Putz et al., 2001). Large openings are subject to invasion by understory shrubs, lianas and herbs that can be an obstacle to tree regeneration by competing with the seedlings of slow growing economically important tree species (Mokake et al., 2018). The logged forest might therefore gradually be replaced by relatively species-poor forests dominated by pioneer species and over time by more diverse mixtures of later successional species, and ultimately the climax forest will re-establish (Chazdon, 2014); thereby affecting its biodiversity.

One approach to recover the original forest is simply to protect these forests and allow nature to take its course; but results from the natural regeneration assessments indicate competition of the seedlings of timber species with the dense undergrowth of lianas, strubs and herbs for nutrients, moisture and light (Vieira and Scariot, 2008; Mokake et al., 2018). Silvicultural interventions including planting of high-value species are therefore necessary to overcome the relative depletion of commercial tree species, to compensate for the slow growth rate, and to ensure a future commercial timber value of the forest (ITTO, 2002) thereby reestablishing or conserving the timber biodiversity of forest stands. Through these interventions, it may be possible to enhance the rate of recovery and, moreover, deliberately manipulate forest composition to meet particular management objectives (Lamb, 2011).

Enrichment planting is a method of silvicultural management process of supplementing natural regeneration with seedlings of commercial and indigenous species (Martinez-Garza and Howe, 2003; Paquette et al., 2006a). Unfortunately, baseline information about ecological processes and the specific growth requirements of many of the commercial species that are available for planting is still very limited (Thomas and Chuyong, 2006; Paquette et al., 2006b). Also many enrichment planting trials in Africa were based on a few or single species (e.g., *Khaya spp*., *Tarrietia utilis*, Dupuy and Koua, 1993) sometimes planted on huge areas (e.g., *Aucoumea klaineana* in Gabon, Brunck et al., 1990). During enrichment planting, species mixtures are desirable for both improving biodiversity and the range of goods and services as well as limiting pest-induced damages (Piotto et al., 2004; Potvin and Gotelli, 2008). Different kinds of mixtures exist ranging from simple mixtures consisting of two or more species planted in single-species blocks or rows (Stanturf et al., 2014). Such mixtures are useful on sites with distinct gradients in environmental factors such as drainage or light. However, it is necessary that these species be planted in specific sites according to their growth requirements (Stanturf et al., 2014). Avon et al. (2013) indicated that, openings created along skid trails can lead to competition

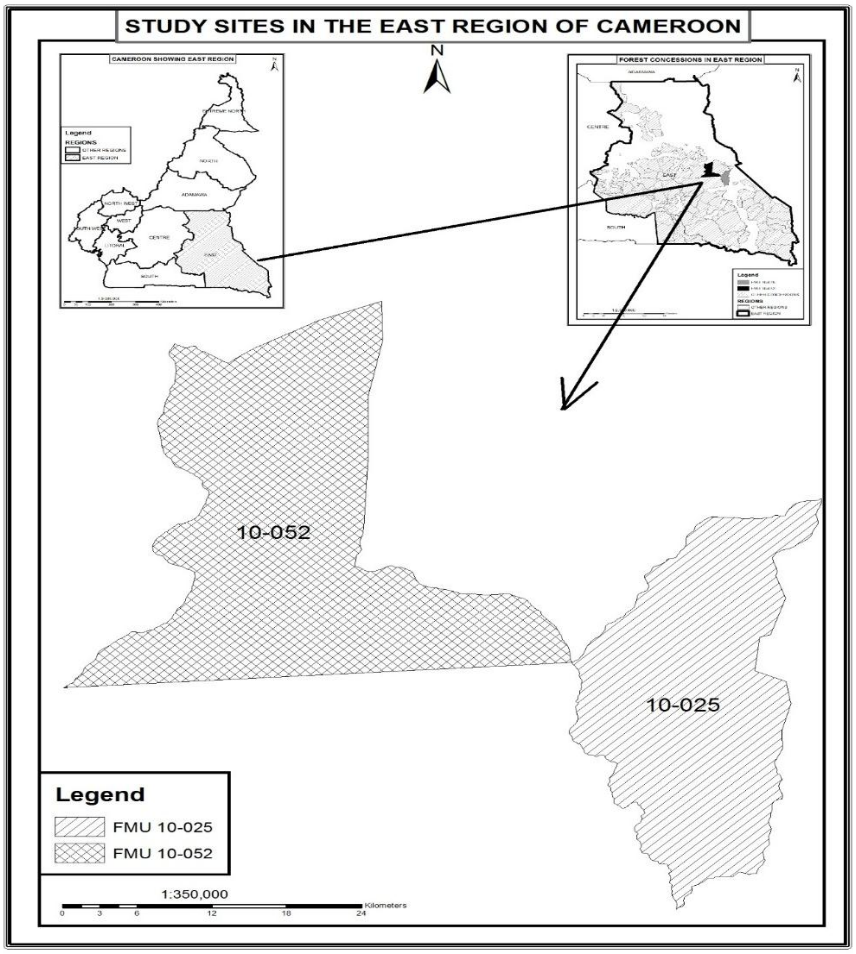

Figure 1. Study site (Localization of FMUs 10-025, and 10-052 logging concessions in the East Region of Cameroon).

sequences between shade-tolerant and shade-intolerant species which in turn affect natural regeneration. Therefore care needs to be taken on the type of species planted on the different sites created during logging. However, there is little data on site tolerance and growth of timber species used for enrichment planting after selective logging in Africa (Dupuy and Mille, 1993; Piotto, 2008; Doucet et al., 2016). Most enrichment plantings carried out are not reported and are not species and site specific to edaphically extreme sites created by logging. Therefore knowledge of the growth requirements of the seedlings of commercial species are necessary if they have to be incorporated into any enrichment planting scheme. The objective of this study was to evaluate the silvicultural requirements in terms of light and moisture of seedlings of some commercial tree species using functional traits to predict species performance under uncontrolled environment of different stand conditions (e.g., log yards, skid trail and under forest canopy) and a controlled environment in a shade house experiment.

MATERIALS AND METHODS

Study sites

An enrichment planting was established in two Forest Management Units (FMU) (FMUs 10-052 and 10-025) in the East Region of Cameroon (Figure 1) while the shade house experiment was carried out at the University of Buea main campus in the South West Region of Cameroon (Figure 2). The East Region occupies the Southeastern portion of the Republic of Cameroon. It lies between latitude 3°08 to 3°21 North and longitude 14°31 to14°52 East. It is bordered to the East by the Central African Republic, to the South by the Republic of Congo, to the North by the Adamawa Region, and to the West by the Centre and South Regions. It has an area of 109,011 km² with its soil predominantly ferrallitic, rich with iron and red in colour. The East Region has a wet equatorial climate with high temperatures (24°C on average) and a lack of

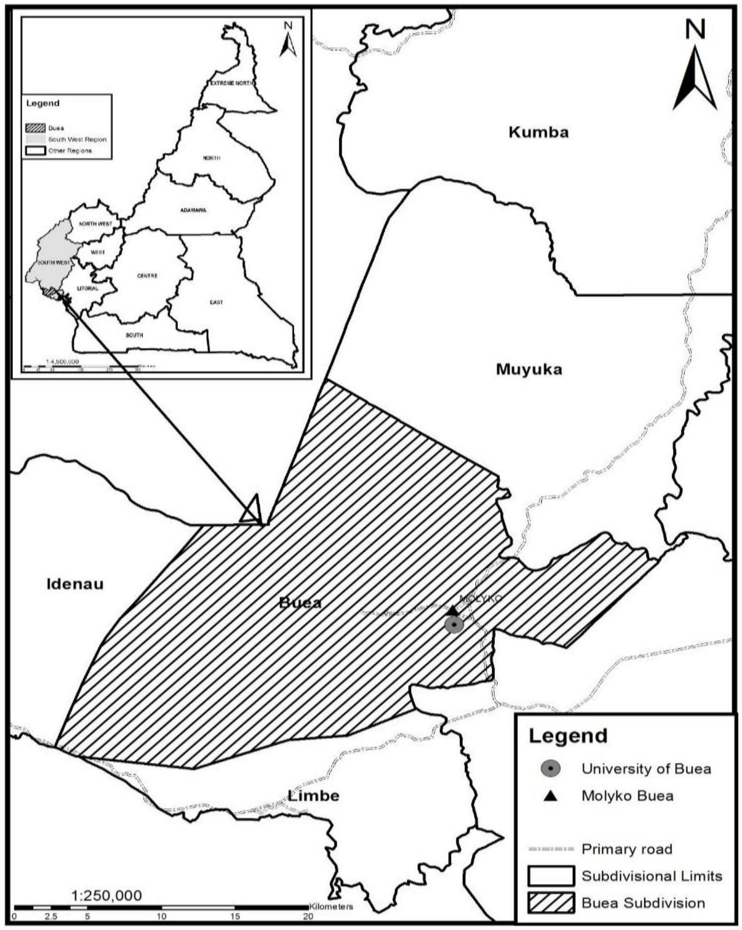

Figure 2. Location of the shade house experiment in the South West Region of Cameroon.

traditional seasons. Instead, there is a long dry season from December to May, a light wet season from May to June, a short dry season from July to October, and a heavy wet season from October to November (Fitzpatrick, 2002). Relative humidity and cloud cover are relatively high, and annual mean precipitation 1500-2000 mm except in the extreme eastern and northern portions, where it is slightly less. Relative humidity is highest in the month of June and lasts till the month of December (Fitzpatrick, 2002).

On the other hand, the shade house experiment was carried out in the South West Region of Cameroon at the University of Buea main campus located in the Fako Division (Figure 2) and in the coastal belt of the Gulf of Guinea (Cronin et al., 2014). Buea is located at Longitude 4° 09' North to Latitude 9° 14' East, having a distance of approximately 823 km from the East region where the seedlings were harvested (Google Maps) and a humid tropical climate with a rainfall not greater than 50 mm over a 5 months span (Oates et al., 2004). The climate is strongly seasonal, with one pronounced dry season between December and February and a long wet season from march to November (Newbery et al., 2006). The site has a precipitation of 100 mm each month which peaks in August (Cronin et al., 2014). The mean annual temperature is about 25^0C (Oates et al., 2004). The relative humidity of the area is between 75 and 85 % throughout the year on the South Western side of Mount Cameroon due to the coastal influence and the incidence of mist and orographic cloud formation (Cronin et al., 2014). The soils are mainly volcanic which are relatively fertile (CDC, 1997). The Mount Cameroon region lies within the tropical rainforest of West Africa. According to the different agro ecological zones in Cameroon, the South West and East Region both belong to the tropical rain forest. However, the South West Region has a monomodal rainy season while the East Region has a bimodal rainy season. This is the more reason why the shade house experiment could conveniently be carried out in the South West Region.

Selection of commercial species used in controlled and uncontrolled environments

15 of the 20 most exploited species in Cameroon were selected based on the seeds and seedlings found on the forest floor for the assessment of their seedling functional performance in both natural forest stands (uncontrolled environment) and shade house (controlled environment) (Table 1).The Fabaceae had 4 species, Sterculiaceae had 3 species, and Meliaceae had 2 species; while the Sapotaceae, Combretaceae, Lecythidaceae, Irvingiaceae, Ochnaceae and Moraceae were represented by a species each (Figures 1 and 2).

Table 1. Commercial tree species and number of their seedlings used in controlled and uncontrolled environments.

Econimically important tree species	Family	Common name	LYs	STs	UFC	SH	Total
Triplochyton scleroxylon K.Schum.	Sterculiaceae	Ayous	174	25	24	0	223
Mansonia altissima (A.Chev.) A. Chev.	Sterculiaceae	Bete	55	13	24	12	104
Aningeria altissima (A. Chev.) Aubrév. and Pellegr.	Sapotaceae	Aningre	82	19	24	9	134
Terminalia superba Engl. and Diels.	Combretaceae	Frake	13	4	24	28	69
Entandrophragma cylindricum (Sprague) Sprague.	Meliaceae	Sapelli	76	20	24	19	139
Erythrophleum sauveolens A.Chev.	Fabaceae	Tali	47	15	24	16	102
Petersianthus macrocarpus (P.Beauv.) Liben.	Lecythidaceae	Abale	0	0	0	3	3
Klainedoxa gabonensis Pierre.	Irvingiaceae	Eveuss	0	0	8	0	9
Pterocarpus soyauxii Taub.	Fabaceae	Padouk rouge	93	15	24	9	141
Afzelia africana Sm. ex Pers.	Fabaceae	Doussie	3	3	0	0	6
Cylicodiscus gabonensis Harms	Fabaceae	Okan	6	0	0	0	6
Entandrophragma excelsum (Dawe and Sprague) Sprague	Meliaceae	Tiama	1	0	0	0	1
Lophira alata Tiegh. ex Keay	Ochnaceae	Azobe	0	0	0	7	7
Milicia excelsa (Welw.) C.C. Berg	Moraceae	Iroko	0	2	0	0	2
Eribroma oblongum Mast.	Sterculiaceae	Eyong	0	0	24	0	24
TOTAL			550	116	200	103	969

LYs = log yards, STs = skid trails and UFC = under forest canopy, and SH= shade house.

Raising of seedlings for enrichment planting and shade house experiments

All the seedlings and seeds for this study was collected from the forest of the East Region. Seedlings for the enrichment planting were collected from the nursery of the National Forestry Development Agency (ANAFOR) located in the FMU 10052 (Plate 1). For the shade house experiment, wildings of *Lophira alata, Pterocarpus soyauxii, Entandrophragma cylindricum,* and *Petersianthus macrocarpus* were collected from the forest floor in the East Region of Cameroon. The seedlings were of that year's seed rain as cotyledonous scares were still very visible. These were wrapped in a mixture of top soil and sand and watered every two hours. Upon getting to the shade house, they were immediately transplanted in to black polythene bags (18 x 17 x 15 cm) filled with top soil. The seedlings of *Erythrophleum sauveolens, Klainedoxa gabonensis*, *Mansonia altissima* and *Terminalia superba* were raised from the seeds of these species collected from the forest of the East Region of Cameroon.

Seeds having a thick seed coat were pre-treated before sowing into the germinator. These included the seeds of *Erythrophleum sauveolens*, which were treated in 10% of concentrated Sulphuric acid for 10-15 minand *Klainedoxa gabonensis* which were soaked in water for three days. The seeds were planted at 1cm depth in a germinator of 1 m × 50 cm and watered daily with the use of an 11 L watering can, in order to maintain the moisture of the soil (Plate 2). The germinator was sheltered at 2 m height with 70% shade cloth spread wide overhead to block direct sunlight. New germinants were censured at 2 days intervals for 30 days as hypocotyls emerged above the soil surface. However some species had no seedlings that germinated, maybe due to the fact the transportation conditions were not favorable enough for the specific species. The germinated seedlings were then transplanted into 18 x 17x 15 cm black polythene bags filled with top soil.

Enrichment planting of seedlings under different stand conditions in the East Region of Cameroon

Each FMU (10-052 and 10-025) has an average of 50-60 small log yards with an average area of 1,050m^2 with many skid trails. Nineteen log yards (LYs) with their corresponding skid trails (STs) were selected randomly for enrichment planting with seedlings of the selected timber species. Seedlings of 10 of the 15 selected species for the study were used for the enrichment planting (Table 1). The

Plate 1. Seedlings in the ANAFOR nursery before transplanting in the log yards and skid trails in the East region of Cameroon. a: *Entandrophragma cylindricum* seeds in the germinator, b: *Pterocarpus soyauxii* seedlings in the germinator, c: pretransplanted *Pterocarpus soyauxii* seedlings from the germinator, d: *Entandrophragma cylindricum* seedlings, e: *Triplochyton scleroxylon* seedlings, f: partial view of nursery site.

leaves of the seedlings were prunned and planted using the line method with a spacing of 5 × 5 m in log yards, skid trails and under the forest canopy. These seedlings were tagged in order to differentiate them from already established and germinating seedlings on the forest floor. A total of 666 seedlings were planted in 19 Log yards (Lys=550) with their corresponding skid trails (STs=116) and 200 under the forest canopy (Table 1). Monthly height measurements of the seedlings were recorded using a metric tape over a period of 34 months (March 2012-December 2014).

Shade house experiment in the South West Region of Cameroon

The shade house was constructed with a Tildnet netting material (Tildnet, UK). A Photosyntheically Active Radaition (PAR) quantum sensor (Skye, USA) was used to measure the amount of light intensity available for the plants. An amount of 65% of sunlight was available to the plants. The three light levels were obtained by varying the layers of the netting material as follows:

(i) High: no netting of approximately 100% Photosyntheically Active Radaition (PAR);
(ii) Medium: single layer of Tildnet netting of approximately 65% PAR;
(iii) Low: double layers of Tildnet netting approximately 20% of PAR.

The moisture levels were as described by Hall et al. (2003);
(i) High: watering with 200 ml of water twice a week
(ii) Low: watering with 200 ml of water once a week.

The seedlings of 8 of the 15 selected exploited species were used for the shade house experiment (Table 1). The unbalanced factorial experiment incorporated two factors: light with three levels (high, medium and low) and moisture with two levels (high and low) giving a six treatment combinations (Table 2). The layout was in three blocks with three replicates. Rain was prevented from adding to the moisture level by placing a transparent plastic sheet atleast one meter above the seedlings. A total of 103 seedlings were used for the shade house experiment and monthly height measurements were recorded over a duration of six months from June 2014 - December 2014.

Data analyses

Growth rates in height of seedlings were determined as described by Hunt (1982);

(i) Absolute growth rates of seedlings

$$\text{Absolute growth rate} = \frac{\text{Log (H2)} - \text{Log (H1)}}{\text{t2} - \text{t1}}$$

Plate 2. Germinating seedlings of some commercial timber species in the germinator for the shade house experiment. a=*Mansonia altissima*, B= seedlings of *Mansonia altissima*, C=germinating seeds of *Alstonia boonei*, D= seedlings of *Alstonia boonei*, E=germinating seeds of *Erythrophleum sauveolens*, F=seedling of *Erythrophleum sauveolens.*

Table 2. Treatments following combinations of the factorial levels for light and moisture in the shade house experiment.

Moisture	Light		
	High	**Medium**	**Low**
High	HLHM	MLHM	LLHM
Low	HLLM	MLLM	LLLM

HLHM= High Light and High moisture, HLLM= High Light and Low moisture MLHM=Medium Light and High moisture, MLLM= Medium Light and Low moisture LLHM=Low Light and High moisture LLLM= Low Light and Low moisture.

(ii) Relative growth rates of seedlings

$$\text{Relative growth rate} = \frac{\text{Log } ((H2)-(H1))}{t2-t1} \times 100$$

Mortality was determined following the approach of Hall and Bawa (1993);

(i) Mortality rates of seedlings

$$\text{Mortality} = \left(\text{In}\left(\frac{N0}{No-Di}\right)\right)/t1$$

Where No =total number of individuals and Di =number of death recorded.

A 2×3 factorial analysis was carried out for the shade house experiment to evaluate main effects and interactions of light and moisture. Means were determined for each species and the Kruskal

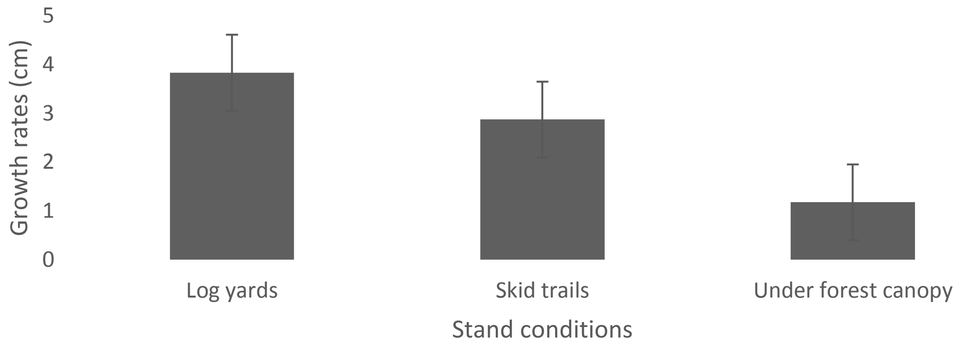

Figure 3. Growth rates in height in log yards, skid trails and under forest canopy in the East Region of Cameroon.

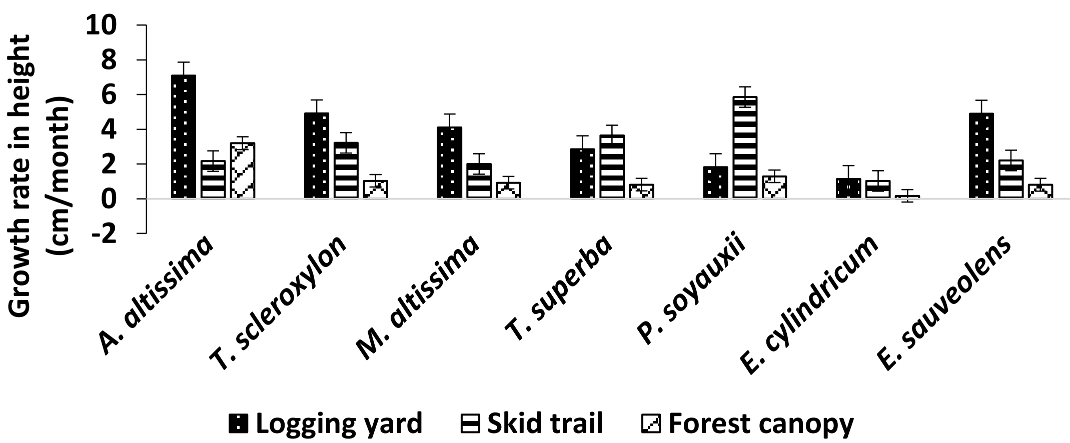

Figure 4. Species growth rate in height across sites. Growth rates in height (cm/month) of seedlings of species in log yards, skid trails and under forest canopy in the East Region of Cameroon.

Wallis and ANOVA tests were used to determine a significance difference between means for the enrichment planting and shade house experiments, respectively. All analyses were done using MINITAB version 17 (MINITAB 2010) and Excel 2013 (Microsoft Corporation 2013) with statistical significance fixed at P < 0.05.

RESULTS

Growth rates in height of seedlings in different treatments/experiment sites

Growth rates in height of seedlings were significantly different (p=0.01) between forest stand conditions with the log yards having the highest (3.8 cm/month) and the least under the forest canopy (1.2 cm/month) (Figure 3). Growth rates in height were also significantly different between species across the stand conditions (p=0.01) with the highest found in *Aningeria altissima* (7.1 cm/month) in the log yards while the least was in *Entandrophragma cylindricum* (0.2 cm/month) under the forest canopy (Figure 4). This is further confirmed by the growth rates in height of each species between the various stands found in Table 3.

Similarly in the shade house, absolute growth in height (cm/month) was significantly different between treatments and species (p=0.01). This was highest in *Pterocarpus soyauxii* (13.3 cm/month) under high light and high moisture condition while *E. cylindricum* had the least absolute growth rate (0.7 cm/month) under low light and high moisture condition. The relative growth in height on the other hand was highest in *A. altissima* (100 cm/month) under medium light and high moisture condition and least in *E. cylindricum* (1.9 cm/month) under low light and high moisture condition (Table 4) indicating that a combined effect of light and moisture has a significant effect on the growth rate in height of the species.

Apparently, *Terminalia superba* and *E. cylindricum*

Table 3. Growth rates in height (cm/month) of seedlings of selected species transplanted in log yards, skid trails and under forest canopy in some logging concessions in the East Region of Cameroon.

Species	Growth rates in height of seedlings (cm/month)		
	Log yards	Skid trails	Under forest canopy
Aningeria altissima	**7.1**	2.2	**3.2**
Triplochyton scleroxylon	4.9	3.2	1.0
Mansonia altissima	4.1	2.0	0.9
Afzelia africana	6.8	4.9	-
Terminalia superba	2.8	3.6	0.8
Pterocarpus soyauxii	1.8	**5.9**	1.3
Entandrophragma cylindricum	**1.1**	**1.0**	**0.2**
Erythrophleum sauveolens	4.9	2.2	0.8
Baillonella toxisperma	2.2	-	-
Cylicodensis gabunensis	4.0	-	-
Entandrophragma excelsum	4.6	-	-
Milicia excelsa	-	5.8	-
Klainedoxa gabonensis	-	-	0.4
Eribroma oblongum	-	-	2.6

-= absent.

Table 4. Absolute and relative growth rate in height (cm/month) of seedlings of selected species across treatments in some logging concessions in the East Region of Cameroon.

Species	Treatments											
	LLLM		LLHM		MLLM		MLHM		HLLM		HLHM	
	A*	R#	A	R	A	R	A	R	A	R	A	R
Petersianthus macrocarpus	1.6	6.4	-	-	5.8	11.7	-	22.1	9.4	34.4	-	-
Mansonia altissima	8.1	32.4	10.7	29.8	10.3	20.9	10.1	15.5	-	-	7.5	23.4
Terminalia superba	2.3	9.0	3.3	5.5	8.3	16.8	7.1	22.6	5.2	19.2	4.9	15.4
Lophira alata	6.8	27.2	5.9	16.5	8.5	17.2	10.4	24.5	-	-	-	-
Pterocarpus soyauxii	1.1	4.5	2.7	7.6	6.7	13.6	11.2	6.8	-	-	**13.3**	41.7
Entandrophragma cylindricum	1.4	5.6	**0.7**	**1.9**	3.4	6.8	3.1	4.2	3.8	13.9	3.2	10.0
Erythrophleum sauveolens	3.7	15	4.1	11.3	4.8	9.7	1.9	-	5.5	20.1	-	-
Klainedoxa gabonensis	-	-	6.7	18.6	-	-	-	4.4	-	-	-	-
Aningeria altissima	-	-	1.9	5.3	1.6	2.2	2.0	**100**	3.4	12.4	3.0	9.5

-=absent, A*= absolute growth rate, and R#= relative growth rate.

found in all treatments in the shade house had a linear increment in mean height with time in all treatments from the medium and high light conditions (Figure 5a and b, respectively). A confirmation that light was the main determining factor of growth.

Species seedling mortality

Mortality was not significantly different between species in the different stand conditions and between stand conditions (p =0.1). Mortality was generally very low for all the seedlings planted with no death recorded along the skid trails (0 %). Mortality was recorded for just 4 species; *Terminalia superba*, and *Baillonella toxisperma* (9.1%) in log yards, and *E. cylindricum* and *Eribroma oblongum* (11.1%) under the forest canopy. Thus mortality was highest under the forest canopy and least in the skid trails.

Similarly, mortality was not significantly different between treatments (p=0.4) and species under controlled conditions (p=0.5). Most species had a zero mortality. However the highest mortality occurred in *T. superba* (11.1%) under low light and high moisture condition and

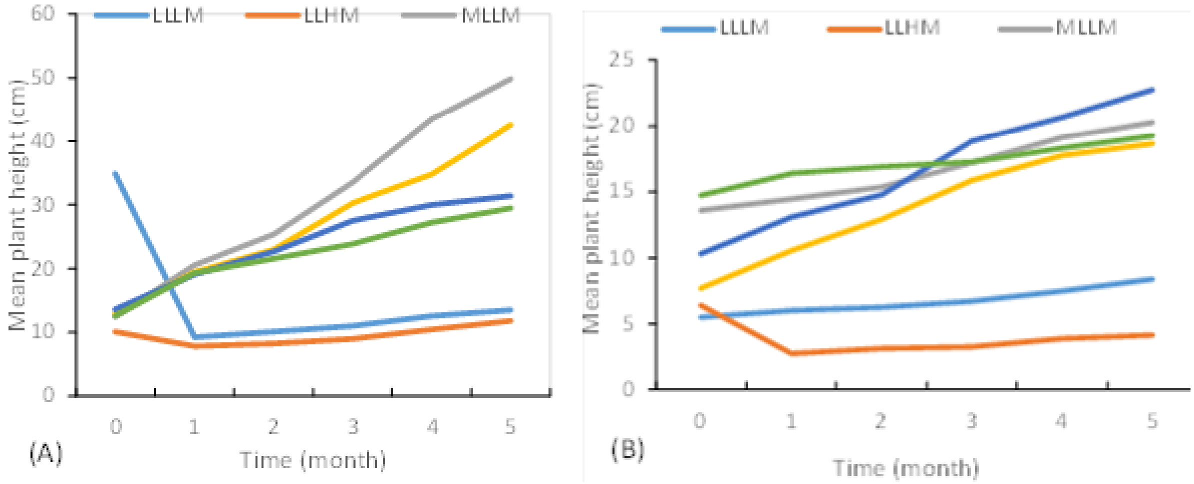

Figure 5. Mean height for different treatments over time for *Terminalia superba* (a) and *Entandrophragma cylindricum* (b) in the shade house.

Table 5. Relative mortality rate (%) between treatments and species of seedlings of selected species across treatments in the Shade house experiment in the South west Region of Cameroon.

Species	Treatments					
	LLLM	**LLHM**	**MLLM**	**MLHM**	**HLLM**	**HLHM**
Petersianthus macrocarpus	0	-	0	-	0	-
Mansonia altissima	0	0	0	0		0
Terminalia superba	5.6	11.1	0	0	0	0
Lophira alata	0	0	0	0	-	-
Pterocarpus soyauxii	5.6	0	0	-	-	0
Entandrophragma cylindricum	0	5.6	0	0	0	0
Erythrophleum sauveolens	0	0	0	0	0	-
Aningeria altissima	-	0	4.3	0	0	0

-=absent.

Table 6. Factorial analysis of the main effects and interactions of light and moisture on selected seedling growth rate under controlled conditions in the South West region of Cameroon.

Species	Source of variation	Mean	F-value	P-value
	Light	5.3	63.69	**0.001**
Growth rate	Moisture	0.3	3.18	0.125
	Light and Moisture	0.6	7.34	**0.024**

least in *Aningeria altissima* (4.3%) under medium light and low moisture condition with no deaths recorded under medium light and high moisture (conditions similar to skid trails) (Table 5). A factorial analysis indicated that light and a combined effect of light and moisture, had significant effects on the growth rates in height of these species in the shade house as shown in Table 6.

Specifically, the research findings revealed that light had a significant influence on all species for growth rate in height except for *A. altissima* ($p = 0.9$) and

Table 7. Factorial analysis of the interactions for growth rate in height between light and moisture.

Species	Source of variation	Growth rate in height		
		Mean	F-value	P-value
	Light	44.99	43.76	0.001
Mansonia altissima	Moisture	21.8	21.16	**0.004**
	Light*****moisture	17.4	16.95	0.003
	Light	20.6	34.18	0.001
Terminalia superba	Moisture	0.18	0.30	0.605
	Light*****moisture	1.01	1.67	**0.266**
	Light	54.2	499.59	0.001
Lophira alata	Moisture	1.44	13.34	**0.011**
	Light*****moisture	24.2	223.23	0.001
	Light	27.17	23.05	0.002
Pterocarpus soyauxii	Moisture	63.63	53.99	**0.001**
	Light*****moisture	59.07	50.12	0.001
	Light	7.61	14.17	0.005
Entandrophragma cylindricum	Moisture	0.99	1.86	0.22
	Light*****moisture	0.07	0.13	**0.879**
	Light	0.7	0.71	**0.529**
Erythrophleum sauveolens	Moisture	12.08	11.80	**0.014**
	Light*****moisture	9.3	9.11	0.015
	Light	3.8	0.12	**0.889**
Aningeria altissima	Moisture	23.5	0.00	0.99
	Light*****moisture	3.8	0.30	**0.750**

Erythrophleum sauveolens (p=0.5). Moisture on the other hand had an insignificant influence on the growth rate for all species except *Mansonia altissima* (p=0.01)*, Lophira alata* (p=0.01)*, Pterocarpus soyauxii* (p=0.01) and *E. sauveolens* (p=0.01). Finally a combined effect of light and moisture had a significant influence on the growth rate in height of *M. altissima*, *L. alata, P. soyauxii, Entandrophragma cylindricum* and *E. sauveolens* (Table 7). Taking into consideration the growth rates and factorial analysis, the growth requirements of these species at the seedling stage can be proposed; with the treatment of low light low moisture not having any species (Table 8).

DISCUSSION

Climatic factors like light, temperature, moisture, and nutrients affects the growth and developmemt of plant species (Yang and Tian, 2004). In the tropical regions, different climatic conditions may have developed under the canopies of great rain forest trees (Forseth, 2010). Because of this, plants are adapted to different types of light and moisture levels adapting easily to their environment. Changes in the light intensity, quality and duration and moisture content are therefore important features of tropical forests. These changes are related to openings in the forest canopy caused by selective logging, branch and tree fall (Girona et al., 2017). Various intensities of light and moisture content affect plant growth, reproduction, primary production and thus indirectly the structure of the forest. Tree growth is thus affected by many factors, such as silvicultural treatment, competition from neighbouring trees, and microclimate (Girona et al., 2017). Separating the effect of these factors can be difficult thus the main objective of this study; to determine the growth requirements of some commercial timber species used for enrichment planting. The main impact of these results would therefore relate to the canopy structure and light penetration, with secondary

Table 8. Shade tolerance of commercial species under controlled and uncontrolled environments in the study site of Cameroon.

Treatments	Species	Shade/Light tolerance	Implications
Low light low moisture		Shade tolerant species	Under forest canopy
Low light high moisture	*Klainedoxa gabonensis, Mansonia altissima*		
Medium light low moisture	*Terminalia superba*	Mid tolerant species	Skid trails
Medium light high moisture	*Lophira alata, Aningeria altissima*		
High light low moisture	*Petersianthus macrocarpus, Entandrophragma cylindricum, Erythrophleum sauveolens, Aningeria altissima*	Shade tolerant species but light demander at a certain level of seedling species development	Log yards
High light high moisture	*Pterocarpus soyauxii*		

effects on temperature and moisture content of vegetation and soils (Kammesheidt, 2002) as light limitation in tropical forests takes many years to re-establish in log yards following forest canopy opening.

The results of this study indicated a significantly higher growth rate in height of commercial species in log yards and least under forest canopy; as well as a higher absolute growth rate in height under high light and low moisture and least in low light and high moisture. This might be due to the light availability caused by the opening of the forest canopy after selective logging. Similar results were obtained by Sist and Nguyen-The' (2002), Brenes et al. (2004) and Ne Win et al. (2012). In Bolivia, Fredericksen and Mostacedo (2000) found the greatest growth rates of tree regeneration on areas with the greatest amount of light transmittance, including log yards and log roads.

The growth and development of plants are affected by environmental factors (Yang and Tian, 2004) which would have effects on plant morphology, especially blade size, texture, thickness and plant morphology (Huang et al., 2009). Among the various environmental factors, light is one of the most important variables affecting photosynthesis as well as plant growth and development (Smith, 2000). Plants require light not only as an energy source but also as a clue to adjust their development to environmental conditions which might be the log yards, skid trails or under forest canopy. During photosynthesis, absorbed energy is transferred to the photosynthetic apparatus, which is comprised of Photosystem I (PSI), Photosystem II (PSII), electron transport carriers (cytochrome b6f (cytb6f), plastoquinone (PQ), plastocyanin (PC)), and ATP synthase. Both quality quantity and duration of incident light can have drastic impacts on photosynthetic activity and photosystem adaption to changing light quality (Belkov et al., 2019) which eventually has an effect on the growth rate.

The greater canopy openness and soil disturbance in log yards favours tree regeneration in log yards than in skid trails (Denslow, 1995; Dickinson and Whigham, 1999). This high degree of light scavenging and likely light limitation found in skid trails and under canopy; confirms the reason why growth of these species is retarded significantly in the other sites as compared to that of the log yards. Also Skid trails (conditions similar to medium light and medium moisture) have higher ground damage as compared to log yards which are usually restored before enrichment. Asner et al. (2004) indicated higher ground damage in skid trails (7-12%) than in log yards (1%) of the total harvest area in the Eastern Amazon of Brazil. This in turn leads to soil compaction and therefore retards seed germination and thus seedling growth after enrichment in the skid trails which is not usually restored. Studies have shown that soil compaction can delay the establishment of seedlings (Pinard et al., 2000; Fredericksen and Mostacedo, 2000). However, if the soils are dry during logging, commercial tree species can regenerate abundantly on skid trails (Dickinson and Whigham, 1999; Dickinson et al., 2000). This is however not the case in this study as the soil type here is clay loam which is easily compacted by logging machines; thus soil compaction should be limited during logging. Also taking into consideration that the level of canopy openness is reduced in skid trails and almost absent under the canopy, the reduced evaporation of water easily leads to soil compaction.

Competing fast growing vegetation like weeds and lianas at ground level can result in growth failure of the slow growing exploited seedlings in skid trails (Ne Win et al., 2012). Asner et al. (2004) indicated canopy gap closure in skid trails (0.5 years post-harvest) recovered faster than the corresponding log yards (1.5 years post-harvest) from selective logging. Due to greater canopy openness and frequent use by logging trucks in the log yards, skid trails had greater competing vegetation than in log yards thus greater growth of competing vegetation in log yards. Breckage and Clark (2003) indicated similar results with seedling growth and survival higher in canopy gaps with forest types of under story removal; evident in log yards than in skid trails. Quang et al. (2020) confirmed that competition from saplings and trees that were situated outside the enriched areas emerged as a major source of competition in some plots. A significantly higher growth in skid trails than under forest canopy may be due to the reduced radiation found under the forest canopy. Similar results were obtained by Duah-Gyamfi et al. (2012) who studied the natural regeneration of timber species following selective logging in Ghana indicating that growth rates were higher in the main skid trails than in unlogged. In the skid trails, the amount of light is moderate keeping enough moisture necessary for the growth of seedlings. In this study no species died in the skid trails indicating the best growth condition for most seedlings in the forest.

Similarly in the shade house experiment, light was the main factor which had a significant influence on the growth of the seedlings of these species. These treatments mimic conditions found in the forest. Light availability in the forest depends on the level of disturbance of the forest canopy. The disturbance categories were characterized in terms of light availability, measured indirectly as canopy openness (Duah-Gyamfi et al., 2014). Log yards had the highest canopy openness, which indicates high light level than skid trails, which indicates the medium light level. Under the forest canopy, only 2-3% of PAR indicating the low light intensity.

However a combined effect of light and moisture had a significant influence on the growth of the seedlings. Most growing plants contain about 90 percent water. Also the light-responsive photosynthetic process is driven by the released electrons through the water-splitting reaction on the PSII side, followed by Nicotinamide adenine dinucleotide phosphate ($NADP^+$) reduction to NADPH, and proton flow into the lumen in order to generate Adenosine Triphosphate (ATP) (Ceccarelli et al., 2004). Generated NADPH and ATP serve as an energy source for the carbon fixation process in photosynthesis (Ceccarelli et al., 2004). This was confirmed by the relative growth rate being highest under medium light and high moisture while the least was observed under low light and high moisture. Furthermore, no deaths were recorded in the skid trails indicating that too much sunlight is not necessary for the seedlings of some of these species. Although light is necessary for the germination of seedlings, the quality quantity and duration of light will determine their survival in a particular environment.

This is in corroboration with the shade house and factorial experiments where most species had a significant growth from the medium light condition and an interaction between light and moisture had a significant growth rate. A linear increment in height over time in log yards is an indication of the presence of light process of photosynthesis after gap opening in the forest structure. This gap opening is also present in the skid trails which form a canopy faster than in the log yards leading to decrease in the growth of most species in the skid trials. This is corroborated by the fact that species like *E. cylindricum* and *T. superba* had a linear increment in all treatments from medium light; results are similar to the results obtained by Doucet et al. (2016) indicating their shade tolerance.

This is further confirmed by the highest mortality under the forest canopy than in skid trails and log yards. Chandrashekara and Ramakrishnan (1993) indicated that the higher irradiance in gaps results in better growth, regardless of the ecological category. According to Kobe (1999), the mortality of certain rainforest tree seedlings such as *Trophis racemosa*, *Castilla elastica*, *Pourouma aspera* and *C. obtusifolia* decreased with increase in light intensity (to 20% full sun). Chazdon et al. (1996), mentioned that light availability would be higher in the center of the gap (that is, in the logging yard) than in the gap edge (skid trails) or in the understorey of a forest. This therefore implies a higher mortality under forest canopy than in log yards.

The growth of these species under the different stand conditions also depends on the growth requirements of the specific species at the seedling stage. Some may be shade tolerant, mid tolerant or shade intolerant or better still shade bearers, non-pioneer or pioneer respectively (Hawthorne, 1995) or late or early-succession species. Restricted as seedlings to gaps, early successional species are light demanders (pioneer species) while late successional species grows under the forest canopy (shade bearers). Mid tolerant species are species which require gaps to develop beyond saplings. These are species that are obvious light-demanders, and typical trees of secondary forest and fallow, yet which exist as seedlings in the deepest shade of little-disturbed forest (Hawthorne, 1995; Antobre et al., 2021). Thus while some species grow in light, others persists grow under shade but do not grow appreciably in the shaded understory; accounting for the heterogeneous structure in tropical forest. The requirement of light for the germination of seeds of certain plant species prevents germination and thus not favourable for seedling establishment and growth (Fenner and Thompson, 2005). The light requirement of such seeds and seedlings acts as a mechanism that determines where and when germination takes place, and is important for survival of the plant species concerned, as it prevents stored seed reserves from being depleted. Some seeds germinate equally well in light and darkness, whilst others germinate better under only light or darkness (Chanyenga et al., 2012). Thus different plants have different light requirements for their growth and development.

The findings of this study indicates that the highest growth rate in *A. altissima* in log yards indicates that the species is a light loving early successional. This was confirmed by the shade house experiment where the species had its highest growth rate under high light and low moisture conditions. High light and low moisture are similar conditions in the log yards after gap opening.

Lemmens (2007) indicated that *A. altissima* thrives more on the driest soils in the semi-deciduous forests of tropical forests. Specifically this species had the highest growth rate in log yards and under the forest canopy this indicates the shade tolerance of this species since it can survive in both conditions. Also this is confirmed by the fact that in the shade house experiment, light did not have a significant effect on the growth of *A. altissima*. This indicates its shade tolerance at the seedling stage having fast growth under openings thus a pioneer species. The highest growth rate of *P. soyuaxii* in skid trails indicates that the species is shade intolerant and a light demander in corroboration with Khurana and Singh (2001) and Doucet et al. (2016) who indicated that *P. soyuaxii* was a non-pioneer and light demander. The species prefers moist and well drained soils with an average temperature of 23°C conditions similar to the log yards. Under the forest canopy, the soil is moist and there are situations of flooding with a temperature reduction which might impede the growth of these species. Also germination and seedling growth are rather fast in this species (Jansen, 2005). This is in corroboration with the results obtained in shade house experiment where *P. soyuaxii* had the highest growth rate in height under high light and high moisture conditions.

This is in contrast with *E. cylindricum* that had the least growth rate in skid trails and under the forest canopy. This may be due to the slow growth of this species with a growth rate of 20-40 cm/year (Kémuezé, 2008). This is an indication of its intolerance of shade and a non-pioneer light demander species (Doucet et al., 2016). Also this species is extremely sensitive to parasites (gall-forming insectsand/or shootborers) (Bosu et al., 2006; Opuni-Frimpong et al., 2008 and Doucet et al., 2016) which are usually persistent under the forest canopy and skid trails due to their high level of moisture as compared to the log yards. Such damage in fallow forests with canopy structure very similar to young plantations has also been reported by Hall (2008). The tradeoffs among survival, growth, and herbivory present a serious challenge for these species (Goodale et al., 2014). This is confirmed by the fact that in the shade house, the species had its best growth rate under high light and low moisture conditions and the fact that it did not have the least growth in log yards. Kémeuzé (2008) also indicated that seedlings of up to 2 years old require light shade but there after they should be gradually exposed to more light.

Mortality was highest in *T. superba* and *Baillonella toxisperma* in the log yards and *E. cylindricum* and *Eribroma oblongum* under the forest canopy. According to the shade house experiment, *T. superba* had the best growth rate under medium light and low moisture; confirming its shade tolerance. Kimpouni (2009) indicated that *T.superba* are often abundant along roadsides and in medium-sized forest gaps indicating they are usually found in areas of reduced light intensity. Also Doucet et al., 2016 indicated that this species is a pioneer species; thus its shade tolerance. Aslo a high mortality of species like *E. cylindricum* under the forest canopy is due to the high mortality of this species in the natural forest with less than 1% reaching 10cm diameter (Kémuezé, 2008). Doucet et al., 2016 indicated a high mortality rate of this species 690 days after enrichment planting. Taking this into consideration it is recommended that *T. superba, M. altissima* and *L. alata* should be planted in skid trails while *P. macrocarpus, E. cylindricum, Erythrophleum sauveolens, A. altissima* and *P. soyauxii* should be planted in log yards However these species might change their growth requirements after the seedling stage. Thus it is recommended that these sites be ameliorated through treatments, to minimize the effects of competition, compaction and other limitations on the regeneration and recovery of logged over forests after the seedling stage for a sustainable development.

Conclusion

The growth rate in height was higher in log yards than in skid trails and under forest canopy. This was due to the amount of light available when a gap is formed under the forest canopy. An interaction of light and moisture influenced the growth in height of these species in the forest ecosystem depending on their growth requirements. The results of this study therefore indicate that every species has a specific growth requirement; thus should be planted where appropriate during enrichment planting at the seedling stage. However some level of management is required to maintain the growth of these species for forest regeneration after logging. Thus further research should be carried out on the survival of these species after the seedling stage inorder to ensure their survival and growth while ensuring sustainable management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

Funding for the fieldwork was supported by the Internanational Tropical Timber Organisation (ITTO) grant, IDEA WILD grant for equipments, Ministry of Higher Education (MINESUP) mobility grant, the Ministry of Higher Education (MINESUP) research modernization allowance and the Fako America Scholarship. We thank Mr Bekolo Bekolo and Mr Njombe Ewusi of the National Forestry Agency (ANAFOR) for introducing us to the timber company and allowing us to use seedlings from their nursery, Mr Decolveneare of SFIL-GVI for allowing us use his forest concessions. We equally thank Mr Bounoungou Zibi for field supervision; Mr Blaise Njimbam, Mr Njoh Jean and Mr Nakoe Roger for field assistance and the staff of the forest company SFIL-GVI

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