Geosfera Indonesia
p-ISSN 2598-9723, e-ISSN 2614-8528
available online at : https://jurnal.unej.ac.id/GEOSI
Vol. 10 No. 3, December 2025, 240-258

https://doi.org/10.19184/geosi.v10i3.53735

Research Article

Exploring the Role of Socio-Economic Factors in Maintaining Biodiversity in Protected Biosphere Reserve

Henry Nuwarinda[1], Samuel Adewale Adelabu[1], Katlego Mashiane[1], Olufemi Sunday Durowoju[1]*, Colbert Mutiso Jackson[1], Abel Ramoelo[2]

[1]Department of Geography, Faculty of Natural and Agricultural Science, University of the Free State, Bloemfontein, South Africa

[2]Centre for Environmental Studies, Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Hartfield, Pretoria, South Africa

*Corresponding author : Durowoju.O@ufs.ac.za

ARTICLE INFO

Received :
4 August 2025

Revised :
3 November 2025

Accepted :
11 November 2025

Published :
22 November 2025

ABSTRACT

Socio-economic factors and conservation of biodiversity interplay is very important but understudied especially in the biosphere reserves. This paper evaluates the contribution of socio-economic factors in sustaining biodiversity in Vhembe Biosphere Reserve, which is abundant in biological diversity and heritage. The study employs the mixed-methods strategy in which the quantitative method is applied using the data provided by the Statistics South Africa (SSA) census on *education, employment,* and *income level* to determine the relationship between this data and the concept of biodiversity conservation. The factors are identified as major contributors to biodiversity destruction in the region. The data on loss of biodiversity were obtained through SSA and analysed using R-Studio with multiple logistic regression. The model that best fit was the *level of education*, the lowest AIC was 66.33, which indicates that the level of education is a significant contributor to the degradation of biodiversity. It is worth noting that the education levels of "*No schooling*", *"Some primary"* and *"Some secondary"* had a great impact on the biodiversity variable. "*No schooling*" was the most significant negative variable that influenced the loss of biodiversity. The research highlighted how environmental education and awareness can be utilised to conserve natural resources. The solution to these socio-economic driving factors would contribute to achieving a sustainable equilibrium between human development and the ecological conservation of the Vhembe Biosphere Reserve. The study will help in comprehending the effects of socio-economics on biodiversity and offer practical implications to policymakers and conservationists around the world.

Keywords: Biosphere; Biodiversity loss; Socio-economic Factors; Income levels

INTRODUCTION

Biospheres refer to the world's ecologies, which are a combination of living organisms and their interactions with the physical world. They are dynamic and interdependent systems that ensure life on Earth and demand close attention to be preserved to stay healthy and functional [1], [2]. They are useful in global, national and local economies such as agriculture, forestry, tourism [3], [4], energy production, transportation [5], mining and infrastructure development [6]. Their production and usage processes reflect socioecological and economic changes occurring at a larger scale where economic globalisation and imminent global land scarcity escalate the management challenges for their future course [7], [8]. Socio-economic growth requires more resource input and, thus, more biodiversity and natural resource consumption during production. Therefore, at the early stages of any developmental economy, humans use more biodiversity resources at the expense of resulting in environmental consequences that lead to destructive biodiversity effects [9], [10], [11]. It is widely acknowledged that nature, culture, and economic development are intricately linked and that naturally protected areas alone cannot halt biodiversity loss. Furthermore, the demand for food and other resources has increased in the past decades, calling for a more integrated approach to conserving biodiversity and sustainably, [12] and [13] defined a driver as any natural or human-induced factor or variable that is casually linked directly or indirectly to a measured change in a response variable that directly or indirectly causes a change in an ecosystem, where changes in ecosystem services can feedback to alter biodiversity drivers. A direct driver undeniably influences ecosystem processes, while indirect drivers operate more diffusely in adjusting one or more direct drivers [12], [14], [15], [16]. Some of the biodiversity loss critical drivers identified in other studies are climate change, agricultural production, fuel-wood collection, nitrogen deposition, livestock grazing, atmospheric carbon dioxide and biotic exchange [17], [18]. The consequences of these drivers vary in different ecosystems, and the various indirect drivers contribute in distinct ways to biodiversity loss in each location [19].

Land use activities like deforestation caused by agriculture expansion, road construction, and fuel wood extraction are some of the key drivers of biodiversity loss in Africa [20], [21], [22]. Specific biospheres provide ecosystem services such as provisioning, regulating, cultural and supporting services, not only for local communities but also for a large population outside their boundaries, as production and utilisation of biospheres continue to be influenced by intrinsic demands and policy decisions made at local, national, and international levels [23], [24], [25]. Biodiversity loss drivers and consumption of natural resource capital for economic gains are inextricably linked, stemming from the utilisation of biodiversity resources for economic advantages [26], [27], [28], [29]. Despite acknowledging the influential role biodiversity plays in supporting terrestrial ecosystes, biodiversity continues to decline at an unprecedented rate on Earth [30], [31], [32].

Several studies have alluded to the fact that anthropogenic activities such as shifting and extensive agriculture by smallholder and commercial farmers, intensification of subsistence and commercial farming in the past four to five decades, burning of biomass and mono-cropping, extensive use of synthetic fertilizers, disposal of herbicides and insecticides in given ecosystems affect terrestrial ecosystem negatively and led to the loss of natural and seminatural habitats and biodiversity loss [12], [33], [34], [35], [36], [37]. Reports have also gathered that biodiversity is often threatened by multiple interacting drivers that work over a period of time and these include but are not limited to increases in temperatures and severe events such as floods, droughts, and heat waves [38], [39]. Some studies indicated that biodiversity loss is also caused by several economic activities, including the location of activities, resource endowments and ecosystem conditions, available technologies and relevant policies [40], [41], [42], [43]. [44] posited that incomes derived from economic activities by individuals determine their level and nature of natural resource consumption and associated services.

[14] and [45] affirmed in their studies that demand for non-agricultural goods and services increases faster than demand for agriculture, which leads to a dramatic change in the structure of economic activities and ecosystem modifications. However, it was recorded that as people's income improves due to economic growth, they tend to shift to non-agricultural goods and services that improve their quality of life. While this was viewed as a positive shift towards pressure reduction on biodiversity ecosystems, some studies also posited that with economic growth, the industrial and service sectors of an economy grow much faster with a significant impact on biodiversity status [46], [29], [47], [48]. Furthermore, the under-pricing and undervaluing of natural resources influence terrestrial biodiversity loss, which suggests that if natural resources and associated ecosystems are

inappropriately priced, converting them to agriculture and other land-use forms is less costly than preserving them [49], [50], [51].

In many parts of Africa, a large share of the population lives in rural areas, often in low-income households that depend heavily on natural resources for their livelihoods. Livestock, wild foods, and wood are directly used by people to cook and heat, and this direct reliance puts pressure on local ecosystems that increases [52], [53], [54]. [12] also observes that the escalation of land use has already lowered biodiversity services in most regions of the world which is also evident at the local scale. Vhembe Biosphere Reserve has various types of diverse ecosystems that are native forests, savannas, grasslands, mountain escarpments, and wetlands, which sustain high biologic diversity [55]. Nevertheless, the area experiences an increasing pressure because of the growing settlements, agricultural practices, mining activities, and other land-based activities that cause loss of biodiversity [56], [57], [58], [59], [60]. Although the Vhembe Biosphere has an ecological significance, the loss of biodiversity in the region has not been quantified and very little has been done to investigate the socio-economic factors that induce biodiversity loss. As the burden of human activity increases, it has been necessary to have knowledge on how socio-economic conditions influence the outcomes of biodiversity. The research fills this gap by defining and evaluating the main socio-economic factors associated with the loss of biodiversity, which presents the evidence that can be used in the more specific and efficient conservation policies towards the Vhembe Biosphere Reserve.

METHODS

Study Area

The Vhembe Biosphere Reserve, which is the subject of the study, is situated in Limpopo Province in latitude 22 o 7 32 s to 23 o 34 14 s and longitude 28 o 39 32 s to 31 o 33 4 s (Figure 1). The reserve boasts of a variety of ecosystems and offers numerous ecosystem services. It has many endangered plant and animal species, with approximately twenty-three vegetation types or biotopes, many of which are either endemic or nearly so. The ecosystems of the region are savannah, grassland, native forests, and a number of wetland systems [55], [61], [62]. In recent decades, the economic development of the area has been very fast, which puts more pressure on natural resources. Human activities in the Vhembe Biosphere Reserve have been on high pressure in the last two decades, which include the growth of settlements associated with rural-urbanization, exploration and development of mining, forest harvesting, forest exploration as well as agricultural growth. Such practices have led to a decrease in biodiversity and changing of the land-use in the region [55], [63], [64]. The reserve has a mixture of different types of soils such as sandy, clay, and red-loam, with red-loam soils being the most widespread and more likely to be fertile. Southpansberg mountain range is one of the key topographical characteristics of the area that has a significant impact on the local climatic patterns. It influences precipitation, temperature, and humidity and determines the drainage system of the area and leads to rather high rates of rainfall The rainy season occurs mainly in summer, from November to March, with annual rainfall varying by location but generally ranging between 500 and 800 mm [61], [62].

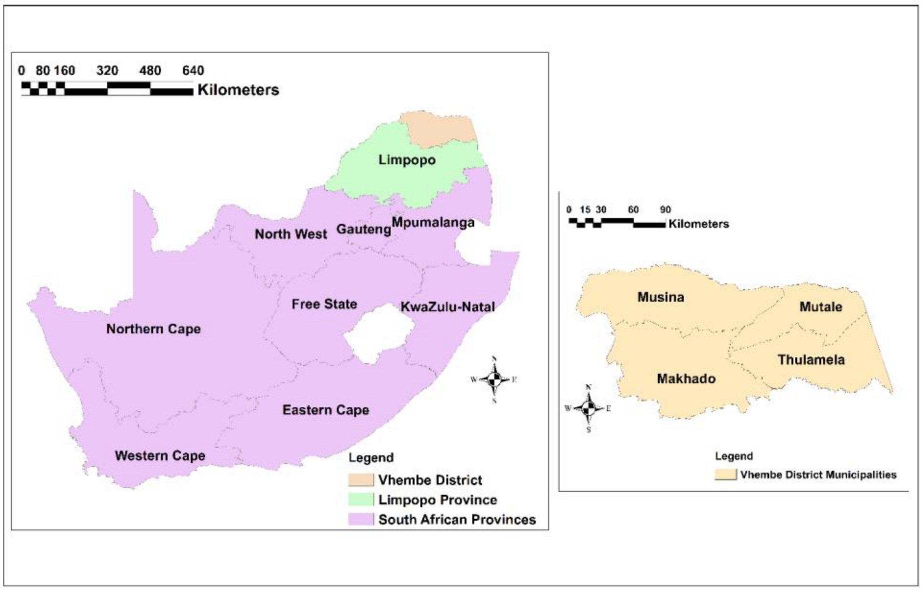

Figure 1. Study area map showing the location Vhembe District Biosphere

Biodiversity Data

In this research, the biodiversity data of losses and gains was generated using the Landcover maps of the South African National Land Cover repository; these maps were computed at a national level using Landsat and Sentinel 2 sensors, 1990-2013 and 2018, respectively. The landcover maps of South Africa can obtained from Department of Environmental Affairs-GIS data. Land cover change was calculated based on vegetation classes by calculating the amount of loss and gains in vegetation over the years above, where the barren land classes (pixels) were regarded as biodiversity loss (0) and vegetated classes were regarded as biodiversity gains (1).

Social-economic Data Preparation

In analysing drivers of biodiversity loss in the Vhembe biosphere, the study considered three (3) socio-economic variables data: income, employment and education levels for the population in the study area between 1990-2014 and 2014-2018, totaling 29 variables (Table 1). The selected socio-economic variables were used to analyse biodiversity loss in the study area, they were considered because they were assumed to be the most significant causes contributing to biodiversity loss [65], [66], [67]. These variables for various households in the municipality were obtained from the Statistics South Africa (SSA) census data repository [68].

Education levels data captured include; the “Non-schooling population”, “Some primary”- population that went to primary school, “Completed primary”- population that completed primary school, “Some secondary”- some of the population that completed secondary school, “Grade 12/Std10”- based on school going age population per ward resident between 15-64 years of age and “Higher”- the population that attended higher institution of learning. The captured employment levels were categorised into four categories: “Employed”, “Unemployed”, “Discouraged work seeker” and “Other not economically active people” per household in each ward (Table 1). For income levels, different income total amounts were captured, ranging from R5,000 to R600,000 of the total monthly incomes of the employed population per ward/household residents between 15 to 64 years of age (Table 1).

Biodiversity Loss Data Preparation

Biodiversity loss data under census classification were acquired through Statistics South Africa [68] and used in this study together with socio-economic variables through the use of statistical software R-Studio for regression analysis. The dependent variable used in the study was biodiversity loss, while the independent variables were the population's education, employment and income levels in the study area. Socio-economic data variables were selected based on their representative potential as biodiversity loss drivers in the Vhembe biosphere. Social-economic data sets were randomly split into 70% calibration and 30% validation for model performance evaluation during logistic regression analysis [69], [61], [70].

Data Analysis

In assessing the relationship between socio-economic variables and biodiversity loss, a logistic regression analysis model was employed to identify the drivers of change (dependent variables) using a set of independent variables categorised by the population's education, employment and income levels in the study area. The advantage of using logistic regression for the analysis in this study is that; it helps to model relationships between a response variable and one or more explanatory variables, where the outcome variable is discrete in taking on two or more possible values [71]. The logistic regression model does not assume linearity between independent and dependent variables and does not assume variables have equal statistical variances [72].

Logistical regression analyses biodiversity loss drivers as the outcome's variable 'natural resource change' had two categories where 1 (dependent variable) indicated change detected and 0 (independent variable) indicated no change detected, this assisted in data description and explanation of the relationship between one dependent variable driver and the independent variables. The data mining analysis package "Rattle" was run stepwise within an R-statistical and programming software implemented in R-studio [73].

The logistic regression equation is: $\log(p/(1-p)) = \beta 0+\beta 1X1+\beta 2X2+ \beta 3X3\ldots+\beta nXn$ .... (1)
where "p" is the probability of the dependent event occurring i.e. *"Biodiversity Loss"; X1* is the *"education levels", X2* is the *"employment levels"* and *X3* is the *"income levels".*

Hence, $\log(p/(1-p)) = \beta 0+\beta 1(Education)+\beta 2(Employment)+ \beta 3(Income)$ ....(2)

Validation of The Logistic Regression Model

In order to verify the effectiveness and integrity of the model, we took 30 per cent of the data to test the model using Area Under the Curve (AUC) and Receiver Operating Characteristics (ROC) curve, as argued in some of the research works. The coefficient of variation and the AUC were considered performance measures of the logistic regression [73], [74], [75]. The most popular metric to determine the accuracy of probability modelling results is AUC; where 1 and 0 denote good and poor performance of a model, respectively [76], [77], [78]. Using all the information created based on the predictors, the ROC curve is useful in showing the quality of the model performance, and a convenient indicator of the quality of models that is threshold-independent [79], [80], [45]. The usefulness of the AUC is that it provides the degree of effectiveness of a model in discriminating between locations that contain a species and those that do not, using the set of predictor variables in total [81].

Akaike Information Criterion (AIC)

AIC is the statistic that is frequently applied to compare models and determine which of them fits a particular dataset best [82]. It assists in determining the best fitting model by balancing goodness of fit with model simplicity, these are used to punish models that contain unnecessary parameters to mitigate the risk of overfitting. In reality, the model that has the minimal AIC is chosen, and it provides an optimal combination of accuracy and complexity [83], [84]. The AIC values would be computed in this study of models that included the socio-economic variables such as education, employment, and income levels to ascertain the most appropriate model to explain the primary cause of biodiversity loss in the Vhembe Biosphere Reserve.

The AIC value for a model is given by: $\mathbf{AIC = 2}\boldsymbol{k} - \mathbf{2ln(}\boldsymbol{L}\mathbf{)}$ .... (3)
where k represents the number of model parameters and L is the maximum likelihood of the model.

RESULTS

Descriptive statistics for all variables

Some of the long-term socio-economic data utilized in this research included education, employment, and income levels, which are the same variables used in the four district municipalities that comprise the Vhembe Biosphere Reserve. A descriptive statistics was used to analyze the minimum, maximum, mean, and standard error of each variable (Table 1). The outcomes reveal that there is a close relationship between the destruction of biodiversity and the level of education in the region. No schooling was the category of education that had the most negative impact on the conservation of biodiversity, which confirms the idea that low educational levels can be a contributor to exploitation and resulting decline of biodiversity. The conclusion of this study can be compared to other works [85], [86]. Moreover, a decrease in income levels has a strong influence on the loss in biodiversity, which is observed in certain studies [87], [88], and an increase in employment and income levels can reduce this effect.

Table 1. Descriptive statistics based on employment, income, and education levels in the study area

Variable Name	No: of Samples	Minimum	Maximum	Range	Sum	Median	Mean	Variance	Standard deviation	Coefficient of variance
F1990_2014_change	127	0	1	1	105	1	0.82	0.14	0.37	0.45
F2014_2018_change	127	0	1	1	105	1	0.82	0.14	0.37	0.45
Employment										
Employed	127	306	7294	6988	189368	1074	1491.08	1310080	1144.58	0.76
Unemployed	127	231	1888	1657	119489	932	940.85	130057.1	360.63	0.38
Discouraged work-seeker	127	40	1472	1432	66102	498	520.48	77908.49	279.12	0.53
Other not economically active	127	1331	5171	3840	387001	2978	3047.25	639890.4	799.93	0.26
Income levels ('000)										
No income	127	156	1841	1685	93412	702	735.52	81280.98	285.09	0.38
5	127	74	1343	1269	71570	551	563.54	46424.11	215.46	0.38
5-10	127	143	3414	3271	185907	1410	1463.83	327627.7	572.38	0.39
10-20	127	479	3976	3497	266966	2053	2102.09	317511.4	563.48	0.26
20-40	127	675	4972	4297	332586	2549	2618.78	628476.2	792.76	0.30
40-80	127	399	2311	1912	140085	990	1103.031	199037.4	446.13	0.40
80-150	127	216	1812	1596	82169	531	647	129898	360.41	0.55
150-300	127	91	2173	2082	58386	346	459.73	132632.4	364.18	0.79
300-600	127	18	1608	1590	30048	148	236.59	79402.83	281.78	1.19
Education										
No schooling	127	193	1872	1679	129697	974	1021.222	104550.1	323.34	0.31
Some primary	127	800	4208	3408	320283	2512	2521.91	370407	608.61	0.24
Completed primary	127	154	1449	1295	65602	489	516.55	26702.03	163.40	0.31
Some secondary	127	1564	5313	3749	375868	2865	2959.59	612038.5	782.32	0.26
Grade 12/Std10	127	406	2806	2400	158046	1155	1244.45	225898.7	475.28	0.38
Higher	127	88	2429	2341	66038	366	519.98	185159.5	430.30	0.82

Source: Author, 2025

Model Performance

During the statistical analysis, AIC models were generated based on dependent variable data used to compare and understand which of the models generated based on the given variables was the best fit to explain biodiversity loss in the study area. In our study, the education level AIC model has the lowest values of 66.333 (Figure 2), while others have higher values above the lowest baseline, with values of 71.311 and 74.545 for employment and income levels, respectively (Figures 3 and 4). Thus, the model is presented with the value of 66.333 as the best-performing model based on the data used.

SOCIAL-ECONOMIC DRIVERS OF BIODIVERSITY

Education Model

Under the model for education levels, certain variables were significant in explaining the changes in biodiversity loss, namely, *"No schooling", "Some primary"* and *'Some secondary"*, as indicated in Table 2. This is because their P-Values are (< 0.05). All the other variables show a weak significance against biodiversity loss (Table 2). Amongst the significant variables, *"No schooling", "Some primary", and 'Some secondary"* have P-values of *(p = 0.03 < 0.05), (p = 0.04 < 0.05) and (p = 0.04 < 0.05)* at *0.05, 0.01* and *0.01* significant level (α), respectively. The study findings reveal that, although having a minute regression coefficient (-0.0028548), *"No schooling"* is the most variable negatively influencing biodiversity among the significant variables with a *z-value of -1.81*.

Table 2. Education Variables

Variable	Estimate	Standard Error	Z value	P value	
No Schooling	-0.0028548	0.001572	-1.81	0.03	°
Some Primary	0.0028733	0.0014303	2.00	0.04	*
Completed Primary	0.0080506	0.005229	1.54	0.12	
Some Secondary	-0.0029348	0.0014763	-1.98	0.04	*
Grade 12/Standard	0.0002188	0.0020259	0.10	0.91	
Higher	0.0008569	0.0019546	0.43	0.66	
Significant codes	0 '***'	0.001 '**'	0.01 '*'	0.05 '°'	0.1 ' '1
AIC =66.333					

Source: Author, 2025

Under the education model in Figure 2, an AUC score of 1.0 was attained, an indication that the model correctly predicted all education variables and their significant contribution to biodiversity in the study area. It should, however, be noted that a score of 1 does not necessarily mean that the model is perfect; it can still have limitations and biases.

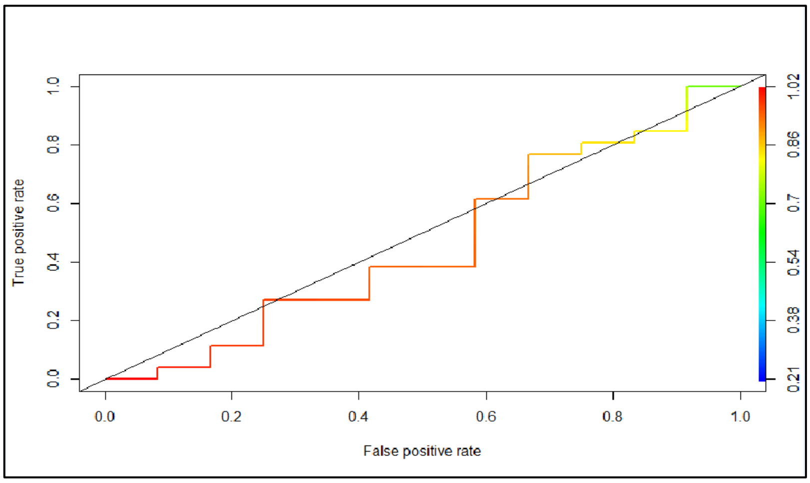

Figure 2. Education variables AUC

Employment Model

The number of *"Employed"* people in the study area positively and significantly influenced biodiversity with a *z-value of 0.15* (Table 3). The *"Unemployed"* and *"Not economically active"* people negatively influenced biodiversity with *z-values of -0.30* and *-0.93* respectively, although not significantly.

Table 3. Employment Variables

Variables	Estimate	Standard Error	Z value	P value	
Employed	6.10	3.91	0.15	0.87	*
Unemployed	-2.90	9.45	-0.30	0.75	
Discouraged work-seeker	1.84	1.35	0.13	0.89	
Others not economically active	-4.35	4.64	-0.93	0.34	
AIC = 71.311					
Significant codes	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 ''1

Source: Author, 2025

The Area Under the Curve (AUC) was generated as a measure of the accuracy of a model to predict the probable contribution of employment to biodiversity loss (Figure 3). An AUC score of 0.06 was observed for employment, this score is a poor score for biodiversity loss assessment in the study area.

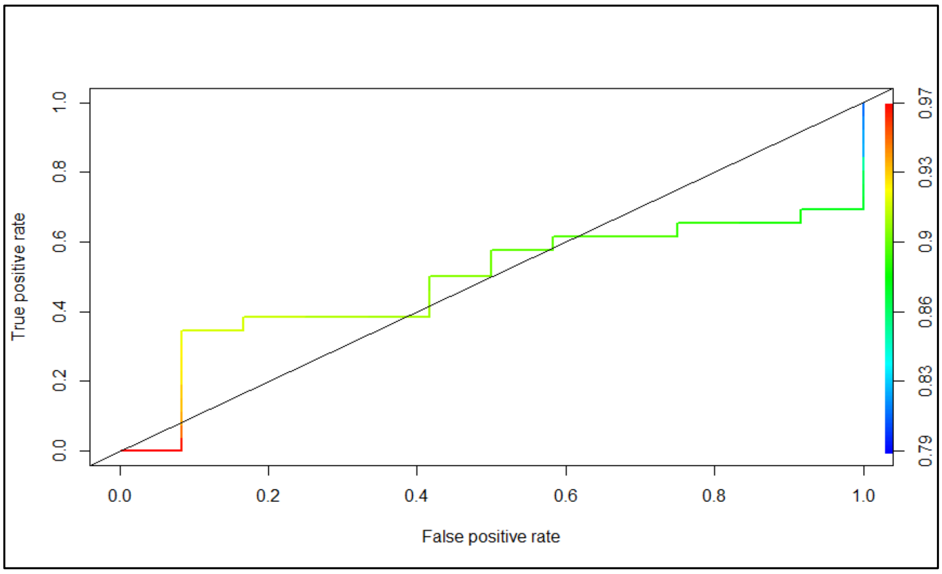

Figure 3. Employment variables AUC

Income Model

Our modelling algorithm showed that the income variables investigated in the study had no influence on the levels of biodiversity (Table 4). Five (5) income levels, *"5000"*, *"10000-20000"*, *"40000-80000"*, *"80000-150000"* and *"150000-300000"*, negatively influenced biodiversity with *z-values of -0.169, -0.538, -0.238, -1.022* and *-0.26* respectively, while four (4) income levels, *"No Income"*, *"5000-10000"*, *"20000-40000" and "3000000-600000"* positively influenced biodiversity.

Table 4. Income Level variables

Variable ('000)	Estimate	Standard Error	Z value	P value
No Income	0.0002179	0.0015212	0.143	0.88
5	-0.0007527	0.0044467	-0.169	0.86
5-10	0.0017471	0.0019013	0.919	0.35
10-20	0.0010326	0.0019183	-0.538	0.59
20-40	0.0004397	0.0014327	0.307	0.75
40-80	-0.0005725	0.00241	-0.238	0.81
80-150	-0.0034547	0.0033817	-1.022	0.30
150-300	-0.0013008	0.0049947	-0.26	0.79
300-600	0.0100561	0.0084491	1.19	0.23
AIC=74.545				

Source: Author, 2025

With an AUC score of 0.6 for income levels in our modelling algorithm, it was concluded that income variables did not have any significant impact on biodiversity loss in the study area (Figure 4).

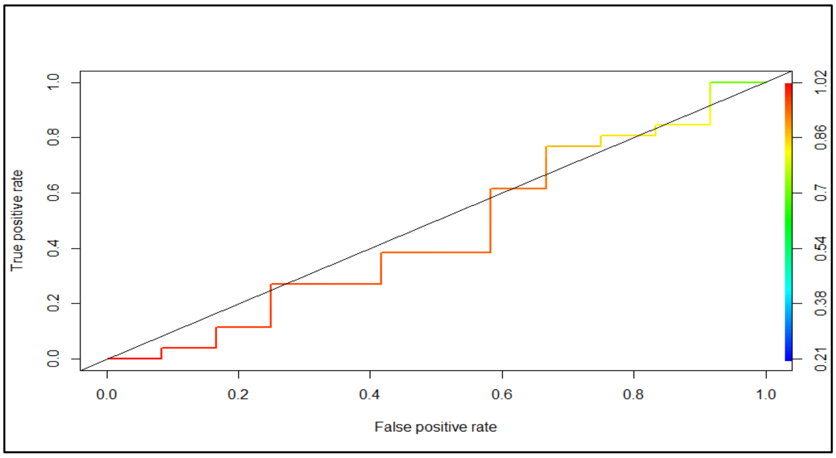

Figure 4. Income variables AUC

Pooled Model

All the social-economic variables in the overall model were insignificant (Figure 5). Employment variables were insignificant in influencing biodiversity. The *"Employed"* positively influenced biodiversity, while the unemployed and job seekers negatively influenced biodiversity. Only three income levels affected biodiversity: *"No Income", "10000-20000"* and *"80000-150000"* (Table 5). *"Some primary"* and *"higher education"* were the two variables that negatively affected biodiversity.

Table 5. Combined model variables: Employment, Education and Income Levels

Variable	Estimate	Standard Error	Z value	P value
Employed	0.0013271	0.0016916	0.78	0.43
Unemployed	-0.0004256	0.0024636	-0.17	0.86
Discouraged work-seeker	-0.0010778	0.0032387	-0.33	0.73
Others not economically active	-0.0029526	0.0015533	-1.90	0.05
No Income	-0.0005283	0.0059019	-0.09	0.92

5k	0.0027898	0.0092722	0.30	0.76
5-10k	0.0035607	0.0074885		0.63
10-20k	-0.0020423	0.007471	-0.27	0.78
020-40k	0.0017877	0.0067718	0.26	0.79
40-80k	0.00026873	0.0067727	0.39	0.69
80-150k	-0.0096403	0.0080541	-1.19	0.23
150-300k	0.0011744	0.0110546	0.10	0.91
300-600k	0.0062801	0.012062	0.52	0.60
No Schooling	-0.0042502	0.0074557	-0.57	0.56
Some Primary	0.0057813	0.0091062	0.63	0.52
Completed Primary	0.0021523	0.0123244	0.17	0.86
Some Secondary	-0.0059558	0.0081848	-0.72	0.46
Grade 12/ Standard 10	0.0075999	0.0091792	0.82	0.40
Higher	-0.0008197	0.0085947	-0.09	0.92
Significant codes. 0 '***'	0.001'**'	0.01 '*'	0.05' ° '	0.1 ' ' 1
AIC =107.28				

Source: Author, 2025

To test the accuracy of this model, the overall area under the curve receiver operating characteristic accuracy curve (AUC-ROC curve) was generated (Figure 5). Because of the high accuracy level of the AUC-ROC curve, it was concluded that there was a significant driver of biodiversity in the Vhembe Biosphere. In our study, the performance of the model based on independent data sets was 0.85. Based on the information used, 70% of the points were used for calibration, and 30% of the points were used for validation. ROC at **0** indicates that the model is weak, and at **1** it indicates that the Model is good. An AUC = 0.85 indicates high significant quantities of loss, which, in this case, indicates high estimates of biodiversity loss (Figure 6).

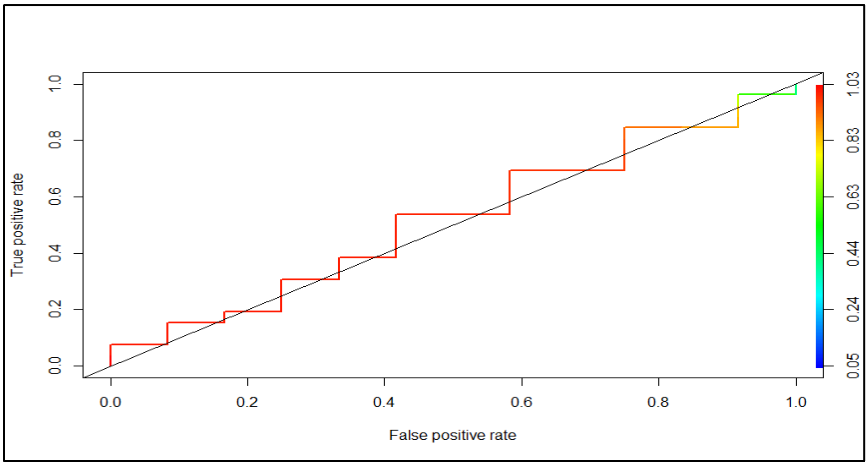

Figure 5. Combined model variables: Employment, Education and Income Levels AUC

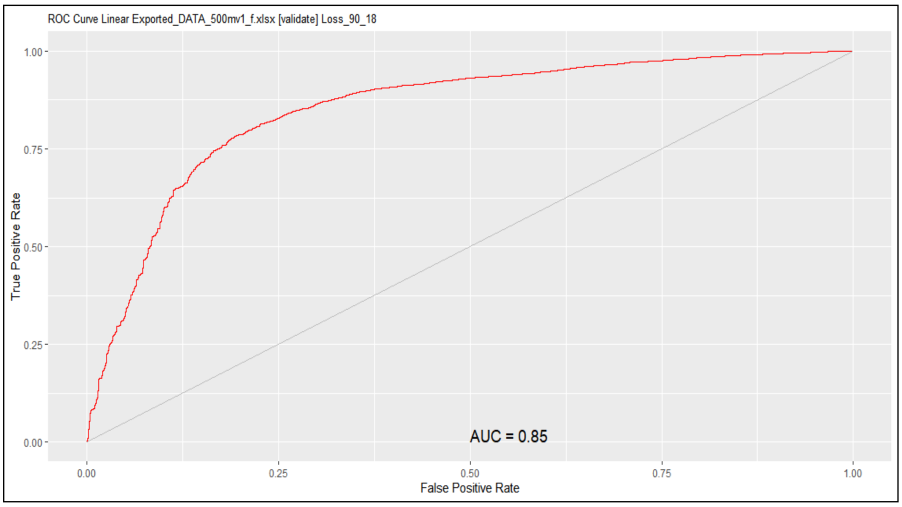

Figure 6. ROC Curve

DISCUSSION

Biodiversity loss is an intricate challenge that is influenced by a nexus of factors, including socio-economic variables which no single solution can be approved to address [89], [90]. Education levels of the population in a given biosphere are essential for the sustainable and equitable use of biodiversity and its conservation [91], [92]. Our analysis established that "No schooling" was a dominant variable negatively influencing biodiversity levels in our study area. This is a true reflection of the assertion that was made in some circles that limited education can contribute to biodiversity resource exploitation and loss in many ways [93]. For example, people lacking education may not truly understand the importance of preserving biodiversity resources or even be aware of the consequences of overexploitation of biodiversity resources as posited in some studies [94], [95], [96]. Moreover, the non-educated population people are most likely to engage in non-sustainable practices, such as deforestation and biomass burning, because of basic knowledge and skill to engage in sustainable biodiversity resource use practices, just as pointed out by [97] and [98]. Another stand-alone variable like climate change has the potential to threaten biodiversity directly by influencing biophysical variables that drive species spatial distribution and indirectly through social-economic changes that influence land use and human behaviour [99], [100]. Furthermore, the study found that "Some primary" contributed to biodiversity levels positively. This justifies the need for education and the fact that higher levels of education are associated with better knowledge and awareness of biodiversity resources and their importance [101], [102]. With more education levels, people have the opportunity to understand the consequences of their actions on biodiversity resources and encourage them to engage in sustainable management practices.

In the study, the results have established that income inequality contributes to the unsustainable use of biodiversity resources and overexploitation as alluded to in some studies [103], [104], where for example people with high incomes are likely to engage in unsustainable biodiversity use practices like deforestation, overfishing, massive urban development because they have greater access to resources to do so and may not likely be dependent on biodiversity for their livelihood [105]. This implies that wealthy individuals or corporations acquire land for intensive agriculture, mining, or real estate development, leading to deforestation, habitat fragmentation, and the loss of wildlife. Weaker families can face the situation when they use natural resources inadequately to satisfy their needs, including gathering firewood, hunting, or engaging in unsustainable farming, which over time may result in the destruction of the habitat and loss of biodiversity [103], [106]. In our research, however, the levels of income were diverse and did not have a considerable impact on the assemblage of biodiversity in the region.

Unemployment is also an important factor that affects the loss of biodiversity [107], [108]. Natural resources are often relied upon by people directly due to high unemployment. The hunting, fishing, and small-scale farming activities conducted in unsustainable forms can be burdensome to wildlife and their natural habitats, thus causing a further decrease in biodiversity [109], [107], [110]. In this paper, the unemployed and economically inactive individuals were identified to negatively affect the level of biodiversity in the Vhembe Biosphere Reserve. Unemployment is close to poverty and income inequality, which in turn stimulates the excessive use of natural resources [111]. Biomass burning and deforestation are some of the practices that economically inactive individuals can use to fulfill their daily needs, which are also involved in habitat degradation and loss of biodiversity [112], [113].

Study Implications on Society, Economy and Biodiversity

Loss of biodiversity interferes with key ecosystem functions like water purification, nutrient cycling, and pollination [3], [114], [115]. It also comes with economic price, such as reduced agricultural production and increased costs of sustainability or recovery of the lost ecosystem services. Social and cultural effects are also significant because, the loss of biodiversity can destroy the traditional knowledge and long-term practices associated with the use of natural resources[116], [117]. Healthy biodiversity on the other hand promotes sustainable development as ecological underpinnings upon which communities depend are maintained. It is therefore crucial to know the cause and effect of biodiversity loss. It offers the understanding of the impacts of human activities on the ecosystems and assists in the formulation of efficient conservation and sustainability plans [118].

CONCLUSION

This paper explored the connection that exists between socio-economic status and the conservation of the biodiversity in Vhembe Biosphere Reserve. The results indicate that socio-economic determinants have a significant impact on defining the outcome of biodiversity, which explains why conservation strategies that consider ecological and human realities are necessary. The education, income, and employment levels became valuable predictors of biodiversity patterns. The lack of education and high unemployment was associated with the expansion of biodiversity loss, which means that economic stability and environmental consciousness play a vital role in contributing the sustainable use of resources. Conversely, an increase in employment and income was more likely to reduce the rate of decline in biodiversity. Even though this paper examined the socio-economic drivers, past studies have indicated that there are other pressures like rural-urban expansion, mining activities, natural resources extraction, invasion of species and climate change, which contribute significantly to the loss of biodiversity. The Vhembe Biosphere case study has valuable lessons to local communities, government agencies, policymakers, and conservation practitioners. It requires collective actions to deal with socio-economic issues that promote the loss of biodiversity. Addressing these root causes, the stakeholders can contribute to a more proportionate relations between people and the environment, thus contributing to the long-term preservation of the biodiversity in the Vhembe Biosphere and other areas of this sort.

DECLARATIONS

Conflict of Interest

We declare no conflict of interest, financial, or otherwise.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent
On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

REFERENCES

[1] C. Folke, R. Biggs, A. V. Norström, B. Reyers, and J. Rockström, "Social-ecological resilience and biosphere-based sustainability science," *Ecology and Society*, vol. 21, no. 3, 2016, doi: 10.5751/ES-08748-210341.

[2] M. Schaafsma, "Natural Environment and Human Well-Being," 2021. doi: 10.1007/978-3-319-95981-8_104.

[3] A. G. Power, "Ecosystem services and agriculture: Tradeoffs and synergies," 2010. doi: 10.1098/rstb.2010.0143.

[4] E. A. Frison, J. Cherfas, and T. Hodgkin, "Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security," *Sustainability*, vol. 3, no. 1, 2011, doi: 10.3390/su3010238.

[5] S. J. Mcgrane, G. J. Allan, and G. Roy, "Water as an economic resource and the impacts of climate change on the hydrosphere, regional economies and Scotland," *Fraser of Allander Institute Economic Commentary*, 2018.

[6] V. Steinbach and F. W. Wellmer, "Consumption and use of non-renewable mineral and energy raw materials from an economic geology point of view," 2010. doi: 10.3390/su2051408.

[7] E. F. Lambin *et al.*, "The causes of land-use and land-cover change: Moving beyond the myths," 2001. doi: 10.1016/S0959-3780(01)00007-3.

[8] UNESCO, *Guidance for the assessment of ecosystem services in African Biosphere Reserves: A way forward to sustainable development*. Unesco Publishing, 2022.

[9] T. Wiedmann and M. Lenzen, "Environmental and social footprints of international trade," 2018. doi: 10.1038/s41561-018-0113-9.

[10] R. Mukwevho, S. A. Adelabu, A. Van Der Walt, C. M. Jackson, and O. S. Durowoju, "Uncovering critical windows: Phenological monitoring of Pteridium aquilinum for early detection and management in the Drakensberg," *Geomatica*, vol. 77, no. 2, 2025, doi: 10.1016/j.geomat.2025.100073.

[11] L. Kombani, S. A. Adelabu, O. S. Durowoju, and C. M. Jackson, "Uncovering the shifts: land surface phenology in Botswana from satellite observations," *Discover Sustainability*, vol. 6, no. 1, 2025, doi: 10.1007/s43621-025-00806-9.

[12] M. E. A. Millennium Ecosystem Assessment, "Ecosystems and human well-being ," vol. 5, Washington DC: Island Press, 2005, p. 563.

[13] R. Spake *et al.*, "Unpacking ecosystem service bundles: Towards predictive mapping of synergies and trade-offs between ecosystem services," *Global Environmental Change*, vol. 47, 2017, doi: 10.1016/j.gloenvcha.2017.08.004.

[14] G. C. Nelson *et al.*, "Anthropogenic drivers of ecosystem change: An overview," 2006. doi: 10.5751/ES-01826-110229.

[15] M. Bustamante *et al.*, "DIRECT AND INDIRECT DRIVERS OF CHANGE IN BIODIVERSITY AND NATURE'S CONTRIBUTIONS TO PEOPLE Coordinating Lead Authors: Lead Authors: Fellow: Contributing Authors: Review Editors: This chapter should be cited as: Chapter 4: Direct and indirect drivers of change in biodiversity and nature's contributions to people. In IPBES (2018): The IPBES regional assessment report on biodiversity and ecosystem services for the."

[16] A. R. Santos, "Ecosystem services and drivers of change in mangroves and seagrasses in Maputo Bay, Mozambique," 2021.

[17] O. E. Sala *et al.*, "Global biodiversity scenarios for the year 2100," 2000. doi: 10.1126/science.287.5459.1770.

[18] J. Xu and A. Wilkes, "Biodiversity impact analysis in northwest Yunnan, southwest China," *Biodivers Conserv*, vol. 13, no. 5, 2004, doi: 10.1023/B:BIOC.0000014464.80847.02.

[19] L. Maxim, J. H. Spangenberg, and M. O'Connor, "An analysis of risks for biodiversity under the DPSIR framework," *Ecological Economics*, vol. 69, no. 1, 2009, doi: 10.1016/j.ecolecon.2009.03.017.

[20] S. R. Freitas, T. J. Hawbaker, and J. P. Metzger, "Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest," *For Ecol Manage*, vol. 259, no. 3, 2010, doi: 10.1016/j.foreco.2009.10.036.

[21] S. L. Barradough and K. B. Ghimire, *Agricultural expansion and tropical deforestation: International trade, poverty and land use*. 2013. doi: 10.4324/9781315870533.

[22] A. L. Skowno, D. Jewitt, and J. A. Slingsby, "Rates and patterns of habitat loss across South Africa's vegetation biomes," *S Afr J Sci*, vol. 117, no. 1–2, 2021, doi: 10.17159/SAJS.2021/8182.

[23] J. Maes *et al.*, "Mapping ecosystem services for policy support and decision making in the European Union," *Ecosyst Serv*, vol. 1, no. 1, 2012, doi: 10.1016/j.ecoser.2012.06.004.

[24] N. Seddon *et al.*, "Biodiversity in the anthropocene: Prospects and policy," 2016. doi: 10.1098/rspb.2016.2094.

[25] C. M. Jackson, O. S. Durowoju, S. A. Adelabu, and S. A. Adeniyi, "An assessment of Kenya's forest policy and law on participatory forest management for sustainable forest management: Insights from Mt. Kenya Forest Reserve," *Trees, Forests and People*, vol. 19, 2025, doi: 10.1016/j.tfp.2024.100770.

[26] UNEP, *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*. 2011.

[27] D. Pearce and D. Moran, *The economic value of biodiversity*. London: Routledge, 2013.

[28] *Food Systems and Natural Resources*. 2016. doi: 10.18356/dcbe47a6-en.

[29] WWF, *Living Planet Report 2020 - Bending the curve of biodiversity loss*. 2020.

[30] J. Bongaarts, "IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services," *Popul Dev Rev*, vol. 45, no. 3, 2019, doi: 10.1111/padr.12283.

[31] N. A. Ansari, C. Agus, and E. K. Nunoo, "Plausible Solutions with Reference to 'SDG15 – Life on Land' Towards an Effective Biodiversity Management," in *SDG15 – Life on Land: Towards Effective Biodiversity Management*, 2021. doi: 10.1108/978-1-80117-814-320211010.

[32] M. Harper *et al.*, "Twenty-five essential research questions to inform the protection and restoration of freshwater biodiversity," 2021. doi: 10.1002/aqc.3634.

[33] Z. Zhang *et al.*, "Effect of conservation farming practices on soil organic matter and stratification in a mono-cropping system of Northern China," *Soil Tillage Res*, vol. 156, 2016, doi: 10.1016/j.still.2015.10.008.

[34] T. Weldeslassie, H. Naz, B. Singh, and M. Oves, "Chemical contaminants for soil, air and aquatic ecosystem," in *Modern Age Environmental Problems and their Remediation*, 2017. doi: 10.1007/978-3-319-64501-8_1.

[35] S. K. Patel, A. Sharma, and G. S. Singh, "Traditional agricultural practices in India: an approach for environmental sustainability and food security," 2020. doi: 10.1007/s40974-020-00158-2.

[36] L. Rani *et al.*, "An extensive review on the consequences of chemical pesticides on human health and environment," 2021. doi: 10.1016/j.jclepro.2020.124657.

[37] Shefali, R. Kumar, M. S. Sankhla, R. Kumar, and S. S. Sonone, "Impact of pesticide toxicity in aquatic environment," *Biointerface Res Appl Chem*, vol. 11, no. 3, 2021, doi: 10.33263/BRIAC113.1013110140.

[38] M. C. Wilson *et al.*, "Habitat fragmentation and biodiversity conservation: key findings and future challenges," 2016. doi: 10.1007/s10980-015-0312-3.

[39] S. Adelabu, O. S. Durowoju, E. G. Adagbasa, A. Matamanda, and A. Olusola, "Footprints of drought in a montane grassland biome: a drought vulnerability index approach to drought conditions," *African Geographical Review*, 2025, doi: 10.1080/19376812.2025.2530636.
[40] R. J. Barro and X. Sala-i-Martin, *Economic Growth*. Massachusetts: MIT Press, 2004.
[41] S. Polasky, E. Nelson, E. Lonsdorf, P. Fackler, and A. Starfield, "Conserving species in a working landscape: Land use with biological and economic objectives," *Ecological Applications*, vol. 15, no. 4, 2005, doi: 10.1890/03-5423.
[42] I. Omann, A. Stocker, and J. Jäger, "Climate change as a threat to biodiversity: An application of the DPSIR approach," *Ecological Economics*, vol. 69, no. 1, 2009, doi: 10.1016/j.ecolecon.2009.01.003.
[43] E. B. Barbier, J. C. Burgess, and C. Folke, *Paradise lost?: The ecological economics of biodiversity*. 2019. doi: 10.4324/9780429342219.
[44] X. Diao, B. Fekadu, S. Haggblade, A. S. Taffesse, K. Wamisho, and B. Yu, "Agricultural Growth Linkages in Ethiopia : Estimates using Fixed and Flexible Price Models," *IFPRI Discussion Paper No. 00695*, vol. 52, no. 00695, 2007.
[45] L. Zhao, A. Dai, and B. Dong, "Changes in global vegetation activity and its driving factors during 1982–2013," *Agric For Meteorol*, vol. 249, 2018, doi: 10.1016/j.agrformet.2017.11.013.
[46] L. Praburaj, "Role of Agriculture in the Economic Development of a Country," *Shanlax International Journal of Commerce*, vol. 6, no. 3, 2018.
[47] D. A. Martin, "Nature losses threaten emerging economies," *SciDev. net-Enterprise*, 2020.
[48] J. Fischer *et al.*, "Using a leverage points perspective to compare social-ecological systems: a case study on rural landscapes," *Ecosystems and People*, vol. 18, no. 1, 2022, doi: 10.1080/26395916.2022.2032357.
[49] D. A. Newburn, P. Berck, and A. M. Merenlender, "Habitat and open space at risk of land-use conversion: Targeting strategies for land conservation," *Am J Agric Econ*, vol. 88, no. 1, 2006, doi: 10.1111/j.1467-8276.2006.00837.x.
[50] K. Kusena, "Land cover change and its impact on human-elephant conflicts in the Zimbabwe, Mozambique and Zambia (ZiMoZa) Transboundary natural resource management," *African Wildlife Foundation working paper*, no. 62, 2009.
[51] E. B. Barbier, "The Policy Implications of the Dasgupta Review: Land Use Change and Biodiversity: Invited Paper for the Special Issue on 'The Economics of Biodiversity: Building on the Dasgupta Review' in Environmental and Resource Economics," 2022. doi: 10.1007/s10640-022-00658-1.
[52] O. Adekola, G. Mitchell, and A. Grainger, "Inequality and ecosystem services: The value and social distribution of Niger Delta wetland services," *Ecosyst Serv*, vol. 12, 2015, doi: 10.1016/j.ecoser.2015.01.005.
[53] M. M. Hassan and M. N. I. Nazem, "Examination of land use/land cover changes, urban growth dynamics, and environmental sustainability in Chittagong city, Bangladesh," *Environ Dev Sustain*, vol. 18, no. 3, 2016, doi: 10.1007/s10668-015-9672-8.
[54] E. J. Z. Robinson, "Resource-dependent livelihoods and the natural resource base," *Annu Rev Resour Economics*, vol. 8, no. 1, 2016, doi: 10.1146/annurev-resource-100815-095521.
[55] A. Driver *et al.*, "National Biodiversity Assessment 2011: an assessment of South Africa's biodiversity and ecosystems," Pretoria, 2012.
[56] Department of Environmental Affairs (DEA), "National list of ecosystems that are threatened and in need of protection," *Government Gazette* , Dec. 09, 2011.
[57] P. G. Desmet, J. Cloete, D. Mphapuli, A. Skowno, and S. Holness, "Making the case for Protected Areas in Limpopo," Sep. 2014.
[58] SEF, "Vhembe Biosphere Reserve Initial Strategic Environmental Management Plan (SEMP)," 2016.

[59] B. Hedden-Dunkhorst and F. Schmitt, “Exploring the potential and contribution of UNESCO biosphere reserves for landscape governance and management in Africa,” *Land (Basel)*, vol. 9, no. 8, 2020, doi: 10.3390/LAND9080237.
[60] T. Dalu, T. Mwedzi, R. J. Wasserman, T. C. Madzivanzira, T. Nhiwatiwa, and R. N. Cuthbert, “Land use effects on water quality, habitat, and macroinvertebrate and diatom communities in African highland streams,” *Science of the Total Environment*, vol. 846, 2022, doi: 10.1016/j.scitotenv.2022.157346.
[61] H. Nuwarinda, A. Ramoelo, and S. Adelabu, “Assessing natural resource change in Vhembe biosphere and surroundings,” *Environ Monit Assess*, vol. 193, no. 7, 2021, doi: 10.1007/s10661-021-09053-7.
[62] H. Nuwarinda, A. Ramoelo, and S. A. Adelabu, “Assessing Natural Resource Change Drivers in Vhembe Biosphere and Surroundings,” *JSM Environ Sci Ecol*, vol. 10, no. 2, p. 1083, 2022, [Online]. Available: www.SoilGrids.
[63] A. L. Skowno *et al.*, *National Biodiversity Assessment 2018 Volume 3 :*, vol. 3. 2019.
[64] L. J. Ramarumo and A. Maroyi, “An inventory of useful threatened plant species in vhembe biosphere reserve, Limpopo Province, South Africa,” *Biodiversitas*, vol. 21, no. 5, 2020, doi: 10.13057/biodiv/d210543.
[65] S. Dietz and W. N. Adger, “Economic growth, biodiversity loss and conservation effort,” *J Environ Manage*, vol. 68, no. 1, 2003, doi: 10.1016/S0301-4797(02)00231-1.
[66] M. L. Avolio, D. E. Pataki, S. Pincetl, T. W. Gillespie, G. D. Jenerette, and H. R. McCarthy, “Understanding preferences for tree attributes: the relative effects of socio-economic and local environmental factors,” *Urban Ecosyst*, vol. 18, no. 1, 2015, doi: 10.1007/s11252-014-0388-6.
[67] E. Gerrish and S. L. Watkins, “The relationship between urban forests and income: A meta-analysis,” 2018. doi: 10.1016/j.landurbplan.2017.09.005.
[68] Statistics South Africa., “Census 2011 Statistical release – P0301.4 / Statistics South Africa,” *Statistics South Africa*, 2012.
[69] M. Mourad, J. L. Bertrand-Krajewski, and G. Chebbo, “Calibration and validation of multiple regression models for stormwater quality prediction: Data partitioning, effect of dataset size and characteristics,” *Water Science and Technology*, vol. 52, no. 3, 2005, doi: 10.2166/wst.2005.0060.
[70] H. Nuwarinda, S. Adelabu, A. Ramoelo, O. Durowoju, C. Jackson, and K. Mashiane, “Interlinking Socio-Economic and Environmental Factors Driving Biodiversity Loss in Vhembe Biosphere,” *Geography Notebooks*, vol. 8, no. 1, 2025, doi: 10.7358/gn-2025-001-nuwa.
[71] J. Fang, “Why Logistic Regression Analyses Are More Reliable Than Multiple Regression Analyses,” *Journal of Business and Economics*, vol. 4, no. 7, 2013.
[72] R. L. Wasserstein and N. A. Lazar, “The ASA’s Statement on p-Values: Context, Process, and Purpose,” 2016. doi: 10.1080/00031305.2016.1154108.
[73] G. J. Williams, “Rattle: A data mining GUI for R,” *R Journal*, vol. 1, no. 2, 2009, doi: 10.32614/rj-2009-016.
[74] D. Peng *et al.*, “Characteristics and drivers of global NDVI-based FPAR from 1982 to 2006,” *Global Biogeochem Cycles*, vol. 26, no. 3, 2012, doi: 10.1029/2011GB004060.
[75] C. Andrade, “The P value and statistical significance: Misunderstandings, explanations, challenges, and alternatives,” 2019. doi: 10.4103/IJPSYM.IJPSYM_193_19.
[76] A. Popovic, M. de la Fuente, M. Engelhardt, and K. Radermacher, “Statistical validation metric for accuracy assessment in medical image segmentation,” *Int J Comput Assist Radiol Surg*, vol. 2, no. 3–4, 2007, doi: 10.1007/s11548-007-0125-1.
[77] J. M. Lobo, A. Jiménez-valverde, and R. Real, “AUC: A misleading measure of the performance of predictive distribution models,” 2008. doi: 10.1111/j.1466-8238.2007.00358.x.
[78] J. F. Mas, B. S. Filho, R. G. Pontius, M. F. Gutiérrez, and H. Rodrigues, “A suite of tools for ROC analysis of spatial models,” *ISPRS Int J Geoinf*, vol. 2, no. 3, 2013, doi: 10.3390/ijgi2030869.

[79] R. de Jong, J. Verbesselt, M. E. Schaepman, and S. de Bruin, "Trend changes in global greening and browning: Contribution of short-term trends to longer-term change," *Glob Chang Biol*, vol. 18, no. 2, 2012, doi: 10.1111/j.1365-2486.2011.02578.x.
[80] Bekkar Mohamed, Djemaa Hassiba Kheliouane, and Taklit Akrouf Alitouche, "Evaluation Measures for Models Assessment over Imbalanced Data Sets ," *Journal of Information Engineering and Applications*, vol. 3, no. 10, 2013.
[81] V. Bahn and B. J. Mcgill, "Can niche-based distribution models outperform spatial interpolation?," *Global Ecology and Biogeography*, vol. 16, no. 6, 2007, doi: 10.1111/j.1466-8238.2007.00331.x.
[82] J. E. Cavanaugh and A. A. Neath, "The Akaike information criterion: Background, derivation, properties, application, interpretation, and refinements," 2019. doi: 10.1002/wics.1460.
[83] K. Aho, D. Derryberry, and T. Peterson, "Model selection for ecologists: The worldviews of AIC and BIC," 2014. doi: 10.1890/13-1452.1.
[84] A. A. Beaujean and G. B. Morgan, "Tutorial on using regression models with count outcomes using R," *Practical Assessment, Research and Evaluation*, vol. 21, no. 2, 2016.
[85] F. Bernardo, I. Loupa-Ramos, and J. Carvalheiro, "Are biodiversity perception and attitudes context dependent? A comparative study using a mixed-method approach," *Land use policy*, vol. 109, 2021, doi: 10.1016/j.landusepol.2021.105703.
[86] S. M. C. Davison *et al.*, "Concern about the human health implications of marine biodiversity loss is higher among less educated and poorer citizens: Results from a 14-country study in Europe," *Front Mar Sci*, vol. 10, 2023, doi: 10.3389/fmars.2023.949263.
[87] Y. R. Waarts *et al.*, *A living income for smallholder commodity farmers and protected forests and biodiversity: how can the private and public sectors contribute? White Paper on sustainable commodity production — Research@WUR*, vol. 122, no. November. 2019.
[88] E. de Lange *et al.*, "A global conservation basic income to safeguard biodiversity," *Nat Sustain*, vol. 6, no. 8, 2023, doi: 10.1038/s41893-023-01115-7.
[89] A. R. E. Sinclair, S. A. R. Mduma, and P. Arcese, "Protected areas as biodiversity benchmarks for human impact: Agriculture and the Serengeti avifauna," *Proceedings of the Royal Society B: Biological Sciences*, vol. 269, no. 1508, 2002, doi: 10.1098/rspb.2002.2116.
[90] K. J. Gaston, T. M. Blackburn, and K. Klein Goldewijk, "Habitat conversion and global avian biodiversity loss," *Proceedings of the Royal Society B: Biological Sciences*, vol. 270, no. 1521, 2003, doi: 10.1098/rspb.2002.2303.
[91] J. A. Ericson, "A participatory approach to conservation in the Calakmul Biosphere Reserve, Campeche, Mexico," in *Landscape and Urban Planning*, 2006. doi: 10.1016/j.landurbplan.2004.09.006.
[92] U. S. Rawat and N. K. Agarwal, "Biodiversity: Concept, threats and conservation," *Environ Conserv J*, vol. 16, no. 3, 2015, doi: 10.36953/ecj.2015.16303.
[93] J. Pretty *et al.*, "The intersections of biological diversity and cultural diversity: Towards integration," *Conservation and Society*, vol. 7, no. 2, 2009, doi: 10.4103/0972-4923.58642.
[94] N. J. Turner and F. Berkes, "Coming to understanding: Developing conservation through incremental learning in the Pacific Northwest," *Hum Ecol*, vol. 34, no. 4, 2006, doi: 10.1007/s10745-006-9042-0.
[95] J. Claudet *et al.*, "A Roadmap for Using the UN Decade of Ocean Science for Sustainable Development in Support of Science, Policy, and Action," 2020. doi: 10.1016/j.oneear.2019.10.012.
[96] E. O. Akindele *et al.*, "Assessing awareness on biodiversity conservation among Nigerians: the Aichi Biodiversity Target 1," *Biodivers Conserv*, vol. 30, no. 7, 2021, doi: 10.1007/s10531-021-02175-x.
[97] G. Schroth, G. a B. Fonseca, C. a. Harvey, H. L. Vasconcelos, C. Gascon, and a. M. N. Izac, "Introduction: The Role of Agroforestry in Biodiversity Conservation in Tropical Landscapes," *Agroforestry and Biodiversity Conservation in Tropical Landscapes*, 2004.

[98] K. T. Osman, *Soil degradation, conservation and remediation*, vol. 9789400775909. 2014. doi: 10.1007/978-94-007-7590-9.
[99] S. Kapitza *et al.*, "Assessing biophysical and socio-economic impacts of climate change on regional avian biodiversity," *Sci Rep*, vol. 11, no. 1, 2021, doi: 10.1038/s41598-021-82474-z.
[100] M. G. Muluneh, "Impact of climate change on biodiversity and food security: a global perspective—a review article," 2021. doi: 10.1186/s40066-021-00318-5.
[101] S. Tonin and G. Lucaroni, "Understanding social knowledge, attitudes and perceptions towards marine biodiversity: The case of tegnùe in Italy," *Ocean Coast Manag*, vol. 140, 2017, doi: 10.1016/j.ocecoaman.2017.02.019.
[102] S. Aswani, A. Lemahieu, and W. H. H. Sauer, "Global trends of local ecological knowledge and future implications," *PLoS One*, vol. 13, no. 4, 2018, doi: 10.1371/journal.pone.0195440.
[103] J. Bansard and M. Schöder, "The Sustainable Use of Natural Resources: The Governance Challenge," *Iisd*, 2021.
[104] N. Li, R. Ulucak, and Danish, "Turning points for environmental sustainability: the potential role of income inequality, human capital, and globalization," *Environmental Science and Pollution Research*, vol. 29, no. 27, 2022, doi: 10.1007/s11356-021-18223-6.
[105] N. Ndima, S. Adelabu, C. M. Jackson, and O. S. Durowoju, "Beyond the green: a geospatial analysis of Urban Public Green Spaces in Bloemfontein City, South Africa," *Transactions of the Royal Society of South Africa*, 2025, doi: 10.1080/0035919X.2025.2581277.
[106] O. S. Durowoju, R. O. Obateru, S. Adelabu, and A. Olusola, "Urban change detection: assessing biophysical drivers using machine learning and Google Earth Engine," *Environ Monit Assess*, vol. 197, no. 4, 2025, doi: 10.1007/s10661-025-13863-4.
[107] D. E. Bowler *et al.*, "Mapping human pressures on biodiversity across the planet uncovers anthropogenic threat complexes," *People and Nature*, vol. 2, no. 2, 2020, doi: 10.1002/pan3.10071.
[108] P. Jaureguiberry *et al.*, "The direct drivers of recent global anthropogenic biodiversity loss," *Sci Adv*, vol. 8, no. 45, 2022, doi: 10.1126/sciadv.abm9982.
[109] K. Abe and M. Saito, "Environmental Protection in the Presence of Unemployment and Common Resources," *Rev Dev Econ*, vol. 20, no. 1, pp. 176–188, Jan. 2016.
[110] I. Daitoh and N. Tarui, "Open access renewable resources, urban unemployment, and the resolution of dual institutional failures," *Environ Dev Econ*, vol. 27, no. 4, 2022, doi: 10.1017/S1355770X21000334.
[111] M. Chibba and J. M. Luiz, "Poverty, Inequality and Unemployment in South Africa: Context, Issues and the Way Forward," *Economic Papers*, vol. 30, no. 3, 2011, doi: 10.1111/j.1759-3441.2011.00129.x.
[112] P. Tran and R. Shaw, "Towards an integrated approach of disaster and environment management: A case study of Thua Thien Hue province, central Viet Nam," *Environmental Hazards*, vol. 7, no. 4, 2007, doi: 10.1016/j.envhaz.2007.03.001.
[113] A. Banerjee and C. Madhurima, "Journal of Horticulture and Forestry Forest degradation and livelihood of local communities in India: A human rights approach," vol. 5, no. 8, pp. 122–129, 2013, doi: 10.5897/JHF2013.0305.
[114] F. Isbell, D. Tilman, S. Polasky, and M. Loreau, "The biodiversity-dependent ecosystem service debt," 2015. doi: 10.1111/ele.12393.
[115] E. Harvey, I. Gounand, C. L. Ward, and F. Altermatt, "Bridging ecology and conservation: from ecological networks to ecosystem function," 2017. doi: 10.1111/1365-2664.12769.
[116] J. M. Bullock, J. Aronson, A. C. Newton, R. F. Pywell, and J. M. Rey-Benayas, "Restoration of ecosystem services and biodiversity: Conflicts and opportunities," 2011. doi: 10.1016/j.tree.2011.06.011.
[117] *Indigenous knowledge: enhancing its contribution to natural resources management*. 2017. doi: 10.1079/9781780647050.0000.

[118] L. Roberts, A. Hassan, A. Elamer, and M. Nandy, “Biodiversity and extinction accounting for sustainable development: A systematic literature review and future research directions,” *Bus Strategy Environ*, vol. 30, no. 1, 2021, doi: 10.1002/bse.2649.