International Journal of Natural Resource Ecology and Management
2021; 6(2): 49-55
http://www.sciencepublishinggroup.com/j/ijnrem
doi: 10.11648/j.ijnrem.20210602.14
ISSN: 2575-3088 (Print); ISSN: 2575-3061 (Online)

Conservation Policy, Type of Protected Area and Deforestation in Mainland Tanzania

Emmanuel Fred Nzunda

Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, Morogoro, Tanzania

Email address:
nzunda@sua.ac.tz, nzundaef@gmail.com

To cite this article:
Emmanuel Fred Nzunda. Conservation Policy, Type of Protected Area and Deforestation in Mainland Tanzania. *International Journal of Natural Resource Ecology and Management*. Vol. 6, No. 2, 2021, pp. 49-55. doi: 10.11648/j.ijnrem.20210602.14

Received: April 29, 2021; **Accepted**: May 17, 2021; **Published**: May 26, 2021

Abstract: Protected areas are an important means of controlling deforestation. However, the effectiveness of protected areas in controlling deforestation depends on type of protected area which determines conservation policy pursued and thus how the protected area is managed. This paper reports on analysis of the relationship between deforestation and type of protected area, namely forest reserve, game reserve and national park in mainland Tanzania. The analysis used maps covering the whole of mainland Tanzania for 1995 and 2010 and applied GIS analytical techniques. Both forest reserves and game reserves had lower deforestation than areas that were not protected whereas national parks had higher deforestation than areas that were not protected. However, forest reserves had higher rate of deforestation than game reserves. These results raise questions with regards to ecological processes and policy options relevant for the three types of protected areas and their effects on deforestation. First, are the differences in deforestation due to varying levels of effectiveness of measures used to control deforestation among the three types of protected areas? Second, what is the role of natural processes such as elephants that kill trees? Third, why should national parks be associated with the highest rate of deforestation? Are forests so bad for wild animals in national parks? These questions form the basis of the discussion of the results.

Keywords: GIS, Spatial Analysis, Effectiveness, Wildlife Policy, Forest Act

1. Introduction

Protected areas are an important means of protecting forests against deforestation and its consequences [1–7]. Between 1970s and 2000s the world's system of protected areas expanded exponentially especially in developing countries where biodiversity is greatest [2]. In the same period, the number of protected areas in the world increased more than tenfold resulting in 1.9 billion hectares under protected areas globally [8]. In view of this importance of protected areas, the government of Tanzania put under protected areas of different types about 43% of all forested land in the country by the 1990s [9]. This included about 12.5 million hectares of forest reserves and 2 million hectares of other types of protected areas including national parks and game reserves [9]. By 2005, about 39.6% of the total land area of Tanzania was in protected areas [2]. Tanzania is also among top 20 developing countries with the largest proportion of their total land area in protected areas [2]. Despite all this, comparative studies that have evaluated the effectiveness of protected areas across the world suggest that the creation of protected areas has had mixed outcomes especially in terms of preventing deforestation [4, 10, 11]. This is due to a number of ecological, socioeconomic and institutional factors including type of protected area [4, 10, 11].

This paper compares effectiveness of different types of protected areas in controlling deforestation by analyzing the variation in the amount of deforestation between different types of protected areas between 1995 and 2010 for the whole of mainland Tanzania. The types of protected areas compared are forest reserves, national parks and game reserves. The analysis used ready-made land cover maps for 1995 and 2010. First, the relationship between deforestation and type of protected area is analyzed. Secondly, the trajectories of deforestation (i.e. land cover types to which forests are converted) for different types of protected area are compared.

In Tanzania, different types of protected areas are managed under different conservation policy in terms of legislation and

strategies. Forest reserves are managed according to the national forest policy [9] and the forest act [12] whereas national parks and game reserves are managed according to the wildlife policy of Tanzania [13] and the wildlife conservation act [14]. The primary aim of forest reserves is to conserve forests and their biodiversity and hydrological values whereas the primary aim of national parks and game reserves is to conserve wild animals and their habitats and biodiversity values. The habitats of wild animals are not necessarily forests and hence the strategies used to manage them may not necessarily conserve forests. For instance, prescribed burning is used to manage habitats in national parks [15, 16]. The prescribed burning may result either in deforestation or prevent forest development [17-20]. Resources available for and used to manage the different types of protected areas also differ. The budget needed to manage forest reserves is always more than the revenues that are generated from the reserves [21]. This may reduce the capacity of the management of forest reserves to implement plans related to control of deforestation and hence lead to deforestation. On the other hand, the national parks and game reserves generate more revenue than their budgetary requirements [22]. Thus the managers of national parks and game reserves may be in a better position to implement what they plan than the managers of forest reserves, although the extra revenue generated is returned to the central government [22]. Forest reserves do not use armed personnel to protect them [12][1] whereas national parks and game reserves use armed personnel [14]. Armed personnel may result in better protection of the protected areas due to the fear of injury and death instilled in the would-be trespassers into the protected areas. The better protection may reduce chances of deforestation due to human disturbances. Thus the differences in aims and strategies of managing different types of protected areas may result in differences in effectiveness of the protected areas in controlling deforestation.

It is useful to analyze trajectories of deforestation because trajectories of deforestation may either directly show primary drivers of deforestation or suggest the drivers [23–28]. For instance, conversion of forest to cultivation may indicate directly that cultivation is the primary driver of deforestation [27, 29, 30]. On the other hand, conversion of forest to bushland or grassland may suggest either a driver of deforestation that directly converts forest to bushland or grassland (e.g. clear felling of forest but not for cultivation) or results into bushland and grassland as transitional states after a land cover that was a direct driver of deforestation [27, 29, 30].

2. Materials and Methods

2.1. Study Area

The study covered the whole of mainland Tanzania (Figure 1). A total of 136 forest reserves, 10 game reserves and 17 national parks were involved in the analysis. According to the calculations based on the pixels involved in the statistical analysis in this study the total areas covered by forest reserves, game reserves and national parks were respectively 420,602.37 ha, 280,084.29 ha and 214,644.04 ha. Only protected areas that had a date of designation and that were designated before 1995 [31] were involved in the analyses.

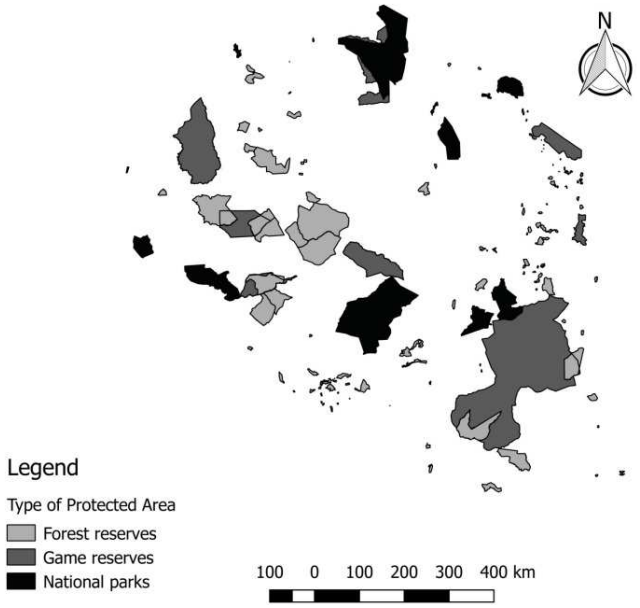

Figure 1. *Forest reserves, game reserves and national parks involved in the study of effects of type of protected area on deforestation in mainland Tanzania. Only protected areas that had designation to type of protected area used in this study before 1995 were involved.*

2.2. Methods

2.2.1. Analysis of Relationship Between Deforestation and Type of Protected Area

The land cover map for 1995 was produced by Hunting Technical Services and published by the Ministry of Natural Resources and Tourism of the United Republic of Tanzania. For 2010, the land cover map was produced by NAFORMA (National Forest Resources Monitoring and Assessment) of the Ministry of Natural Resources and Tourism of the United Republic of Tanzania. Both maps were acquired as shape files and were rasterized to grids of 1,090.79 m resolution (low resolution was used to enhance processing speed). From the land cover maps, forest area within 9 × 9 pixel window was calculated as sum of pixels with forest land cover within the grids. The 9 × 9 pixel window maps were created in QGIS 2.4 using the Vector Grid tool. For the same windows, deforestation was calculated as forest area difference by subtracting the forest area map of 2010 from that of 1995. Thus high positive values in the resulting forest area difference map represented deforestation, zero represented no change in forest area and negative values represented forest gain within a window. Forest was defined as all classes that were mapped as mangrove forest, montane and lowland forest, plantation forest and woodland in the 1995 and 2010 land

[1] This was true for the period covering the study (1995-2010) although things may have changed afterwards.

cover maps [32, 33]. The reclassification was done in GRASS version 6.4.2 using the recoding function.

Spatial data for forest reserves, game reserves and national parks were obtained as shape files from the World Database on Protected Areas (WDPA) [31]. The shape files were rasterized and harmonized in terms of coordinate reference system to match the rest of the data used in the study.

The general linear model (GLM) for univariate dependent variables was used to analyse the effects of type of protected area on deforestation [34]. Pair-wise comparisons (Table 1) between protected area categories were performed within the GLM using difference contrast [35]. The normal distribution and the identity link function were assumed for the GLM. The model of the GLM was of the form:

$$\text{Deforestation} = b_0 + b_i P_i + \sum c_i X_i + e$$

Where b_0 = intercept, b_i = slope of the relationship between deforestation and type of protected area for a comparison i, c_i = slope of the relationship between deforestation and other explanatory variables, P_i = categorical value for type of protected area for a pixel i whereby 1 = if pixel is of the type of protected area and 0 = if pixel is not of the type of protected area, X_i = value of an explanatory variable other than type of protected area for a pixel i and e = error (i.e. variation in deforestation that is not explained by the model).

Table 1. *Sample sizes for pair-wise comparisons of effects of type of protected area on deforestation in mainland Tanzania.*

Comparison	Sample size	
	0	1
Forest reserve (1) vs not a protected area (0)	9947	797
Game reserve (1) vs not a protected area (0)	9947	1081
National park (1) vs not a protected area (0)	9947	963
Forest reserve (0) vs Game reserve (1)	797	1081
Forest reserve (0) vs National park (1)	797	963
Game reserve (0) vs National park (1)	1081	963

Sample size is number of pixels representing the type of protected area.

The overall performance of the GLM models was assessed using the coefficient of determination and the analysis of variance [34]. The effect of each of the explanatory variables on deforestation was assessed using the slope of the GLM model for each explanatory variable [34]. To reduce error (i.e. the amount of variation in deforestation not explained by the explanatory variables), the GLM analyses also included forest type, slope, aspect, elevation, regional GDP in 2002, rainfall, population density in 2002, forest area in 1995 and distance to railway, river, road and town as further explanatory variables. All statistical analyses were done in spread sheet and statistical analysis software using values extracted by the tool for extraction of zonal statistics in SAGA 2.1.2.

2.2.2. Comparison of Trajectories of Deforestation for Different Types of Protected Area

Further analysis was performed to determine the trajectories of forest land cover changes (that is land cover types to which forest was converted). This analysis included five land cover types: forest, bushland, grassland, cultivation and others that were harmonized for analysis of deforestation on the basis of the 1995 and 2010 land cover maps [32, 33]. Maps were produced to show unchanged forest and, changes to bushland, grassland, cultivation and others in terms of number of pixels within 9 × 9 windows that experienced the change. The mean and standard deviation of the changes associated with each type of protected area were produced.

3. Results

3.1. Relationship Between Deforestation and Type of Protected Area

The models for all the comparisons were statistically significant (Table 2). The highest amount of variation in deforestation was explained by the model comparing game reserves against national parks and the lowest was for the model comparing forest reserves to national parks (Table 2). For all the models, the amount of variation in deforestation explained by the explanatory variables was less than 50% (Table 2).

Deforestation was lower for forest reserves and for game reserves than for areas that were not protected (Table 2). However, deforestation was higher for national parks than for areas that were not protected (Table 2). Game reserves had lower deforestation than forest reserves and national parks (Table 2). Deforestation did not differ for forest reserves than for national parks (Table 2).

Table 2. *Results of pair-wise comparisons of effects of type of protected area on deforestation in mainland Tanzania.*

Comparison	Reference category*	Overall model performance			‡Pair-wise comparison		
		R_2	F	p	B	F	p
Forest reserve vs not a protected area	Not a protected area	0.27	241.44	<0.001	482.44	15.21	<0.001
Game reserve vs not a protected area	Not a protected area	0.29	279.13	<0.001	803.86	35.36	<0.001
National park vs not a protected area	Not a protected area	0.27	246.28	<0.001	-459.00	15.83	<0.001
Forest reserve vs Game reserve	Forest reserve	0.28	49.07	<0.001	1321.39	20.81	<0.001
Forest reserve vs National park	Forest reserve	0.23	31.67	<0.001	-204.61	1.13	0.288
Game reserve vs National park	Game reserve	0.38	75.94	<0.001	-2509.84	134.33	<0.001

*Reference category is used to interpret B values. Positive B values mean higher deforestation for the reference category than its contrast while negative B values mean lower deforestation for the reference category than its contrast.

‡Pairwise comparison was performed within general linear model (GLM) analysis involving other factors to reduce the error term. The other factors involved in the GLM analysis included forest type, slope, aspect, elevation, regional GDP in 2002, rainfall, population density in 2002, forest area in 1995 and distance to railway, river, road and town. Difference contrast was used (Seltman 2015).

3.2. Trajectories of Deforestation for Different Types of Protected Area

Most of the forest on forest reserves and unprotected areas was converted to cultivation and least to others (Table 3). Most of forest on game reserves and national parks was converted to bushland (Table 3). Conversion of forest to grassland was also higher for forest that was on game reserves and national parks than for forest that was on forest reserves and on unprotected areas (Table 3). Conversion of forest to cultivation was much lower on areas that were game reserves and national parks than on areas that were forest reserves (Table 3).

Table 3. *Trajectories of deforestation for types of protected area in mainland Tanzania.*

	Forest to bushland		Forest to cultivation		Forest to grassland		Forest to others		Unchanged forest	
	Mean	**STD**	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
Not protected	304*	946	1,400	2,038	52	284	32	203	1,602	2,499
Forest reserve	337	891	1,301	1,987	25	125	17	92	4,109	3,384
Game reserve	783	1,592	63	437	134	550	56	307	3,731	3,015
National park	1,470	2,850	79	371	201	719	32	228	2,152	3,289

*Numbers of pixels.

4. Discussion

Lower deforestation for forest reserves and game reserves than for areas that are not protected is expected because deforestation is expected to be lower in protected areas than otherwise [1, 4, 7, 10, 32, 33]. However, higher deforestation in national parks than in areas that are not protected is not expected. Thus we see that although national parks have more resources for management, the use of the resources does not translate into control over deforestation. Higher deforestation for areas that are national parks may be due to use of fire to maintain grassland [15-17]. The results of analysis of trajectories of deforestation show that most of forest in national parks was converted to grassland and bushland (Table 3). If fire is not used, forest growth over an area may be encouraged. For instance, about 29 years of fire suppression from a protected area on Accra plains in south-eastern Ghana caused the plains to become forested, and *Ceiba pentandra*, a fire sensitive tree species became dominant [15, 36]. Not all national parks in Tanzania use fire however. For instance, fire is not used for management of Lake Manyara National Park, which is thus experiencing loss of grassland due to encroachment by bushland [15].

The high rate of deforestation in national parks raises some questions. First, are forests so bad for wild animals? This may not be true because in the past the national parks had forests and were good habitat for wild animals. Also, not all animals need habitats other than forests. Some (e.g. the leopard) need forests. Second, management of some forest reserves was shifted from Division of Forestry to Tanzania National Parks (TANAPA) to be managed the way national parks are managed. This means that these forest reserves may be at risk of losing forest cover due to deforestation. Third, if fire or whatever management approach that is used results in deforestation, is that approach appropriate? An appropriate approach would result in maintenance of forests in balance with other habitats over the years just as they were in the past. The results herein show deforestation which means the management approach results in imbalance in favour of bushland and grassland.

Another reason for higher deforestation in national parks than in areas that are not protected may be higher number of animals that kill trees (and thus may contribute to deforestation) especially elephants in national parks [15, 37]. However, game reserves also do have high numbers of these animals and they do not have as high deforestation as national parks. Other factors that are also the same across the categories of protected areas compared here include climate change. The higher deforestation in national parks than in other protected areas cannot be attributed to climate change because the change occurs in other types of protected areas too unless there is a reason to believe differently.

Forest reserves have higher rate of deforestation than game reserves. The first reason for this difference may be higher availability of resources for management for game reserves than for forest reserves. The second reason may be difference in approach of management: game reserves use armed personnel that scare people. This is why conversion of forest to cultivation is lower in game reserves and most of the conversion is to grassland and bushland (Table 3) that are not caused directly by use of land by people unlike cultivation.

Apart from the differences in resources and styles of management as per conservation policy, spatial attributes may contribute to this difference. Forest reserves are more in number, smaller in area of individual protected area and more scattered in distribution (Figure 1). Thus there is more perimeter exposed to human encroachment and conversion to other land uses and covers. The wide distribution also results in higher cost of management and hence less effectiveness of management. Other reasons for higher deforestation for forest reserves than game reserves are remoteness of location of game reserves in comparison to forest reserves (Table 4). When people that are closer to or within protected areas have easy access to markets through being closer to roads or towns, they tend to cause higher deforestation within protected areas unless they have alternative means of livelihood than dependence on forests [38]. For instance, human pressure on forests near urban and peri-urban areas resulted in clearing of large parts of forest reserves to farms and settlements near Dar es salaam [39, 40].

In general, all the three types of protected area showed some deforestation to varying amounts of grassland, bushland, cultivation and others (Table 3). Other reasons than those discussed above for the causes of deforestation within protected areas could be boundary conflicts [41] and deliberate deforestation in protected areas due to hatred of the protected areas by people surrounding the protected areas [42]. It is also worth noting that some of the land use and cover changes observed may be due to inaccurate classification of land use and cover since no land use and cover classification project may achieve 100% accuracy.

Table 4. *Distance from protected area to town.*

Type of protected area	Distance to town (km)		Pairwise comparison using ANOVA*		
	Mean	STD	National parks	Game reserve	Forest reserve
National park	105.13	39.18		1,705.18 (<0.001)	
Game reserve	152.01	43.72			489.93 (<0.001)
Forest reserve	122.57	53.76	254.71 (<0.001)		

*Numbers are F value (p-value).

5. Conclusions

Deforestation was lower for forest reserves and for game reserves than for areas that were not protected. However, deforestation was higher for national parks than for areas that were not protected. Game reserves had lower deforestation than forest reserves and national parks. Deforestation did not differ for forest reserves than for national parks. Forest was lost more to cultivation for forest reserves and areas that were not protected than for game reserves and national parks, which lost forest more to bushland and grassland. This could probably be due to fear of armed personnel who guard national parks and game reserves against cultivators and other encroachers/trespassers unlike forest reserves for which there was no protection by armed personnel. Forest reserves have less resources for protection, are smaller in number and more scattered and closer to towns than game reserves, which probably makes them more prone to deforestation. National parks use prescribed burning to promote grass for herbivores, an approach that may cause deforestation. Further research should confirm the hypothetical explanations given for the variation in rate of deforestation among the types of protected areas studied. In addition, there is need to investigate the implications of high rate of deforestation in general for the whole country but especially in national parks, for which the rate of deforestation is higher than for areas that are not protected, unlike forest reserves and game reserves.

Disclosure Statement

No potential conflict of interest was reported by the author.

Funding

This work is a spin-off from the work supported by The Climate Change Impacts, Adaptation and Mitigation (CCIAM) programme [grant number E 60106] through the project titled 'Modelling Scenarios of REDD + in Response to Regulation of Population, Agricultural, Woodfuel and Settlement Dynamics in Tanzania'.

Acknowledgements

The authors thank Prof. Boniphace P. Mbilinyi for provision of the 1995 and 2010 land use/land cover maps, Mr. Nurdin Chamuya for permission to use NAFORMA 2010 land cover map, Mr. Charles A. Chunga for collation of a large portion of the data used in this study and Dr. Alfred Chitiki for provision of the DEM data. Comments given by the anonymous reviewers and the support and instructions from the editorial office of the journal are heartily appreciated.

References

[1] R. Walker *et al.*, "Protecting the Amazon with protected areas," *PNAS*, vol. 106, no. 26, pp. 10582–10586, 2009.

[2] L. Naughton-Treves, M. B. Holland, and K. Brandon, "The role of protected areas in conserving biodiversity and sustaining local livelihoods," *Annu. Rev. Environ. Resour.*, vol. 30, pp. 219–252, 2005, doi: 10.1146/annurev.energy.30.050504.164507.

[3] J. M. Hall *et al.*, "Ecological and Social Outcomes of a New Protected Area in Tanzania," *Conserv. Biol.*, vol. 28, no. 6, pp. 1512–1521, 2014, doi: 10.1111/cobi.12335.

[4] B. Gizachew, J. Rizzi, D. D. Shirima, and E. Zahabu, "Deforestation and Connectivity among Protected Areas of Tanzania," *Forests*, vol. 11, no. doi: 10.3390/f11020170, 2020.

[5] FAO, "The State of the World's Forests: Forests, biodiversity and people," Rome, 2020. doi: 10.1515/9783035608632-002.

[6] FAO, "Global Forest Resources Assessment 2020 Report United Republic of Tanzania," Rome, 2020.

[7] B. Mackey *et al.*, "Understanding the importance of primary tropical forest protection as a mitigation strategy," *Mitig. Adapt. Strateg. Glob. Chang.*, vol. 25, no. 5, pp. 763–787, 2020, doi: 10.1007/s11027-019-09891-4.

[8] S. Chape, S. Blyth, L. Fish, P. Fox, and M. Spalding, "United Nations List of Protected Areas. IUCN, Gland, Switzerland and Cambridge, UK and UNEP-WCMC, Cambridge, UK. ix+44pp].," 2003. http://www.iucn.org/themes/wcpa/wcp2003/english/outputs/.

[9] URT, *National Forest Policy*, vol. 92, no. 9. Ministry of Natural Resources and Tourism, The United Republic of Tanzania. Dar es Salaam, 1998.

[10] J. Southworth, H. Nagendra, and D. K. Munroe, "Editorial. Introduction to the special issue: Are parks working? Exploring human-environment tradeoffs in protected area conservation," *Appl. Geogr.*, vol. 26, no. 2, pp. 87–95, 2006, doi: 10.1016/j.apgeog.2005.11.001.

[11] M. Cropper, J. Puri, and C. Griffiths, "Predicting the Location of Deforestation: The Role of Roads and Protected Areas in North Thailand," *Land Econ.*, vol. 77, no. 2, pp. 172–186, 2001.

[12] URT, *The Forest Act*, vol. 83, no. 7. Ministry of Natural Resources and Tourism, The United Republic of Tanzania. Dar es Salaam, 2002.

[13] URT, *The Wildlife Policy of Tanzania*. Ministry of Natural Resources and Tourism, The United Republic of Tanzania. Dar es Salaam, 1998.

[14] URT, *The Wildlife Conservation Act*. Ministry of Natural Resources and Tourism, The United Republic of Tanzania. Dar es Salaam, 2009.

[15] S. N. Hassan, *Effects of fire on large herbivores and their forage resources in Serengeti, Tanzania*, no. November. Thesis for the degree Philosophiae Doctor. Department of Biology. Faculty of Natural Sciences and Technology. Norwegian University of Science and Technology, 2007.

[16] A. M. Manyonyi, S. B. Mariki, L. L. Mnyone, S. R. Belmain, and L. S. Mulungu, "Effects of prescribed burning on rodent community ecology in Serengeti National Park," *J. Vertebr. Biol.*, vol. 69 (2): 200, no. DOI: 10.25225/jvb.20001, 2020.

[17] H. Eva and E. F. Lambin, "Fires and land-cover change in the tropics: a remote sensing analysis at the landscape scale," *J. Biogeogr.*, vol. 27, no. 3, pp. 765–776, 2000, doi: 10.1046/j.1365-2699.2000.00441.x.

[18] A. J. Tepley *et al.*, "Influences of fire–vegetation feedbacks and post-fire recovery rates on forest landscape vulnerability to altered fire regimes," *J. Ecol.*, vol. 106, no. 5, pp. 1925–1940, 2018, doi: 10.1111/1365-2745.12950.

[19] A. Christopoulou *et al.*, "Assessing the impact of different landscape features on post-fire forest recovery with multitemporal remote sensing data: The case of Mount Taygetos (southern Greece)," *Int. J. Wildl. Fire*, vol. 28, no. 7, pp. 521–532, 2019, doi: 10.1071/WF18153.

[20] J. Qiu, H. Wang, W. Shen, Y. Zhang, H. Su, and M. Li, "Quantifying forest fire and post-fire vegetation recovery in the daxing'anling area of northeastern china using landsat time-series data and machine learning," *Remote Sens.*, vol. 13, no. 4, pp. 1–17, 2021, doi: 10.3390/rs13040792.

[21] A. Akida, I. Mnangwone, and L. Lyimo, "Financing for Sustainable Forest Management in Tanzania," INDUFOR Oy, Helsinki, Finland, 2012.

[22] R. Mabugu and P. Mugoya, "Financing, Revenue-Sharing, and Taxation Issues in Wildlife Management Areas," Wildlife Division, Ministry of Natural Resources and Tourism and USAID/Tanzania, 2001. [Online]. Available: papers3://publication/uuid/4D75EBDC-FBA2-45A5-9E94-700A7F9C4F90.

[23] H. Geist and E. Lambin, "What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on sub-national case study evidence," LUCC International Project Office, Louvain-la-Neuve, Belgium, 2001.

[24] N. B. P. Jaimes, J. B. Sendra, M. G. Delgado, and R. F. Plata, "Exploring the driving forces behind deforestation in the state of Mexico (Mexico) using geographically weighted regression," *Appl. Geogr.*, vol. 30, pp. 576–591, 2010, doi: 10.1016/j.apgeog.2010.05.004.

[25] R. G. J. Pontius, E. Shusasand, and M. McEachern, "Detecting important categorical land changes while accounting for persistence," *Agric. Ecosyst. Environ.*, vol. 101, pp. 251–268, 2004.

[26] J. J. Schulz, L. Cayuela, C. Echeverria, J. Salas, and J. M. R. Benayas, "Monitoring land cover change of the dryland forest landscape of Central Chile (1975-2008)," *Appl. Geogr.*, vol. 30, no. 3, pp. 436–447, 2010, doi: 10.1016/j.apgeog.2009.12.003.

[27] M. S. Reis, L. V. Dutra, M. I. S. Escada, and S. J. S. Sant'Anna, "Avoiding invalid transitions in land cover trajectory classification with a compound maximum a posteriori approach," *IEEE Access*, vol. 8, pp. 98787–98799, 2020, doi: 10.1109/ACCESS.2020.2997019.

[28] Y. Wang *et al.*, "Mapping tropical disturbed forests using multi-decadal 30m optical satellite imagery," *Remote Sens. Environ.*, vol. 221, no. April 2018, pp. 474–488, 2019, doi: 10.1016/j.rse.2018.11.028.

[29] P. Verburg, "The CLUE-S model. Tutorial CLUE-s (version 2.4) and DYNA-CLUE (version 2) Peter Verburg, Wageningen University.," no. version 2. 1999.

[30] R. Verburg, E. Stehfest, G. Woltjer, and B. Eickhout, "The effect of agricultural trade liberalisation on land-use related greenhouse gas emissions," *Glob. Environ. Chang.*, vol. 19, no. 4, pp. 434–446, 2009, [Online]. Available: http://www.sciencedirect.com/science/article/B6VFV-4X1R2T0-1/2/e60c3294bcbc656a5b2b7cf6e9c1891f.

[31] UNEP-WCMC, "World Database on Protected Areas," UNEP-WCMC: Cambridge, UK., 2016. doi: www.protectedplanet.net.

[32] E. F. Nzunda and F. Midtgaard, "Spatial relationship between deforestation and protected areas, accessibility, population density, GDP and other factors in mainland Tanzania," *For. Trees Livelihoods*, vol. Online, no. 10th May 2017, pp. 1–12, 2017, doi: 10.1080/14728028.2017.1322921.

[33] E. F. Nzunda and F. Midtgaard, "Deforestation and loss of bushland and grassland primarily due to expansion of cultivation in mainland Tanzania (1995–2010)," *J. Sustain. For.*, vol. 38, no. 6, 2019, doi: 10.1080/10549811.2019.1598437.

[34] G. P. Quinn and M. J. Keough, *Experimental design and data analysis for biologists.* Cambridge University Press, Cambridge., 2002.

[35] H. J. Seltman, *Experimental Design and Analysis*. 2015.

[36] W. P. Carson and D. K. Abbiw, "No Title The vegetation of a protection site on the northern Accra Plains, Ghana.," *Afr. J. Ecol.*, vol. 28, pp. 143–146, 1990.

[37] N. A. Nasseri, L. D. Mcbrayer, and B. A. Schulte, "The impact of tree modification by African elephant (Loxodonta africana) on herpetofaunal species richness in northern Tanzania," *Afr. J. Ecol.*, vol. 49, pp. 133–140, 2011, doi: 10.1111/j.1365-2028.2010.01238.x.

[38] H. Nagendra, S. Pareeth, and R. Ghate, "People within parks - Forest villages, land-cover change and landscape fragmentation in the Tadoba Andhari Tiger Reserve, India," *Appl. Geogr.*, vol. 26, no. 2, pp. 96–112, 2006, doi: 10.1016/j.apgeog.2005.11.002.

[39] J. M. Lupala, M. V Mdemu, and S. P. Butungo, "Effects of Peri-Urban Land Use Changes on Forest Ecosystem Services: The Case of Settlements Surrounding Pugu and Kazimzumbwi Forest Reserves in Tanzania," *J. Geogr. Geol.*, vol. 6, no. 4, pp. 231–240, 2014, doi: 10.5539/jgg.v6n4p231.

[40] J. J. Kashaigili, M. V. Mdemu, A. R. Nduganda, and B. P. Mbilinyi, "Integrated Assessment of Forest Cover Change and Above-Ground Carbon Stock in Pugu and Kazimzumbwi Forest Reserves, Tanzania," *Adv. Remote Sens.*, vol. 02, no. 01, pp. 1–9, 2013, doi: 10.4236/ars.2013.21001.

[41] C. Capitani *et al.*, "From local scenarios to national maps: a participatory framework for envisioning the future of Tanzania," *Ecol. Soc. 21 (3) 4.*, vol. 21, no. 3, 2016, doi: dx.doi.org/10.5751/ES-08565-21030.

[42] P. Mayaux, P. Holmgren, F. Achard, H. Eva, H. Stibig, and A. Branthomme, "Tropical forest cover change in the 1990s and options for future monitoring," *Philos. Trans. R. Soc. B-Biological Sci.*, vol. 360, no. 1454, pp. 373–384, 2005, doi: 10.1098/rstb.2004.1590.