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ORIGINAL ARTICLE

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Roads to development? A comparison of development corridors vs regional roads in the Zambezi Region, Namibia

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ABSTRACT
Despite the increasing popularity of development corridors, their effectiveness in promoting regional development compared to regional roads remains uncertain. This study utilised satellite imagery to compare land use transformation within a 10km corridor effect zone along the *Walvis Bay - Ndola - Lubumbashi Development Corridor* (*WBNLDC*) and regional roads in Namibia's Zambezi Region. Overall, the Zambezi Region experienced a strong increase in built-up areas (+165%) and cultivated land (+136%) between 2000 and 2023 at the expense of forest (−18%) and grasslands (−18%). Cultivated and built-up areas expanded most intensively along regional roads, where most of the population resides, particularly after road tarring. This suggests regional roads drive land use change more effectively. The findings imply that local communities profit more from regional roads, and targeted investment in such infrastructures might be more beneficial to support the region's food basket goals and improve livelihoods rather than international corridors like the *WBNLDC*.

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Land use change; development corridors; regional roads; cultivated land; built-up area; livelihoods

Key policy highlights

- The research uses the expansion of cultivated land and built-up areas along development corridors and regional roads as proxies for rural development, highlighting the economic significance of agriculture for rural communities' livelihoods.
- Observed land-use changes suggest that infrastructure development, mainly through regional roads, can potentially improve rural livelihoods by linking built-area and cultivated land expansion to broader economic opportunities.
- The study emphasises the need for policies that strengthen rural connectivity, promote inclusive development, and maximise the benefits for local communities.

1. Introduction

In recent years, development corridors have emerged as promising drivers of economic development, particularly in peripheral regions like Sub-Saharan Africa. Development corridors are regional strategies meant to integrate places and foster development (Mulenga, 2013). These corridors, often in the form of highways, are envisioned as pathways that connect various regions to global markets, facilitating the efficient movement of goods and services, and fostering economic growth (Hope & Cox, 2015; Priemus & Zonneveld, 2003).

Previous research has shown that understanding the dynamics of land use change is crucial for comprehensively assessing the outcomes of development corridors (Sang et al., 2022; Zheng et al., 2021). The effect of development corridors on land use patterns, both direct and indirect, leads to significant transformations in landscapes and human activities (Sang et al., 2022; Van Der Ree et al., 2015). In recent years, doubts have been raised whether the outcomes of these corridors truly align with the anticipated outcomes, which include benefiting the locals (Enns, 2018; Witte, 2014). It is expected that a more affordable access to markets will reduce transport cost, promote job creation and improve livelihoods. However, development corridors are reported to pose social and environmental challenges, including uneven developmental impacts, marginalising the poor, threatening biodiversity and vulnerability to the impacts of climate change (Byiers et al., 2016)

Launched in 1999 with the opening of the Trans-Caprivi Highway, the *Walvis Bay Ndola Lumbumbashi Development Corridor (WBNLDC)* is a crucial transportation link connecting the Walvis Bay port to Zambia and the Democratic Republic of Congo. This corridor supports Vision 2030 and Namibia's National Development Plans (NDPs), which collectively call for infrastructure development,

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employment creation and improved income equality (Republic of Namibia, 2021). In respect to the Zambezi Region, the corridor development plan foresees a stimulation of economic activities through agricultural intensification, manufacturing, tourism, and logistics (Aurecon, 2014). To sum it up, the purpose of the *WBNLDC* is not only focusing on central nodes along the corridor like Walvis Bay or Katima Mulilo, but it also purposively aims to unlock the economic potential in the rural areas in between (Ndjavela, 2021; Southern African Development Community [SADC], 2007).

Previous studies in the Zambezi Region demonstrate that the region has witnessed a noticeable increase in tourism and conservation activities since then (Gronau et al., 2017; Zeller, 2009), but more recent studies have indicated that some of the anticipated benefits of the corridor have not yet materialised, neither in tourism nor in agriculture (Hulke et al., 2021; Kalvelage et al., 2021; Ratz, 2021). This raises questions about the developmental impacts of the *WBNLDC* in the Zambezi Region and more generally, whether development corridors are really conducive to achieving inclusive development, directly benefiting local communities. Consequently, there is an ongoing call to prioritise regional road infrastructure instead (Dannenberg et al., 2018; Kingombe, 2011; Titheridge et al., 2014). However, there is a lack of studies comparing the impact of development corridors vis a vis regional roads.

Using Zambezi Region as a case study, this study aims to compare land use changes along the *WBNLDC* and regional roads in the Zambezi Region using GIS and RS to provide a first assessment of the developmental impact of development corridors compared to regional roads. The expansion of cultivated land, which is the most prominent livelihood strategy in the Zambezi Region (Colpaert et al., 2013) and the expansion of the built-up area are used as a proxy for improved economic opportunities for small-scale farmers. This clearly links our study to the United Nations's Sustainable Development Goals (SDGs), which call for sustainable infrastructures and building inclusive communities (SDG 2, 11, and 15) (United Nations, 2015) and is, to our knowledge, the first study doing it for the Zambezi Region.

The study employs a methodology adapted from Rufin et al., 2022, to deliver a novel contribution and valuable insights into the interactions of development corridors, regional roads, and land use patterns. This study offers policymakers valuable information on changes and policy reforms to prioritise strategies that truly benefit regional development. It also supports SDGs and the country 's NDPs through evidence-based planning.

2. Materials and methods

2.1. Study area

The study is centred on the Zambezi Region in north-eastern Namibia, covering 14 530 km^{2,} more than half of which is under conservation. This region is characterised by subsistence agriculture and has faced high unemployment (48% in 2016) and poverty rates (54% in 2021) (Colpaert et al., 2013; Namibia Statistics Agency, 2017; 2021). Infrastructural projects such as the *WBNLDC* in 1999 and the Zambezi River Bridge to Zambia in 2004 were introduced to not only connect the seaport of Walvis Bay to Zambia and the Democratic Republic of Congo, but also to connect and bring the Zambezi Region closer to the rest of Namibia (Southern African Development Community [SADC], 2007) through improved connectivity (Zeller, 2009). This was followed by the tarring of regional roads in the Zambezi Region as part of the larger infrastructural development in the region, which was completed in 2014 (New Era, 2014). The analysis focuses on the impact of the WBNLDC compared to regional roads, particularly Regional Road 1 (Linyanti – M0125) and Regional Road 2 (Ngoma – T 807). The Zambezi Region has been identified as having the potential to become a key contributor to Namibia's food security, often referred to as the nation's 'breadbasket'; and having agricultural growth is one of its main developmental visions (Kiesel et al., 2022). This study analysed changes in land use, focusing on cultivated land and built-up areas along roads, as these indicators directly reflect the region's development trajectory, particularly given its dependence on agriculture for their livelihoods. The expansion of cultivated land is intepreted as the expansion of agricultural production improving the livelihoods of the local population and food security (Kuang et al., 2022). The increase in built-up areas stands for the expansion of settlements which represent market and job opportunities, provision of public infrastructure like schools, and medical centres and is used as another proxy for improved livelihood conditions (FAO et al., 2023) (Figure 1).

2.2. Mapping land use change

Landsat 5 TM; Landsat 7 ETM+, Landsat 8 OLI, Planet scope daily scenes and monthly base map images for Africa provided by the Norwegian International Climate and Forest Initiative (NICFI) project were primarily used to classify land use changes in the study area for the year 2000, 2004, 2015, and 2023. The 2000 images marked the *WBNLDC*'s inauguration, while the 2004 images marked the WBNLDC's completion to Zambia and DRC. Images from 2015 represented the tarring of regional roads as an

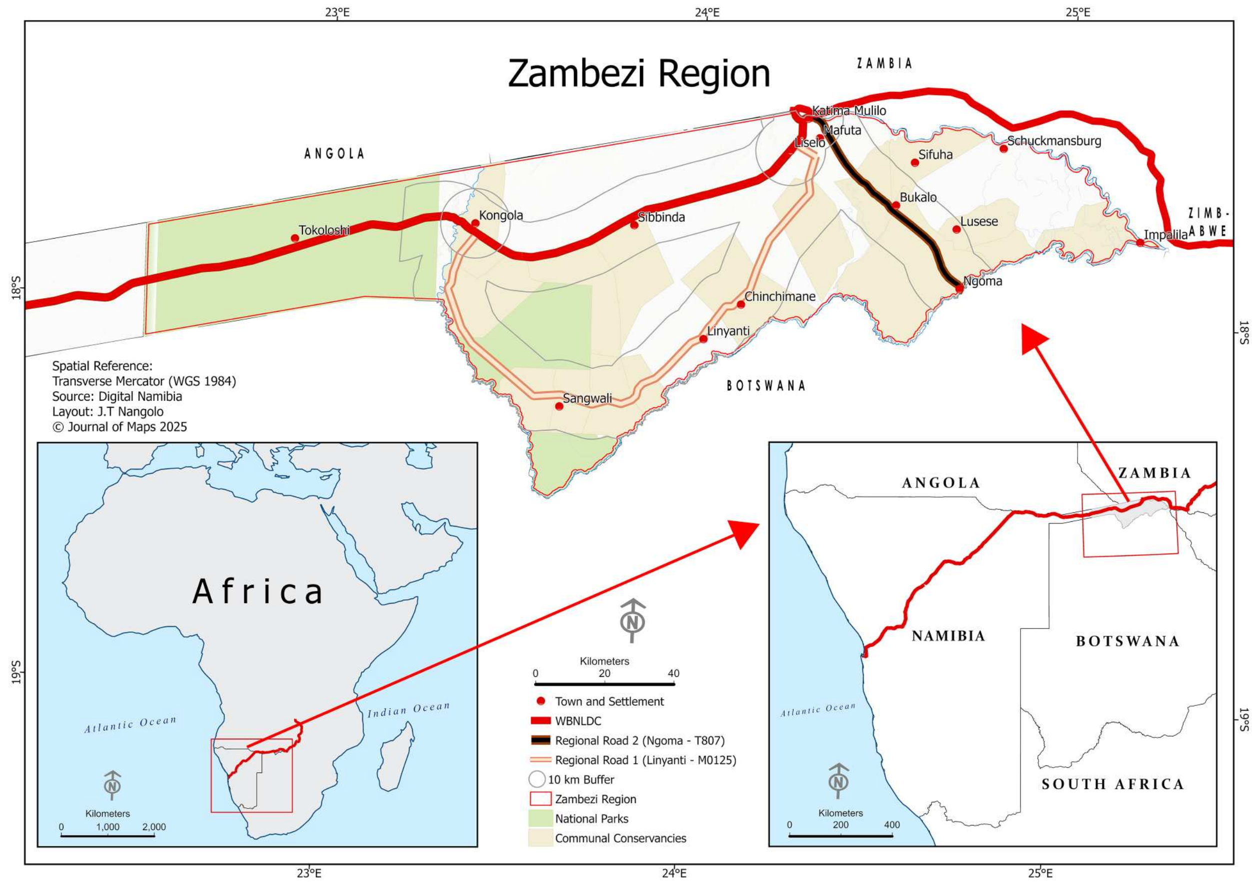

Figure 1. Map of Zambezi Region. Source: Authors' own design; Figure one shows the study area for this research, highlighting the Zambezi Region as the main focus. It includes a 10 km buffer zone along the development corridor and selected regional roads.

important milestone for the region. Planet scope images for 2023 were included to create a complete time series for analysing the land use change along the *WBNLDC* and regional roads in the Zambezi Region. Data processing was done using Google Earth Engine (GEE) due to its high computational capabilities and ability to handle large datasets. Following examples from the literature (Li et al., 2022; Sang et al., 2022), a corridor effect zone extending 10 km on either side of these roads was established, with separate buffers around the settlements and towns of Kongola, Liselo, and Katima Mulilo where the regional roads intersect the *WBNLDC*. In this study, the areas around the Katima Mulilo and Liselo intersections are combined and referred to as 'Katima' because they are close and overlap.

2.2.1. Data preprocessing

The analysis was carried out following a methodology adapted from Rufin et al. (2022). First, we searched the GEE database for all the images captured during our years of analysis. A total of 30 Landsat 7 images for 2000, 52 Landsat 5 images for 2004, 130 Landsat 8 images for 2015, and 13 planet scopes for 2023 scenes were used for the analyses. Each year of analysis was processed separately following similar steps (Figure 2) to allow for time series comparisons.

Images went through image processing to prepare them for analysis such as data cleaning, conversion to spectral reflectance and calculation of the Normalized Difference Vegetation Index (NDVI) (Equation 1), as well as computation of spectral temporal metrics (Goodwin et al., 2013; Rouse et al., 1974). For each year of analysis, we calculated the median, standard deviation, 25th percentile, 75th percentile, and interquartile range for the Green, Blue, Red, Nir, and NDVI bands (Rufin et al., 2022; Xiong et al., 2018). In order to identify agricultural land patterns, which are normally challenging in small-scale agricultural systems, we calculated the texture and contrast index based on the NDVI at various radii (Rufin et al., 2022; Xiong et al., 2018). We added auxiliary data on agriculture and built-up areas from existing sources (Reichelt-Zoho et al., 2022) to the statistical metrics to aid with image classification for 2015 and 2023. Temporal metrics, texture, contrast index, and auxiliary data were stacked together and sub-set into smaller tiles for image classification.

The formula for NDVI is as follows:

$$NDVI = \frac{Nir - Red}{Nir + Red}$$

where: NDVI is the Normalized Difference Vegetation

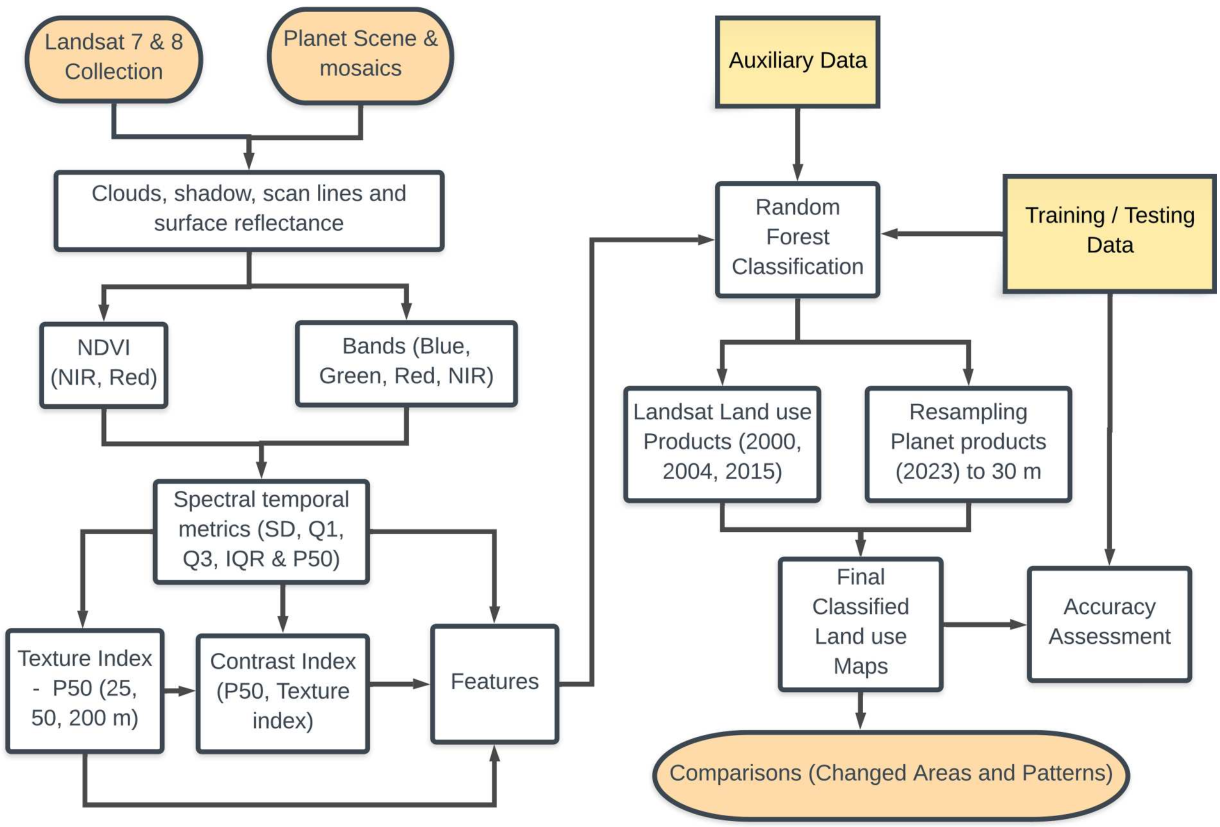

Figure 2. Workflow Diagram. Source: Authors' own design; Figure two illustrates the methods and steps used in this study, from selecting data to preprocessing, image classification, and deriving the changes and patterns of changes.

Index, NIR is the Near Infrared band, and Red is the Red band.

2.2.2. Ground truthing

To evaluate image classification accuracy, 759 randomly distributed ground control points were collected from the field in June and July 2023. These points are essential for measuring how accurately pixels are classified into the correct land cover category (Rwanga & Ndambuki, 2017; Sang et al., 2022). In this study, a confusion matrix (Lewis & Brown, 2001) was created and used to calculate the overall accuracy and the F1-score which was used as a measure of accuracy. The overall accuracy represents the percentage of correctly classified points, while the F1-score provides deeper insights into the effectiveness of the classifiers across individual classes and beyond the overall accuracy (Muntean & Militaru, 2023).

2.2.3. Land use classification and change analysis

A random forest supervised classification approach was utilised to classify the study area into six land use classes, including built-up, cultivated land, waterbody, forest, grassland, and wetland (Breiman, 2001; Rufin et al., 2022). Firstly, an independent training dataset was created using the knowledge of the study area, visual interpretation, and Google Earth. Secondly, for the first three years of our analysis, the training dataset was split into 90% for model training and 10% for testing accuracy. In the last year of analysis, the entire training dataset was used to train the model, and its accuracy was tested using the in situ ground truth data. Due to the size of the study area, a classifier was first trained based on the model training data. This classifier was later used to classify individual tiles making up the entire study area. Finally, the classified tiles were combined for further analysis.

Post-classification change detection was employed to create a land use transfer matrix, which illustrates the movement of land use across different categories over time. To measure the magnitude and rate of changes in land use categories, both rate of change, single and dynamic land use dynamic degree indices were calculated (Equations 2, 3, 4). These indices provide a quantitative assessment of the extent and speed of land use change over the study period as well as the overall land use dynamics across multiple intervals and land use categories. The following table presents the equations used to calculate these measures in the study (Sarfo et al., 2024; Xiao et al., 2024):

(1) $\textit{Rate of change}\ (\%) = \frac{A_2 - A_1}{A_1} * 100$, where A_1 is the area at the start of a study period, and A_2 is the area at the end of the study period

(2) *Single Dynamic Degree of Change* $\frac{A_2 - A_1}{A_1} * \frac{1}{T} * 100$; where T is the study duration

(3) *Comprehensive Dynamic Degree of Change* $\frac{\sum (U_{ij} + U_{ji})}{A_{total} * T} * 100$ where U_{ij} is the area of land use type $_i$ converted to type $_j$, and U_{ji} is the area of land use type $_j$ converted to type $_i$.

3. Results

3.1. Accuracy assessment

Based on the confusion matrixes, table 1 (Table 1) reveals that the overall accuracy for all years of classification is above 80%. This indicates a substantial and almost perfect agreement between the classification and the testing data (Rwanga & Ndambuki, 2017; Sang et al., 2022), making the classification reliable.

The F-score (Table 1) indicated that classes such as forest, cultivated land, and built-up land performed exceptionally well, while grassland and wetlands suggested that the model had trouble classifying these classes.

Table 1. Classification Accuracy for all years of classification and F1 score for the 2023 results.

Land use class	2023 F-score (F1)
Waterbody	0.7
Cultivated land	0.93
Built-up	0.92
Forest	0.89
Wetland	0
Grassland	0.4
Overall accuracy 2023	**80%**
Overall accuracy 2015	**86%**
Overall accuracy 2004	**85%**
Overall accuracy 2000	**88%**

Source: Authors

3.2. Land use change

Land use changes were evident along roads in the Zambezi Region from 2000 to 2023 (Figures 3 and 4). Forests remained the dominant land use throughout the study period, covering more than 40% of the area within 10 km of the roads analysed. In 2000, grassland was the second most dominant land use after forest. However, by 2023, cultivated land had become the second-largest category, accounting for about 24% of the area – an increase of 14% since 2000. Both forests and grasslands saw significant decreases by 2023, while cultivated land and built-up areas showed notable growth. Spatially, cultivated land and built-up areas were most prominent along roads and near major towns and settlements, including Katima Mulilo, Bukalo, Ngoma, Linyanti, Sagwali, Kongola, and Sibbinda. Although all roads

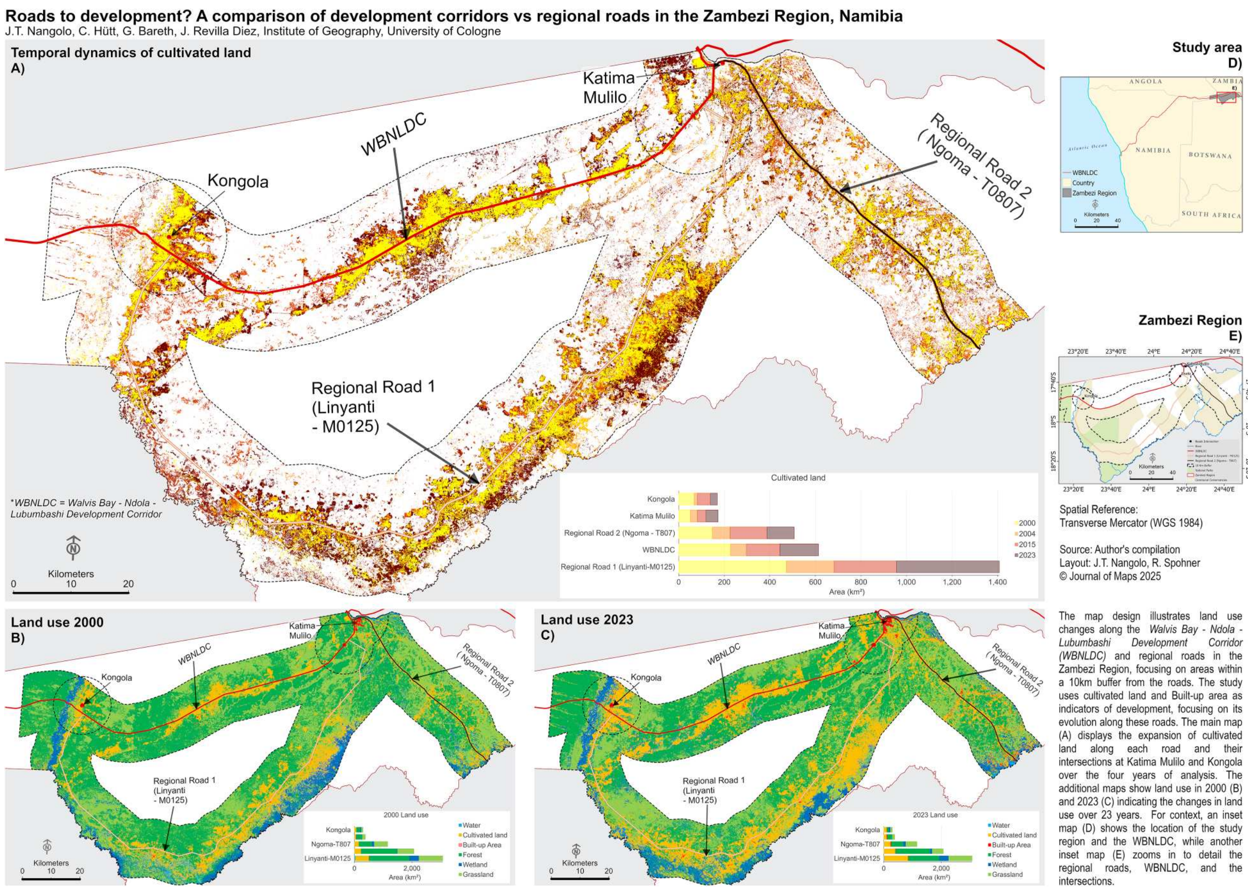

Figure 3. Land use change dynamics along the WBNLDC and regional roads in the Zambezi Region from 2000 to 2023. Source: Authors' own design. Figure three shows the land use changes within a 10 km radius along the development corridor and regional roads over a 23-year period in the Zambezi Region.

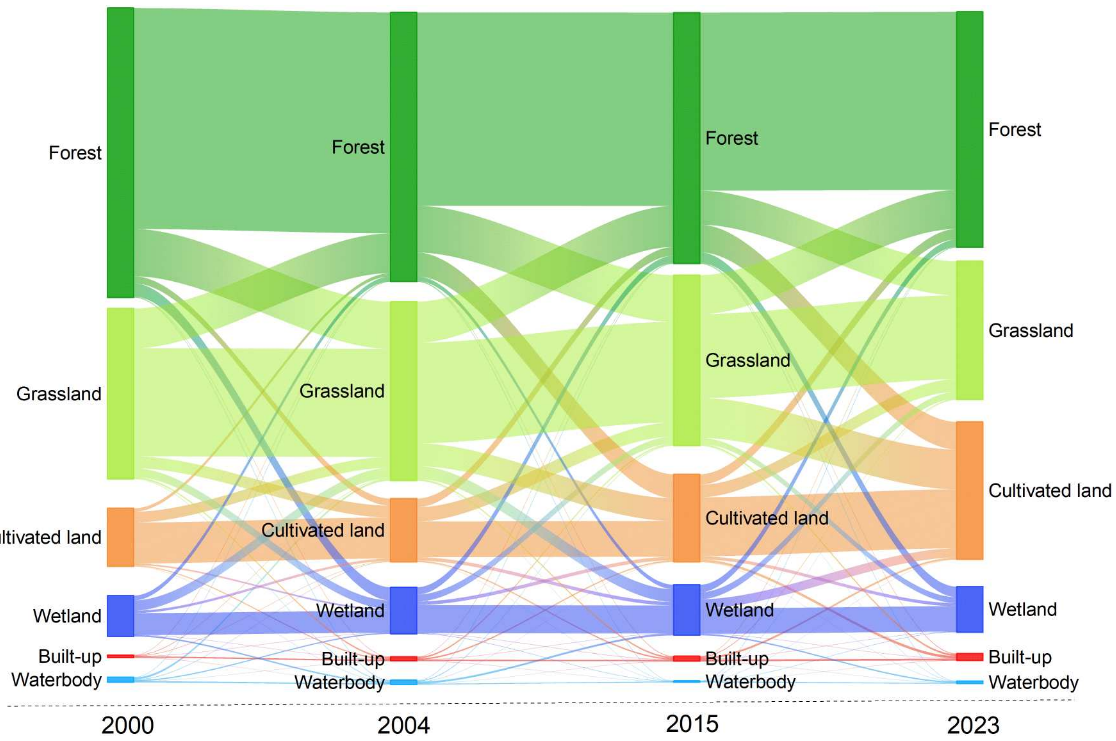

Figure 4. Land use changes along 10 km of roads in the Zambezi Region. Source: Authors's own design; Figure four shows the land use change along 10 km of all selected roads in Zambezi region from 2000, 2004, 2015 to 2023.

Table 2. Overall Land use change within the 10km buffer of all roads in Zambezi Region.

Land use class	2000 Km^2	2000 %	2004 Km^2	2004 %	2015 Km^2	2015 %	2023 Km^2	2023 %
Waterbody	60.7	0.9	49.5	0.8	18.4	0.3	32.0	0.5
Cultivated land	675.1	10.3	735.9	11.2	1018.3	15.5	1595.8	24.3
Built-up	30.4	0.5	51.2	0.8	60.0	0.9	80.8	1.2
Forest	3354.5	51.0	3118.7	47.5	2910.3	44.3	2728.4	41.5
Wetland	475.9	7.2	542.0	8.2	588.4	9.0	529.6	8.1
Grassland	1975.6	30.1	2075.0	31.6	1976.9	30.1	1604.9	24.4
Total	**6572**	**100**	**6572**	**100**	**6572**	**100**	**6572**	**100**

Source: author's calculations.

experienced an upward trend in cropland, the most changes were found at Linyanti between 2000 and 2023. Meanwhile the Ngoma Road experienced the most significant increase in built-up area.

The temporal analysis (Figure 3A) shows an upward trend in cultivated land and built-up area during the first years of analysis after the opening of the Trans-Caprivi Highway in 2000, which continued for the next eleven years after the completion of the Zambezi bridge, albeit at a very slow pace (Table 2). After 2015, coinciding with the tarring of regional roads in 2014, the rate of expansion for built-up area and cropland increased sharply.

An analysis of road types and development strategies revealed notable differences (Figure 3, Tables 3 and 4). The Linyanti Road experienced the most significant expansion of cultivated land, with the majority of the increase (419.6 km²) occurring after its tarring (419.6

Table 3. Changes in cultivated land along the WBNLDC and regional roads in the Zambezi region.

Buffer Zone	2000 Km^2	2000 %	2004 Km^2	2004 %	2015 Km^2	2015 %	2023 Km^2	2023 %	2000–2004 Km^2	2004–2015 Km^2	2015–2023 Km^2	2000–2023 Km^2	2000–2023 %
WBNLDC	201.5	34.2	231.0	36.1	324.8	36.3	399.1	27.4	29.5	93.8	74.3	197.6	98.1
Ngoma-T807	77.9	13.2	72.2	11.3	157.9	17.7	226.9	15.6	-5.7	85.7	69.0	149.0	191.3
Linyanti-M0125	309.9	52.6	336.3	52.6	411.0	46.0	830.6	57.0	26.4	74.7	419.6	520.7	168.0
Total	**589.3**	**100.0**	**639.5**	**100.0**	**893.7**	**100.0**	**1456.6**	**100.0**	-	-	-	-	-
Katima	42.9	42.2	56.4	49.3	74.0	42.7	100.1	49.2	13.5	17.6	26.1	57.2	133.3
Kongola	58.7	57.8	57.9	50.7	99.5	57.3	103.2	50.8	-0.8	41.6	3.7	44.5	75.8
Total	**101.6**	**100.0**	**114.3**	**100.0**	**173.5**	**100.0**	**203.3**	**100.0**	-	-	-	-	-

Source: author's calculations.

Table 4. Built-up area changes along the WBNLDC and regional roads in the Zambezi region.

Buffer Zone	Land use								Land use change				
	2000		2004		2015		2023		2000–2004	2004–2015	2015–2023	2000–2023	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	Km^2	Km^2	Km^2	%
WBNLDC	3.9	18.8	7.4	19.9	4.6	10.2	8.6	16.0	3.5	-2.8	4.0	4.7	120.5
Ngoma-T807	4.8	23.2	8.0	21.6	12.0	26.5	27.2	50.7	3.2	4.0	15.2	22.4	466.7
Linyanti-M0125	12.0	58.0	21.7	58.5	28.7	63.4	17.9	33.3	9.7	7.0	-10.8	5.9	49.2
Total	**20.70**		**37.10**	**100.00**	**45.30**	**100.00**	**53.70**	**100.00**	-	-	-	-	-
Katima	9.3	91.2	13.6	89.5	13.7	87.8	23.1	79.9	4.3	0.1	9.4	13.8	148.4
Kongola	0.9	8.8	1.6	10.5	1.9	12.2	5.8	20.1	0.7	0.3	3.9	4.9	544.4
Total	**10.2**	**100.0**	**15.2**	**100.0**	**15.6**	**100.0**	**28.9**	**100.0**	-	-	-	-	-

Source: author's calculations.

km^2), compared to 26.4 km² before the corridor's completion and only 74.7 km² after the corridor's completion. The *WBNLDC* also showed an upward trend in cultivated land, but the increase was comparatively smaller, with 29.5 km² before and 93.8 km² after the corridor's completion. For built-up areas, the Ngoma Road saw the largest expansion, mirroring the trend observed for cultivated land, with the most growth occurring after the tarring of regional roads. Both the Linyanti Road and the *WBNLDC* experienced similar increases in built-up areas. At road intersections, built-up area expansion was also much higher after the tarring of regional roads, with Katima Mulilo leading in built-up area growth, while Kongola recorded the largest increase in cultivated land.

From 2000 to 2004, the single dynamic degree of change (Figure 5) revealed that cultivated land had the highest expansion along *WBNLDC* (3.7%), followed by Linyanti (2.14%), while Ngoma *(2.1%)* had the lowest. However, after the completion and opening of the Zambezi Bridge (2004–2015), the results reveal a significant reductions in dynamic changes across all roads except Ngoma . In the final period (2015–2023), following the tarring of regional roads, the dynamics of cultivated land and built-up areas surged significantly. Linyanti regained its dominance in cultivated land expansion with a dynamic degree above 10%, similarly Ngoma showed substantial growth in built-up areas, leading with a dynamic change degree of 15.9%. A similar trend can be

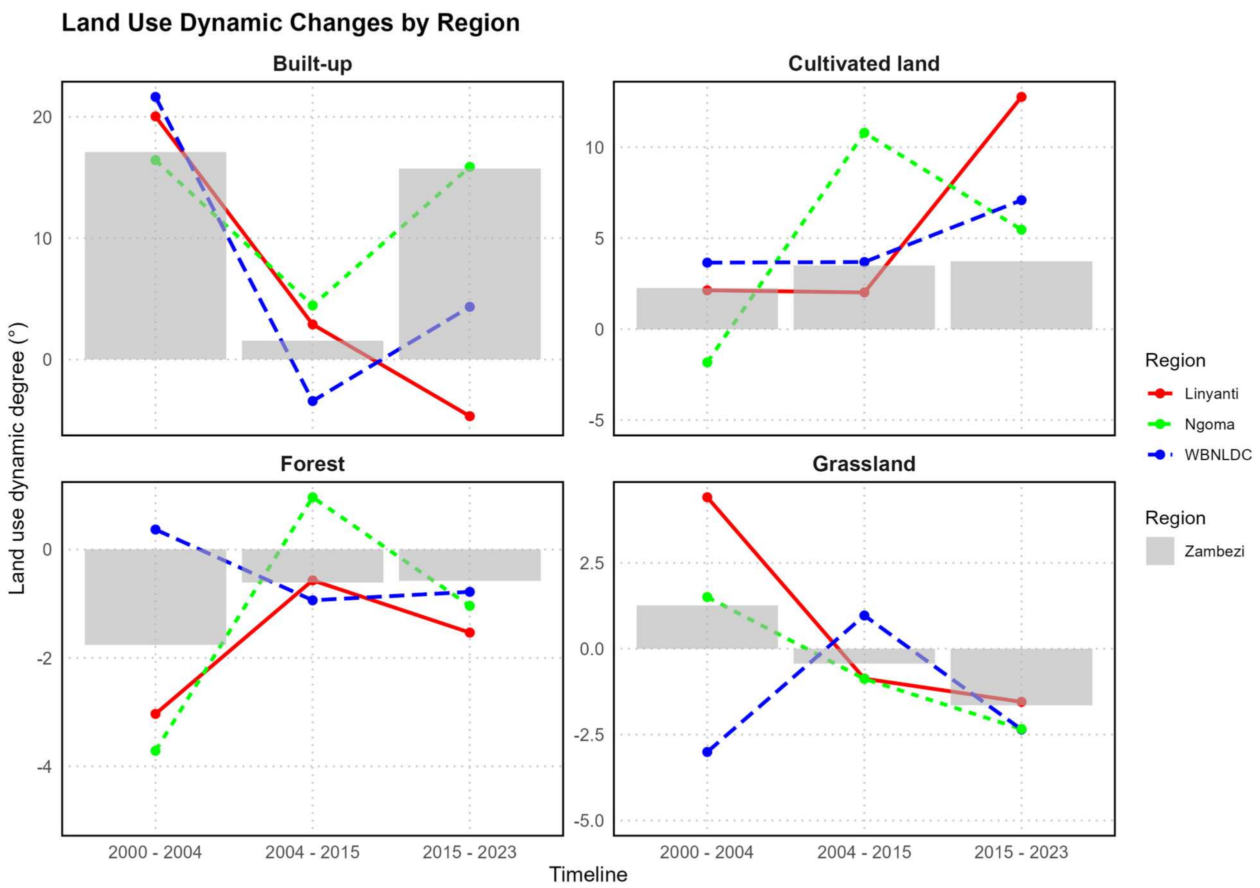

Figure 5. Single land use dynamic degree. Source: Authors' own design; Figure five shows the magnitude of change for different land use at different time periods of analysis.

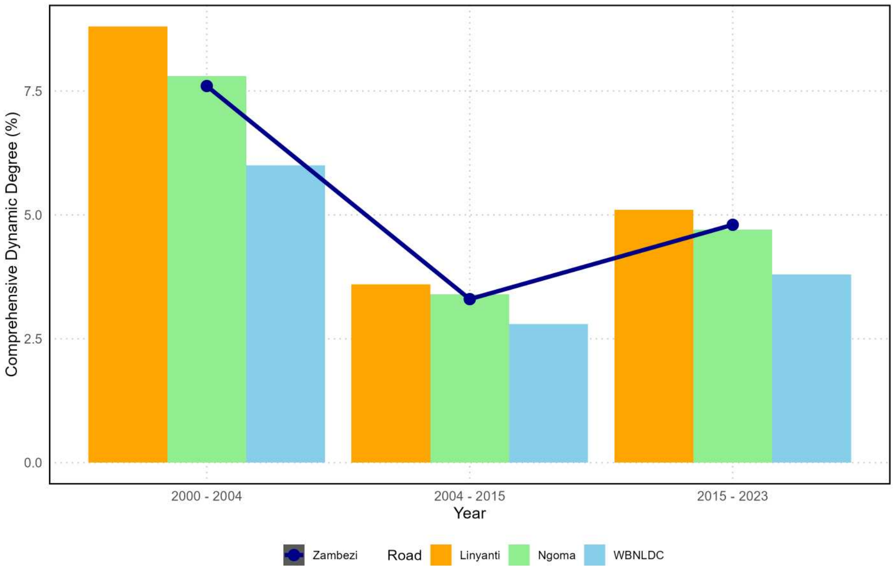

Figure 6. Comprehensive land use dynamic degree within the Zambezi Region. Source: Authors' own design; Figure six shows the overall rate of change across all land use types along different roads at different time of analysis

observed using the comprehensive dynamic degree of change (Figure 6). The Linyati road had the highest dynamic degree of land use change at the start of the analysis. However, a decline in changes was observed for all roads, with *WBNLDC* having the lowest changes. The last period of analysis (2015–2023) shows that the indices slightly increased, with Linyanti taking the lead and increasing above 5%.

4. Discussion

Overall, the findings support the idea that road construction promotes accelerated land conversion near transportation infrastructure as indicated in previous studies elsewhere (Jedlička et al., 2019; Sanchez & Moore, 2000; Zheng et al., 2021). A notable decline in forests and grasslands, as previously documented (Gbagir et al., 2019; Kamwi et al., 2017), was attributed to cultivated land and built-up area expansion. While prior research in the region has acknowledged road development as a significant driver of land use change, it often lacked a focus on the road types, timelines, and their links to regional development.

This study addressed these gaps, examining how roads affect land use change and identifying which roads are more conducive to regional development and rural livelihoods. The use of a 10 km buffer along all roads facilitated effective spatial analysis, while a time series analysis provided temporal insights by comparing changes before and after road developments. A combination of single and comprehensive dynamic degrees of change enabled the comparison across land uses and locations over time. Developmental policies and activities in the Zambezi Region and Namibia were analysed to contextualise the drivers of change. The integrated land use plan for the Zambezi Region, for instance, set objectives such as establishing an agricultural hub by 2020 and improving rural and urban livelihoods by 2025 (Ministry of Lands and Resettlement [MLR], 2015) (Figure 7).

The opening of the Trans-Caprivi Highway in 1999 was a pivotal moment for the region's development, coinciding with an increase in cultivated land. This highway aimed to connect farmers to broader markets, thus improving livelihoods. Subsequent infrastructure, such as the Zambezi River bridge, further enhanced connectivity, promising economic opportunities beyond the region's borders. Despite these advancements, cultivated land expansion rates after 2004 were lower than anticipated, suggesting the corridor's limited impact on agricultural production. Consequently, the government of Namibia introduced the Dryland Crop Production Programme (DCPP) in 2006, targeting farmers in northern communal areas, including the Zambezi Region. This programme sought to improve crop production through better seeds, fertilisers, and farming techniques (MAWF, 2017; Nakale, 2022; Kiesel et al., 2022). However, cultivated land expansion during this period remained modest, indicating that the corridor's completion had minimal influence on agricultural productivity, even when coupled with DCPP initiatives.

The tarring of regional roads, completed in 2014, marked another significant milestone. This coincided with the launch of the Comprehensive Conservation Agriculture Programme (CCAP) in 2015, which aimed to enhance the resilience of small-scale farmers to climate change through conservation agriculture (MAWF, 2017; Nghishidivali, 2023). This period recorded the highest expansion of cultivated land and built-up areas, underscoring the significant impact of road tarring on agricultural expansion

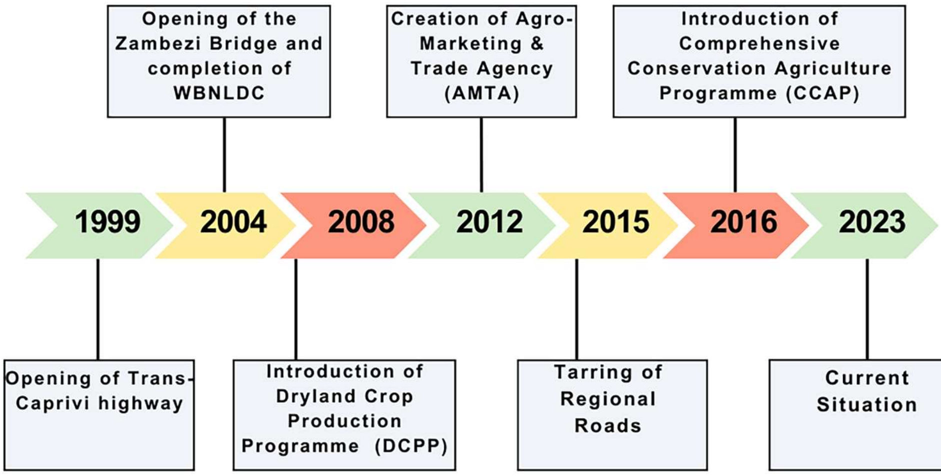

Figure 7. Policies and developmental activities in Zambezi Region. Source: Authors' own design based on (MLR, 2015, Ministry of Agriculture, Water and Forestry [MAWF], 2017; Nakale, 2022; Kiesel et al., 2022); Figure seven presents the timeline and development stages the Zambezi Region underwent during the study period, including policies related to agriculture and overall development.

compared to the previous periods. Our observations confirmed that different road types have varying impacts on land use patterns (Su et al., 2014).

Cultivated land expansion was most prominent along the Linyanti Road, while built-up areas expanded significantly along the Ngoma Road. This highlights the role of regional roads in connecting smaller settlements and facilitating both cultivated land and built-up area growth. The conditions around Ngoma, including its proximity to conservancies, agricultural land, and human settlements, likely encouraged farming activities along the road (Gbagir et al., 2019; MLR, 2015). Enhanced road connectivity, particularly through road tarring, has further implications for regional development. Improved accessibility has increased tourist influx to the Zambezi Region, prompting the construction of additional hotels and lodges to accommodate rising demand (Kalvelage et al., 2021).

This agrees with a study in Malaysia that highlighted that the regional roads play a major role in connecting settlements to the labour market and resource allocation, thus influencing the growth rate of populations in settlements (Jain & Gupta, 2023; Shashyna et al., 2021). The population in the study area was 79,826 people in 2001, growing at an annual rate of 1.3% to reach 90,596 people in 2011 (Namibia Statistics Agency, 2011). This growth was slower than the 1.8% annual increase recorded between 1991 and 2001 (Namibia Statistics Agency, 2011). However, the most significant population increase occurred after the tarring of regional roads, with an annual growth rate of 3.8% between 2011 and 2023. During this period, the population surged to 142,373 by 2023, suggesting that improved road infrastructure may have played a key role in driving this rapid growth (Namibia Statistics Agency, 2024). This strong population increase and built-up area increase after the tarring of the roads supports the idea that regional roads are much more important for regional development. Furthermore, improved connectivity has facilitated economic activity, as farmers in the region frequently travel to Katima Mulilo, a growing economic hub, to sell surplus produce (Corry & Voigts, 2023; Dlamini, 2017; Nakale, 2017; Zeller, 2009), leveraging the road's role in regional trade and the positive impact of enhanced connectivity on their livelihoods.

Kongola and Katima Mulilo have experienced expansion in terms of both cultivated land and built-up area, which could either be attributed to influences from both regional and development corridors and thus becoming potential growth poles along the corridors. It could also be due to demographic and strategic locations as previously mentioned in studies. Clearly, the WBNLDC has also enhanced its accessibility across borders, resulting in increased commercial activities and multinational investments in services such as petrol stations, supermarkets, hardware stores, and banks (Zeller, 2009). In addition, the increase in built-up areas at Katima Mulilo could be attributed to its strategic location between major tourist destinations, the Chobe River in Botswana, Victoria Falls in Zimbabwe, and Livingstone in Zambia, which has made it a popular stopover or the start of a trip to these larger attractions that are all reachable through roads. While this study has not explored these changes from other perspectives, such as employment opportunities or economic activities, future research could focus on comparing nodes along the corridor to better understand the factors contributing to built-up area expansion at specific localities.

Previous studies in the Zambezi Region have indicated that the establishment of trade routes, such as the *WBNLDC*, often leads to the growth of settlements and farms near roads, contributing to increased cultivated land and built-up areas around transportation infrastructure (Colpaert et al., 2013; Gbagir et al., 2019). Our study complements these findings by observing similar trends, with cultivated land expansion occurring notably around settlements. However, we found that the rate of cultivated land expansion was significantly lower along the WBNLDC compared to regional roads. This disparity suggests that regional roads, such as the Linyanti-M0125 and Ngoma roads, which experienced greater expansions in both cultivated and built-up areas, are more conducive to localised changes.

Based on the results and policies analysed, our results suggest that the WBNLDC might not have achieved its goal of attracting substantial agricultural investments or significantly improving rural livelihoods. This indicates that development corridors may not significantly improve rural livelihoods as initially promised. While such corridors facilitate trade and international cooperation, they should not replace policies aimed at local development. The limited cultivated land expansion along the WBNLDC implies that its expected outcomes, particularly in fostering agricultural growth, have not fully materialised. These actual outcomes reflect some of the broader challenges associated with development corridors in Africa. As noted by Müller-Mahn (2020), such corridors are often framed as pathways to modernity and progress, but they can also function as 'dreamscapes' that prioritise external economic interests over the needs of local communities. In this regard, while the WBNLDC was expected to catalyse agricultural investment, its impact on local livelihoods has been limited, raising questions about the effectiveness of such corridors in delivering the promised benefits. These findings also suggest that development strategies may succeed in regions with pre-existing infrastructure, as seen in parts of Asia (e.g. Xiao et al., 2024; Zheng et al., 2021), where large-scale corridors have fostered land use changes and economic growth. However, the true success depends on the region's specific context and the involvement of local stakeholders, particularly in rural areas, to ensure their promises materialise in an African setting. In this case, regional roads have demonstrated a more immediate and tangible impact on land use and livelihoods, emphasising the importance of localised infrastructure for sustainable rural development.

This study deliberately focused on land use changes and their implications within the Zambezi Region, using cultivated land and built-up area as key indicators of livelihoods given its cultural and economic significance providing first indicator of the potential impacts on the livelihoods. This calls for a future broader analysis encompassing multiple perspectives and proxies through direct measurements of the livelihood dynamics, such as household surveys to indicate population changes, land ownership patterns, and employment opportunities to capture shifts in livelihood and economic activity resulting from infrastructure developments.

5. Conclusion

This study assessed the impact of the *WBNLDC* corridor and regional roads on land use changes in the Zambezi Region from 2000 to 2023, focusing on cultivated land and built-up area expansion as proxies for improved livelihoods. Results revealed increased cultivated land and built-up area while forest and grasslands decreased throughout the study area. It became clear that while cultivated land and built-up areas expanded across all roads, most changes occurred along regional roads after being tarred, suggesting that they are more responsible for land use changes than the development corridor. This implies that the developmental outcome of the corridor remains rather limited and questions its contribution to poverty eradication and improving livelihoods. This suggests that large-scale infrastructure projects may not fully realise their potential at a local level without local development policies.

Software

Data processing and analysis were performed using GEE and Esri's ArcGIS Pro.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data supporting this study's findings are available upon request from the corresponding author.

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