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Increasing signs of forest fragmentation in the Cross River National Park in Nigeria: Underlying drivers and need for sustainable responses

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ABSTRACT

Protected areas are expectedly intact habitats for biodiversity and key for ecosystem conservation. However, where inadequately protected, human-induced forest fragmentation can degrade them and reduce their functioning. Therefore, monitoring forests in protected areas is essential to ascertain their protection. This paper assesses forest fragmentation in the Cross River National Park, a biodiversity hotspot in the tropical rainforest of Nigeria. Forest fragmentation was analyzed using the Driver-Pressure-State-Impact-Response framework. Fragmentation analysis of the State used class-level pattern metrics on Landsat and Sentinel images from the years 2000, 2015 and 2020. Forest fragmentation has reduced total forest area, decreased average size of forest patches, increased the number of forest patches and amount of edge. Only the isolation of forest patches has not yet reached a measurable intensity. However, spatio-temporal forest fragmentation over the years 2000, 2015 and 2020 indicates a rising trend, especially between 2015 and 2020. The Drivers, Pressures, Impacts and Responses were investigated through a systematic literature review. Many studies show that the main proximate Drivers of forest fragmentation are agricultural activities mainly by the local communities, demand for forest resources by the growing population, and by external actors through illegal logging and infrastructure building, which have increased. However, wider literature highlight issues of disproportionately blaming local resource users, and the need to examine the neglect of justice, rights and local values, and their implications for sustainable protected areas. Reported Impacts include hindered migration of the endangered Cross River gorilla and impaired ecosystem services like water cycling, carbon sequestration and disease regulation. Responses have generally excluded the local communities, have failed or are yet to become effective. There is thus a need to identify, together with the involved actors, why measures have failed and to implement more sustainable options to reduce fragmentation in the park while addressing local users' needs.

1. Introduction

Protected areas (PA) are key for biodiversity and ecosystem conservation (Watson et al., 2014). Studies have shown that a well-managed PA can preserve biodiversity effectively (Gray et al., 2016; Leverington et al., 2010). PA can thus help to achieve the Aichi Biodiversity Targets and the Sustainable Development Goals (Naidoo et al., 2019). They are equally relevant in facilitating countries to achieve land degradation neutrality (Ifejika Speranza et al., 2019). Given that many protected areas are forest landscapes, monitoring them is essential to secure their functions and to prevent downgrading, downsizing and degazettement (Pack et al., 2016).

Forest fragmentation, which is defined as the breaking up of large and continuous landscapes into smaller and isolated patches that are separated by anthropogenic-transformed matrix (Lindenmayer and Fischer, 2006), is globally pervasive and a key factor driving biodiversity loss and impairing ecosystem functions (Haddad et al., 2015). Thus, forest fragmentation, represented by a reduced area-size, a decrease of average patch-size, an increasing number of patches, isolation of patches, and an increasing amount of edges (Barnes et al., 2017; Bogaert et al., 2011), is mainly induced by anthropogenic land-use change and constitutes a major threat to the effectiveness of PA. In addition to the extinction of species, forest fragmentation leads to land conversion and land degradation (Matin and Behera, 2019), even decades after the actual fragmentation occurred (Haddad et al., 2015; Renó et al., 2016). PA-cases in the Democratic Republic of Congo (Shapiro et al., 2016) and

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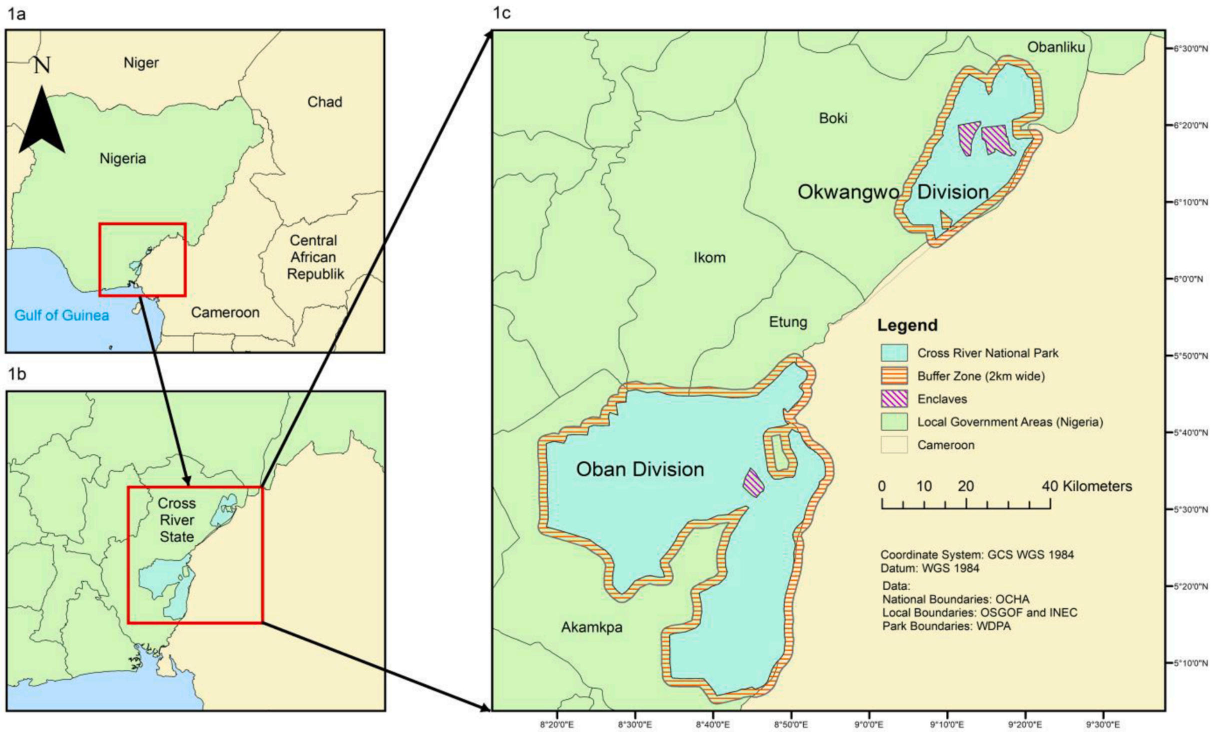

Fig. 1. Location and features of the study area (1a: Location of the CRNP in Nigeria; 1b: Location of the CRNP in Cross River State; 1c: Features of the CRNP, including enclaves, buffer zone and the Local Government Areas).

Tanzania (Zambrano et al., 2020) show, that fragmentation leads to increasing carbon emissions and disrupts biological functional diversity. Further, fragmentation alters the interaction between species and their migration between patches (Bender et al., 2003), worsens exposure to human pressure (Haddad et al., 2015) and endangers the capacity of ecosystems to conserve species richness (Barnes et al., 2017).

Globally, PA are under increasing human pressure (Jones et al., 2018), particularly in tropical regions (Geldmann et al., 2019). As their surrounding forest-landscapes are converted to other land uses, in particular agricultural land (ibid.), the pressure on PA to provide ecosystem services hitherto obtained from their surrounding landscapes intensifies (Spracklen et al., 2015). This is also the case in Nigeria, where its landscapes and PA are increasingly degraded and fragmented (Adenle et al., 2020; Adenle and Ifejika Speranza, 2020). Despite growth in size and numbers and their high potential to conserve ecosystems, most PA in Nigeria lack adequate protection or are ineffectively managed (Abdulaziz et al., 2015). Illegal logging, agricultural activities, poaching, extraction of non-timber forest products and cattle herding are major threats (Imarhiagbe et al., 2020).

However, spatially explicit knowledge is lacking about the extent of forest fragmentation in PA in Nigeria. Most studies focus on analyzing land use and land cover (LULC) without adequately focusing on PA. Given their importance as habitat for endemic species, ensuring that PA function requires generating knowledge about their status. This is particularly the case for the Cross River National Park (CRNP), the largest rain forest area in Nigeria, a biodiversity hotspot and bordering Korup National Park in Cameroon. This study thus aims to investigate forest fragmentation in the CRNP using the Driver-Pressure-State-Impact-Response-framework (DPSIR) to: 1) assess the land use and land cover change of the CRNP; 2) to explore the spatio-temporal dynamics of forest fragmentation in the division, enclaves, and buffer zone of the CRNP based on an improved set of class-level pattern metrics; 3) investigate the drivers, and pressures, associated with fragmentation in the CRNP; 4) and to investigate the impacts on biodiversity and ecosystem services (ES) of forest fragmentation and responses to reduce it. This study contributes to the broader goal of nature conservation as knowledge about the state of the CRNP and the factors driving its fragmentation will provide insights on measures for a more effective management of the national park.

2. Methods

2.1. Study area

The Cross River National Park (CRNP) is located in Cross-River State in south-eastern Nigeria (Fig. 1) and lies between lat. 5.09°N and 6.47°N, and lon. 8.31°E and 9.36°E. The CRNP is one of eight National Parks in Nigeria and is subdivided into two non-contiguous divisions: the Oban Division and the Okwangwo Division (Jacob et al., 2015). The CRNP is under the responsibility of the Nigerian National Park Service (NNPS), which is subordinated to the Federal Ministry of the Environment and led by a Conservator General. Additionally, all National Parks in Nigeria are led by a Conservator of Parks (Ambe and Onnoghen, 2019).

The park was established in 1991, intersects with five Local Government Areas (Obanliku, Boki, Etung, Ikom and Akampka) and borders the Korup National Park and the Takamanda National Park, both located in Cameroon (Fig. 1). This contiguity with PA in Cameroon makes the CRNP a potential part of a larger transboundary PA. About 105 buffer zone communities were created through the establishment of the park, some of them being enclave communities located inside the park (Enuoh and Ogogo, 2018a). However, the exact locations and extent of the buffer zone and its containing communities are not adequately defined (Ogogo et al., 2010).

The CRNP is part of the West African Guinean Forests. Its vegetation consists of moist lowland rainforest with a dry season (November – March) and a rainy season (March – November) (Jacob et al., 2015). Annual rainfall ranges between 2000 mm and 3000 mm (Adetola and Adetoro, 2014) and daily average temperatures range between 14 °C and 25 °C (Ogogo et al., 2010). The CRNP is a Pleistocene biodiversity

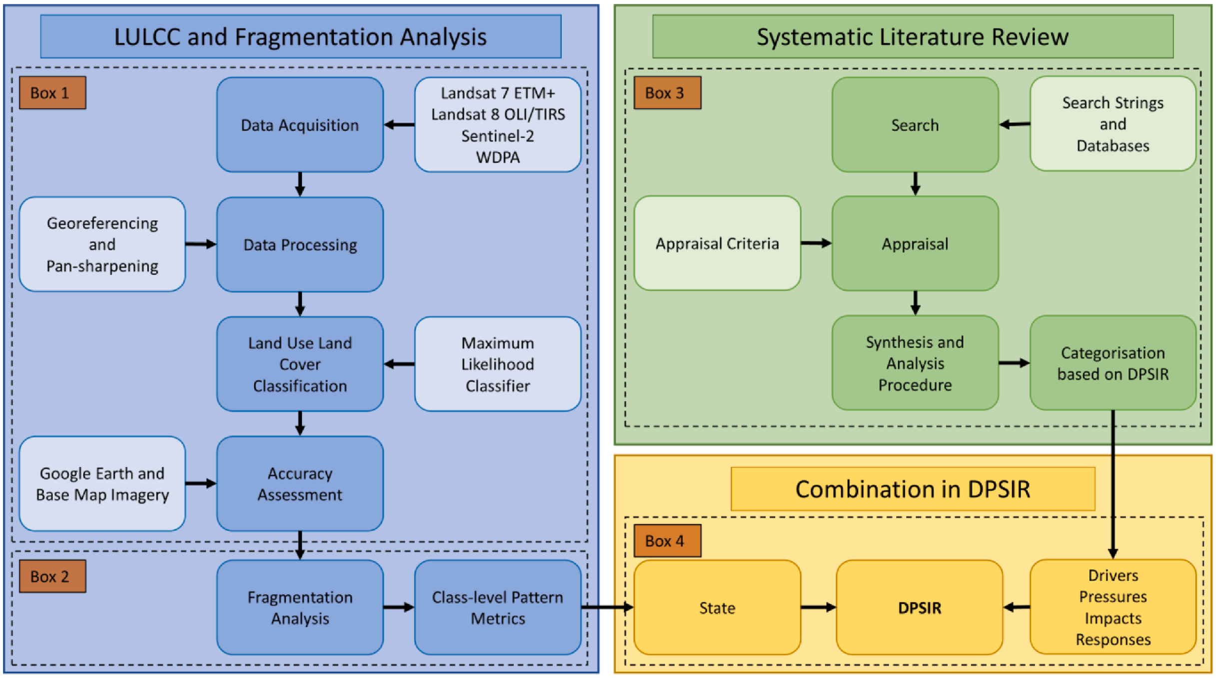

Fig. 2. Methodological workflow. LULCC: land use and land cover change; DPSIR: Driver-Pressure-State-Impact-Response; ETM+: Enhanced Thematic Mapper; OLI/TIRS: Operational Land Imager / Thermal Infrared Sensor.

refuge and home to many endemic and critically endangered species like the Cross River gorilla *Gorilla gorilla diehli*, which lives in the Okwangwo Division (Bergl et al., 2012). The national park is on the United Nations' list of 25 Biodiversity Hotspots in the World (Olory, 2018) and is an Important Bird and Biodiversity Area (BirdLife International, 2021).

2.2. The Driver-Pressure-State-Impact-Response-framework (DPSIR)

The DPSIR-framework is used to assess and analyze interactions between the environment and society and is therefore useful to describe the origins and consequences of fragmentation (European Environment Agency, 1999). The single components of the DPSIR are defined as follows (European Environment Agency, 1999; Maxim et al., 2009): Drivers are changes in social, economic, and institutional systems, which trigger, directly and indirectly, Pressure on ecosystems. Drivers can also be natural factors such as droughts, pest infestation or climate change (Brouwers et al., 2013; Forzieri et al., 2021). Pressures are the consequences of human activities, which influence ecosystems and can cause changes in the State of ecosystems. State therefore refers to the condition and changes of an ecosystem. In this study, the State describes the condition of the forest in the CRNP, which is measured by forest fragmentation. Impacts are due to the changes in the State (e.g., environmental functions), which can lead to further ecological, social, and economic impacts. Responses are the policy and management activities/actions to prevent, compensate, reduce, or adapt to changes in the environment, initiated by individuals, groups, institutions, or governments. Responses are triggered by Impacts and can be directly aimed at Drivers, Pressures, State, or Impacts. Although the DPSIR framework has been criticized for ignoring complex interactions (Gari et al., 2015; Hou et al., 2014; Tscherning et al., 2012), it provides a useful overview of the cause-effect relationships between social, ecological and economic system components (Burkhard et al., 2012; Hou et al., 2014; Mandić, 2020) and can be applied from the global to local scale (Carr et al., 2007).

2.3. Datasets and processing

Landsat data was collected from the United States Geological Survey Earth Explorer (https://earthexplorer.usgs.gov/) (Fig. 2 Box 1). The images from the year 2000 are from Landsat 7 ETM + Collection 1 Level-1, while the images for the years 2015 and 2020 are from Landsat 8 OLI/TIRS Collection 1 Level-1 (Table A.1). The years were chosen based on data availability and the least possible cloudiness (checked in Google Earth Engine). The image of 2000 was selected to serve as a baseline. A time-step of 5 years was selected so that changes in LULC are detectable. Each year required two tiles to cover the entire extent of the CRNP. The Landsat Image for the year 2020 and Path 188 / Row 056 was replaced by a Sentinel-2 image due to too many clouds, which is practicable according to Mandanici and Bitelli (2016). The shapefile of the CRNP was extracted from the World Database on Protected Areas (UNEP-WCMC, 2020).

Each image and shapefile were projected to WGS 1984 UTM Zone 32 N (Fig. 2 Box 1). Further, the Sentinel images were resampled from 10 m to 30 m, to have the same spatial resolution as the Landsat images. As each image was classified separately, no further processing was necessary (Young et al., 2017). Additional to the original Landsat images, a set of pan-sharpened Landsat images was created for better visual resolution (15 m × 15 m) and interpretation (Lin et al., 2015).

2.4. Methods

This study applies the DPSIR to assess forest fragmentation in the CRNP. To obtain information regarding the State component of the DPSIR, first a land use/land cover change classification was conducted for 2000, 2015, and 2020 (Fig. 2 Box 1) and then a fragmentation analysis of the resulting maps were undertaken (Fig. 2 Box 2). In the next step, a Systematic Literature Review (SLR) was done to acquire information concerning the Driver, Pressure, Impact and Response components of the DPSIR (Fig. 2 Box 3). Finally, the results of the fragmentation analysis and the SLR were discussed and combined in the DPSIR (Fig. 2 Box 4).

2.4.1. Image analysis

For the image analysis, the two divisions i.e., Oban and Okwangwo of the CRNP were investigated separately to distinguish the spatial differences in LULC change and forest fragmentation. In addition, the enclaves, and the buffer zone of the CRNP were investigated. Because the

Table 1
Class-level pattern metrics.

Metric	Unit	Description	Represented Effect
Total Area (TA)	km^2	Measures the total area covered by forest.	The lower the total forest area, the higher the fragmentation.
Number of Patches (NP)	Quantity	Measures the number of patches consisting of forest.	The higher the NP, the higher the forest fragmentation.
Mean Patch Size (MPS)	km^2	Measures the size of an average forest patch.	The lower the MPS, the higher the fragmentation.
Total Edge (TE)	km	Measures the total length of all forest edges.	The higher the total edge length, the higher the fragmentation.
Landscape Division Index (LDI)	0–1	Measures the probability, that two randomly chosen points are not in the same forest patch (Jaeger, 2000).	The higher the LDI, the more isolated and thus fragmented the patches.

buffer zone of the CRNP is not clearly defined (see section 2.1), a buffer zone with a width of 2 km was assumed for the further investigation of forest fragmentation. The detail of the image analysis is provided in the sections below.

Based on the downloaded Landsat and Sentinel images, the Maximum Likelihood Classifier in ArcGIS Desktop 10.7 was used to conduct a supervised classification of LULC (Fig. 2 Box 1). In addition to the Landsat and Sentinel images, high-resolution Google Earth images, base map imagery (provided directly in ArcGIS Desktop 10.7) and the previously pan-sharpened Landsat images were consulted for better visual interpretation of LULC. The LULC classes were chosen based on a previous study in the Oban Division of the CRNP by Okeke and Imong (2018) where Forest, Agriculture/Shrub-cover/Disturbed Forest, Built-up/Bare land and Water were mapped. Cloud covered areas were classified and defined as No Data. In this study, forest is defined as "land spanning more than 0.5 ha with trees higher than 5 m" (FAO, 2018: 4) and a tree canopy cover of more than 60% in the respective area (Molinario et al., 2017). Land with predominantly agricultural or urban land use was excluded from the forest class (FAO, 2018). The definitions of further land cover classes were modified from the FAO Land Cover Classification System (Di Gregorio, 2005) (Table A.2).

Subsequent to the LULC classification, a pixel-based accuracy assessment of the LULC classification was performed to quantitively assess the effectiveness of the classification (Rwanga and Ndambuki, 2017). The overall accuracies and corresponding kappa coefficients were calculated. Overall classification accuracies were rated as fit for further use when over 85 % (Wulder et al., 2006), while kappa coefficients were rated as fit for further use when better than 0.8 (Rwanga and Ndambuki, 2017). Additionally, error matrices with user's and producer's accuracies were calculated and possible confusions between LULC classes were addressed.

The forest fragmentation was analyzed (Fig. 2 Box 2) using the ArcGIS Desktop extension V-Late 2.0, a vector-based landscape analysis tool (Lang and Tiede, 2003), which has been used in other studies for fragmentation analysis (e.g. Nunes De Oliveira et al., 2017; De Matos et al., 2019). The following class-level pattern metrics (McGarigal and Marks, 1995; Turner, 1989) were calculated to capture fragmentation: Total Area, Mean Patch Size, Number of Patches, Landscape Division Index (Jaeger, 2000) and Total Edge (Table 1). These class-level pattern metrics were chosen because previous studies show that they capture fragmentation adequately (Armenteras et al., 2003; Tapia-Armijos et al., 2015; De Matos et al., 2019). Using the FAO (2018) definition, a forest patch is defined as an area that is at least 5000 m^2 (0.5 ha) large and is separated from other forest patches by other LULC classes. Thus, forest patches smaller than 5000 m^2 were per definition excluded from the Forest class.

2.4.2. Systematic literature Review

The Systematic Literature Review (SLR) was conducted based on the procedure by Mengist, Soromessa and Legese, (2020) to investigate the anthropogenic Drivers, Pressure, Impacts and Responses of forest fragmentation in the CRNP (Fig. 2 Box 3). First, 18 different search terms were formulated for the SLR (Table A.7). Terms such as "Cross River National Park", "Cross River State" or "Nigeria" were chosen to restrict the results to the area of interest. Additional terms like "Fragmentation" and "Forest Loss" were chosen to find results associated with forest fragmentation. Further terms like "Management" or "Ecosystem Services" enabled to find other processes and activities, which are linked to forest fragmentation (Table A.3). The terms were searched in the document title, abstract and keywords in the databases Web of Science, Science Direct and Scopus.

In a second step, grey literature, duplicates, presentation, keynotes, non-English or non-German literature and inaccessible publications were excluded. Peer-reviewed publications, reports from national or international conferences, publications from government bodies (local to national) and publications of non-governmental institutions have been included (appraisal criteria). In a further step, the abstracts were read. Publications irrelevant to the research objectives were excluded. An additional skim-reading of the main body excluded further irrelevant publications. In the last step, the remaining publications were synthesized. The relevant data were sorted according to Drivers, Pressures, Impacts and Responses, and finally, integrated into the DPSIR together with the results from the fragmentation analysis (Fig. 2 Box 4). The literature found through the SLR was additionally enhanced in the discussion with further important literature regarding the CRNP.

3. Results

3.1. LULC classification and change

The LULC classification in Table 2 shows that forest decreased over the 20 years period (Fig. 3a). The decrease in the 5 years between 2015 and 2020 is approximately four times bigger than in the previous 15 years between 2000 and 2015. Overall, from 2000 to 2020 52.46 km^2 of forest were lost. In contrast, built-up / bare land and agriculture / shrub-cover / disturbed forest increased during both periods. Built-up / bare land increased by 47 % (6.57 km^2) from 2000 to 2015 and by 14 % (2.90 km^2) from 2015 to 2020, whereas agriculture / shrub-cover / disturbed forest increased by 14 % (3.92 km^2) from 2000 to 2015 and by 125 % (39.14 km^2) from 2015 to 2020. Thus, the overall increase of built-up / bare land between 2000 and 2020 is 9.48 km^2, while agriculture / shrub-

Table 2
Changes in land use and land cover.

LULC Classes	2000	2015	2020	Change in Area (2000–2015)		Change in Area (2015–2020)		Change in Area (2000–2020)	
	[km^2]	[km^2]	[km^2]	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]
Forest	3252.36	3242.04	3199.00	−10.32	−0.32	−42.14	−1.29	−52.46	−1.61
Built-up / Bare Land	14.00	20.57	23.47	6.57	46.96	2.90	14.12	9.48	67.71
Agriculture / Shrub-cover / Disturbed Forest	27.30	31.22	70.36	3.92	14.38	39.14	125.35	43.06	157.75
Water	0.78	0.60	0.59	−0.18	−22.97	0.00	−0.45	−0.18	−23.32

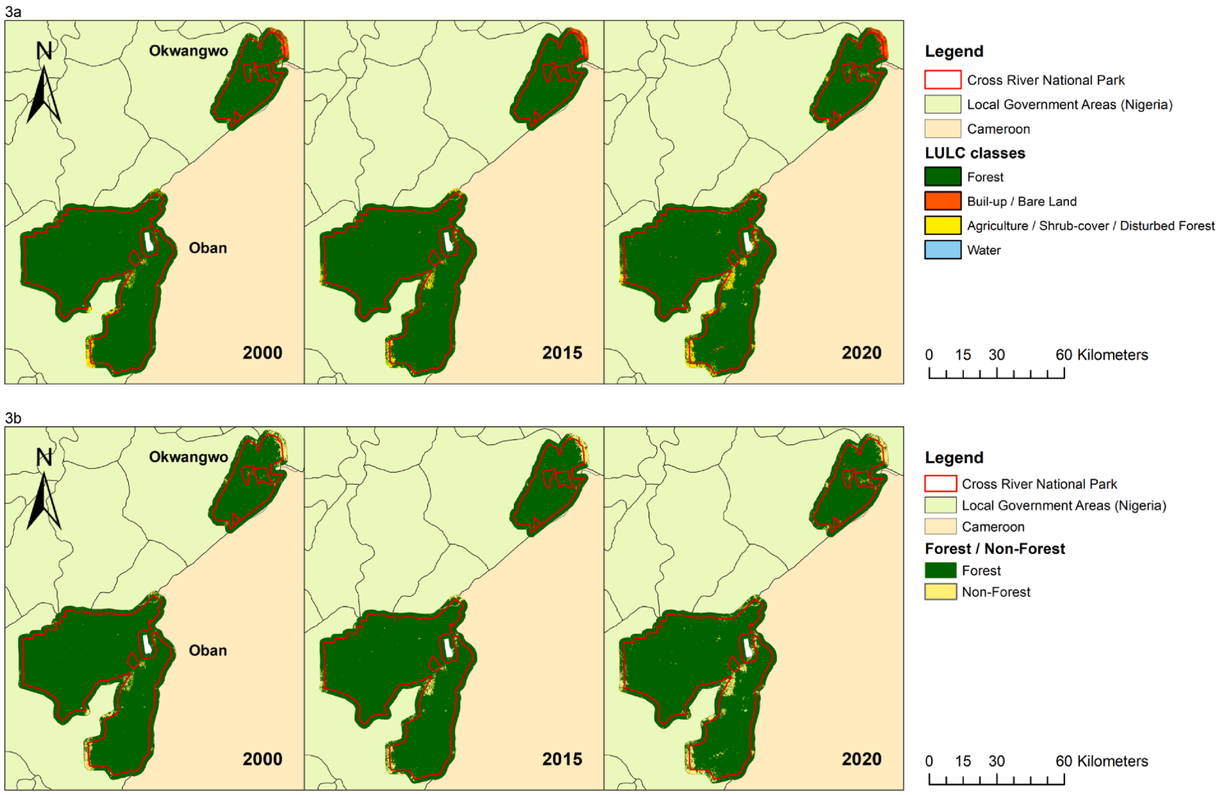

Fig. 3. The LULC map 3a and resulting fragmentation map 3b for the years 2000, 2015 and 2020, for both Divisions (Oban and Okwangwo). The areas outside the CRNP boundaries represent the buffer zone respectively the enclaves. The white area in Oban Division is neither an enclave nor in the buffer zone.

Table 3
Class-level pattern metrics for the CRNP (including both divisions). TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020	Change in Metric (2000 – 2015)		Change in Metric (2015 – 2020)		Change in Metric (2000 – 2020)	
				[%]	[abs.]	[%]	[abs.]	[%]	[abs.]
TA [km^2]	3252.36	3242.04	3199.90	−0.32	−10.32	−1.30	−42.14	−1.61	−52.46
NP [#]	67	91	257	35.82	24	182.42	166	283.58	190
MPS [km^2]	48.54	35.63	12.45	−26.61	−12.92	−65.05	−23.18	−74.35	−36.09
TE [km]	1506.48	1534.80	2252.16	1.88	28.32	46.74	717.36	49.50	745.68
LDI [0–1]	0.30	0.31	0.31	0.76	<0.00	0.13	<0.00	0.89	<0.00

Table 4
Changes of class-level pattern metrics for Oban and Okwangwo Division. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

	Oban Division Changes						Okwangwo Division Changes					
Metric	2000 – 2015		2015 – 2020		2000 – 2020		2000 – 2015		2015 – 2020		2000 – 2020	
	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]
TA [km^2]	−0.44	−11.79	−1.50	−39.67	−1.93	−51.46	0.25	1.47	−0.42	−2.47	−0.17	−1.00
NP [#]	52.08	25	219.18	160	385.42	185	−5.26	−1	33.33	6	26.32	5
MPS [km^2]	−34.54	−19.14	−69.14	−25.08	−79.80	−44.22	5.82	1.81	−25.31	−8.35	−20.97	−6.53
TE [km]	7.47	80.28	53.73	620.76	65.22	701.04	−12.04	−51.96	25.45	96.60	10.34	44.64
LDI [0–1]	0	<0.00	0	<0.00	0	<0.00	−19.05	<0.00	17.65	<0.00	−4.76	<0.00

cover / disturbed forest increased by totally 43.06 km^2. Water body, which is mainly the Cross River, stayed relatively the same during the analyzed periods.

3.1.1. Accuracy assessment

Overall accuracies of 91.14 %, 89.97 % and 92.77 % were calculated for years 2000, 2015 and 2020, respectively. In addition, the corresponding kappa coefficients were 0.87, 0.84 and 0.88 for the respective years. Both overall accuracies and kappa coefficients were rated as fit for further use. Moreover, error matrices with user's and producer's accuracy indicated primarily a confusion of built-up / bare land with agriculture / shrub-cover / disturbed forest in the years 2015 and 2020 and a confusion of agriculture / shrub-cover / disturbed forest with forest for the year 2015 (Table A.4 – A.6).

Table 5
Changes of class-level pattern metrics for the buffer zones of Oban and Okwangwo Division. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

	Oban Division Buffer Zone Changes						Okwangwo Division Buffer Zone Changes					
Metric	2000 – 2015		2015 – 2020		2000 – 2020		2000 – 2015		2015 – 2020		2000 – 2020	
	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]
TA [km^2]	0.24	1.60	−5.45	−36.69	−5.22	−35.10	1.93	4.63	−3.39	−8.31	−1.53	−3.68
NP [#]	3.28	4	92.06	116	98.36	120	−3.17	−2	39.34	24	34.92	22
MPS [km^2]	−2.94	−0.16	−50.77	−2.71	−52.22	−2.88	5.27	0.20	−30.67	−1.23	−27.02	−1.03
TE [km]	5.05	76.62	27.55	439.38	33.98	516.00	−30.03	−224.58	47.61	249.12	3.28	24.54
LDI [0–1]	−21.30	−0.14	41.84	0.22	11.62	0.08	−27.99	−0.02	1040.4	0.48	721.15	0.46

Table 6
Changes of class-level pattern metrics for Oban and Okwangwo Division. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

	Oban Division Enclaves Changes						Okwangwo Division Enclaves Changes					
Metric	2000 – 2015		2015 – 2020		2000 – 2020		2000 – 2015		2015 – 2020		2000 – 2020	
	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]	[%]	[abs.]
TA [km^2]	0.24	0.05	−3.73	−0.77	−3.50	−0.72	1.62	1.00	−5.55	−3.49	−4.03	−2.49
NP [#]	0.00	0	200.00	2	200.00	2	0.00	0	100.00	2	100.00	2
MPS [km^2]	0.24	0.05	−67.91	−13.99	−67.83	−13.94	1.62	0.50	−52.78	−16.59	−52.01	−16.09
TE [km]	0.89	0.30	50.35	17.10	51.69	17.40	−31.76	−37.14	118.50	94.56	49.10	57.42
LDI [0–1]	–	–	–	0.01	–	0.01	0.19	0.00	0.19	0.00	0.38	0.00

3.2. Spatio-temporal analysis of forest fragmentation

3.2.1. CRNP fragmentation pattern metrics

The fragmentation metrics for the CRNP (including both divisions) are shown in Table 3, while Fig. 3b shows the fragmentation map. Changes are given as percentages and absolute (abs.) values. Overall, the CRNP lost 1.61 % of its forest since 2000 and covers 3199.90 km^2 in 2020. The Number of Patches (NP) increased by 24 in the first time-step and by 166 in the second time-step. With the increase in NP the Mean Patch Size (MPS) consequently declined to 12.45 km^2 in 2020, since the Total Area (TA) did not expand. The Total Edge (TE) rose by 1.88 % in the first time-step and by 46.74 % in the second time-step, which corresponds to an increase of 745.68 km from 2000 to 2020. The Landscape Division Index (LDI) stayed approximately the same with an increase of under 1 % for all time-steps (Table 3).

3.2.2. Oban and Okwangwo Division fragmentation pattern metrics

The fragmentation metrics for the Oban and Okwangwo Division are shown in Table 4. For the Oban Division, the TA did decrease in all time-steps. 11.79 km^2 of forest was lost between 2000 and 2015 and 39.67 km^2 between 2015 and 2020. The NP increased by 25 patches in the first time-step and by 160 patches in the second time-step. With the increase in NP, the Mean Patch Size (MPS) consequently declined, while the TE increased. The TE gained around 7.5 % between 2000 and 2015 and around 54 % between 2015 and 2020. The LDI stayed approximately the same for all three years (Table 4). On the other hand, the TA in Okwangwo Division expanded by 1.47 km^2 between 2000 and 2015. In the following 5 years the TA dwindled by 2.47 km^2. Overall, the Okwangwo Division lost 1 km^2 forest between 2000 and 2020. NP decreased by 1 in the first time-step and increased by 6 in the second time-step. Consequently, the MPS increased by 5.82 % between 2000 and 2015 and decreased by 25.31 % between 2015 and 2020. The TE declined in the first time-step by 51.96 km. In the second time-step between 2015 and 2020 the TE increased again by 96.60 km. The LDI stayed under 0.00 for all three years (Table 4). More detailed metrics for both divisions and for each year can be consulted in Table A.8 and A.9 in the appendix.

3.2.3. Oban and Okwangwo Division buffer zone fragmentation pattern metrics

The fragmentation metrics for the buffer zone of Oban and Okwangwo Division are shown in Table 5. The TA of the buffer zone of Oban Division increased by 1.60 km^2 in the first time-step between 2000 and 2015. In the second time-step the TA decreased by 36.69 km^2, resulting in an overall decrease of 35.10 km^2. NP increased by 4 in the first time-step and by 116 in the second time-step. The MPS declined by 2.94 % between 2000 and 2015 and 50.77 % between 2015 and 2020. The TE increased by 76.62 km in the first time-step and by 439.38 km in the second, reaching a total growth of 516 km between 2000 and 2020. The LDI declined by 21.30 % between 2000 and 2015. In the following 5 years the LDI again rose by 41.84 % (Table 5).

In comparison, the buffer zone of Okwangwo Division gained 4.63 km^2 TA in the first time-step. In the following 5 years between 2015 and 2020 the TA again declined by 8.31 km^2, meaning an overall loss of 1.53 % forest. NP decreased by 2 in the first time-step and then increased by 24. Consequently, the MPS first increased between 2000 and 2015 and then decreased between 2015 and 2020, overall declining by 27.02 %. The TE decreased in the first time-step by 224.58 km. In the second time-step, the TE again increased by 249.21. The LDI decreased from 0.06 in 2000 to 0.05 in 2015 and gain increased by 0.48 in 2020 (Table 5). More detailed metrics for the buffer zones of both divisions can be consulted in Table A.10 and A.11 in the appendix.

3.2.4. Oban and Okwangwo Division enclaves fragmentation pattern metrics

The fragmentation metrics for the enclaves of Oban and Okwangwo Division are shown in Table 6. The enclaves in the Oban Division had expanded in TA by 0.05 km^2 between 2000 and 2015. The TA dwindled again by 0.77 km^2 between 2015 and 2020. In 2000 and 2015 the enclave contained 1 forest patch. In 2020 the NP rose to 3. Consequently, the MPS increased in the first time-step by 0.24 % and decreased by 67.91 % in the second time-step. TE grew by 0.30 km between 2000 and 2015 and by 17.10 km between 2015 and 2020. The LDI for the years 2000 and 2015 is 0 since the enclave consists of a single patch in these years. The LDI for the year 2020 is 0.01 (Table 6).

In contrast, the TA of the enclave in the Okwangwo Division increased by 1 km^2 between 2000–2015 and decreased by 3.49 km^2

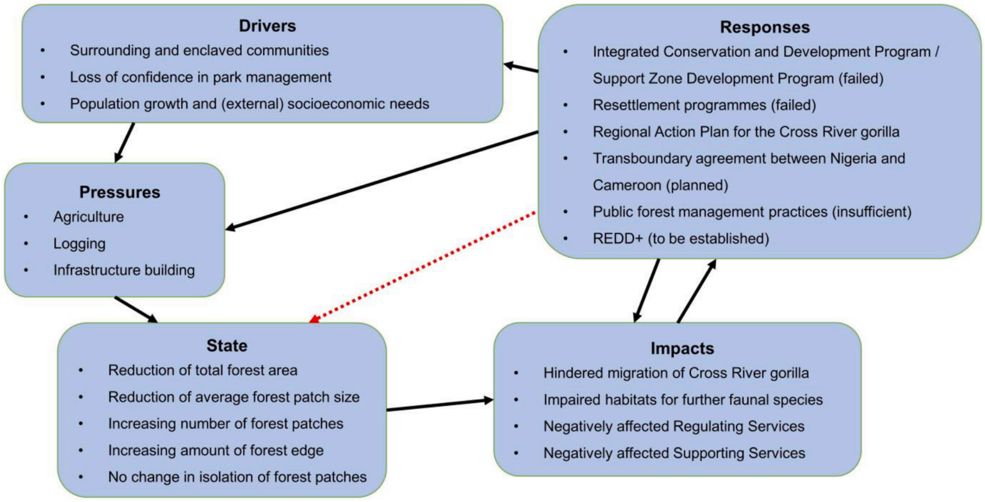

Fig. 4. The DPSIR with the combined results of the fragmentation analysis and SLR. The red dotted arrow indicates the missing Responses aimed directly at the forest fragmentation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table A1
Characteristics of the Landsat and Sentinel images used for the land use and land cover classification. ETM+: Enhanced Thematic Mapper; OLI/TIRS: Operational Land Imager / Thermal Infrared Sensor.

Satellite	Path/Row	Acquisition date [dd/mm/yyyy]	Cloud Cover [%]	Resolution [m]
Landsat 7 ETM+	187/056	10/12/2000	1.00	30
Landsat 7 ETM+	188/056	17/12/2000	0.00	30
Landsat 8 OLI/TIRS	187/056	10/01/2015	0.27	30
Landsat 8 OLI/TIRS	188/056	17/01/2015	1.47	30
Landsat 8 OLI/TIRS	187/056	24/01/2020	0.64	30
Sentinel-2	T32NMM (Tile Number)	20/01/2020	0.00	10 (sampled to 30 m)

Table A2
Land use and land cover classes and their description based on (Di Gregorio, 2005).

LULC Classes	Description
Forest	"Land spanning more than 0.5 ha with trees higher than 5 m" (FAO, 2018: 4) and a tree cover of more than 60% (Molinario et al., 2017). Land with predominantly agricultural or urban land use is excluded from the forest (FAO, 2018).
Agriculture / Shrub-cover / Disturbed Forest	Vegetation is smaller than 5 m and covers more than 10% of the surface. Woody vegetation if tree height is smaller than 5 m or tree cover<60%. Includes all agricultural landcover.
Built-up / Bare land	Vegetation covers<10% or complete lack of vegetation. Includes urban areas and roads.
Water	Waterbodies. Includes natural and artificial waterbodies.

between 2015–2020. This means an overall loss of TA of 4.03 % from 2000 to 2020. The NP was 2 for the years 2000 and 2015 and then increased to 4 in 2020. The MPS grew between 2000 and 2015 by 1.62 % and declined by 52.78 % between 2015 and 2020. TE decreased by 37.14 km between 2000 and 2015. In the following 5 years the TE again expanded by 94.56 km. The LDI increased in the first and second time-step by 0.19 % (Table 6). More detailed metrics for the enclaves of both divisions can be consulted in Table A.12 and A.13 in the appendix.

3.3. Systematic literature Review

The search terms yielded 138 publications, whereby 57 originate from Web of Knowledge, 74 from Scopus and 7 from Science Direct. The 138 publications were tested with the previously defined appraisal criteria (Fig. A.1). 72 publications were excluded (primarily duplicates). The subsequent abstract reading and main body skim-reading excluded further 50 publications, which were irrelevant to the objectives of this study. 16 publications remained for the synthesis. An additional publication of the Nigerian Federal Ministry of Environment was included afterwards.

3.3.1. Synthesis – Drivers, Pressure, Impact and Response

3.3.1.1. Drivers. The most frequently mentioned Drivers of forest fragmentation are the surrounding and enclaved communities. The communities have a long history of forest use and local management (Ite, 1998). With the establishment of the CRNP, the local people lost legal access to the park's resources. This resulted in a reduction in livelihoods with considerable costs to the communities (Ezebilo, 2012, 2011, 2010). An Integrated Conservation and Development Program (ICDP), the so-called Support Zone Development Program (SZDP), primarily financed by the European Commission (Schoneveld, 2014), was planned to compensate for these restrictions e.g. with income from tourism and investment in rural development activities (Enuoh and Bisong, 2014). However, the European Commission withdrew its financial support in 1995 due to political reasons and none of the promised interventions was implemented (Schoneveld, 2014). This led to resentment and loss of confidence in the park management by the local people (Ezebilo and Mattsson, 2010; Schoneveld, 2014). The local people are left with no alternatives but to use the forest in and around the CRNP (Ite, 1997), due to the failure of the "conservation-with-development strategy" (Ite, 1998: 140).

Similarly, the resettlement of the communities inside the CRNP to outside locations failed. With the establishment of the CRNP, the World Wide Fund for Nature (WWF) and the Overseas Development of Natural Resources Institute (ODNRI; currently Natural Resources Institute, NRI), from the United Kingdom, recommended resettling enclaved communities in the year 1989. Ever since the resettlement program is still to be implemented and communities are still located inside the park or just at

Table A3
Searching terms for the Systematic Literature Review and the number of results in the respective database.

Search Term	Web of Knowledge	Scopus	Science Direct	Acquisition date
"Cross River National Park" AND "Forest Fragmentation"	0	0	0	27/06/2020
"Cross River National Park" AND "Habitat Fragmentation"	1	1	0	27/06/2020
"Cross River National Park" AND "Fragmentation"	1	1	0	27/06/2020
"Cross River State" AND "Forest Fragmentation"	0	0	0	27/06/2020
"Cross River State" AND "Habitat Fragmentation"	1	2	0	27/06/2020
"Cross River State" AND "Fragmentation"	2	2	0	27/06/2020
"Nigeria" AND "Forest Fragmentation"	11	9	1	28/06/2020
"Nigeria" AND "Habitat Fragmentation"	21	29	1	28/06/2020
"Nigeria" AND "Fragmentation" AND "Protected Area*"	4	2	0	28/06/2020
"Cross River National Park" AND "Management"	6	13	2	29/06/2020
"Cross River National Park" AND "Biodiversity Loss"	0	0	0	29/06/2020
"Cross River National Park" AND "Forest Loss"	1	2	0	29/06/2020
"Cross River National Park" AND "Biodiversity Conservation"	4	6	2	29/06/2020
"Cross River National Park" AND "Ecosystem Service*"	1	1	0	29/06/2020
"Cross River State" AND "Ecosystem Services"	1	1	0	29/06/2020
"Cross River State" AND "Biodiversity Loss"	0	1	0	29/06/2020
"Cross River State" AND "Forest Loss"	1	1	1	29/06/2020
"Cross River State" AND "Biodiversity Conservation"	2	3	0	29/06/2020

its border (Enuoh and Bisong, 2014). Furthermore, human population growth and consequently, the growing socioeconomic demands are mentioned as Drivers of forest fragmentation in Cross River State (Ezebilo, 2010).

For the CRNP, rising rural poverty and unemployment including the absence of non-farm employment opportunities plus infrastructure development and increasing rural population were identified as common drivers of degradation (Adesina, 2012; Iwuchukwu and Igbokwe, 2012; Schoneveld, 2014).

3.3.1.2. Pressures. Agricultural land use is the most frequently mentioned human activity that causes forest loss and thus forest fragmentation. Agricultural land use includes the cultivation of cocoa, oil palm, plantain and banana through slash and burn agriculture (Enuoh and Bisong, 2014; Imarhiagbe et al., 2020). Logging also causes forest fragmentation (Adetola and Adetoro, 2014; Enuoh and Bisong, 2014; Imarhiagbe et al., 2020; Imong et al., 2014). Furthermore, infrastructural development, such as roads (Imong et al., 2014) or development corridors like the proposed Cross River Superhighway (Mahmoud et al., 2017), directly intersect with the CRNP and its surrounding forests and open up increased opportunities for further human activities like plantations and deforestation (Friant et al., 2020; Schoneveld, 2014).

According to Schoneveld (2014), the establishment of plantations in the area has created job opportunities for the communities which also trigger migration into the CRNP. The migrants later permanently settled in the region or practice subsistence farming to compensate for their loss of jobs from plantation-based employment. As Schoneveld (2014) noted, massive conversion of forests to smallholder agriculture occurred between 1986 and 2002 due to migration. Further, the collection of Non-Timber Forest Products (NFTPs) and logging Forest Timber Products (FTPs) intensified forest exploitation. Conflicting and overlapping boundaries between concessions and the CNRP foster encroachment (Schoneveld 2014), thereby encouraging the downgrading and declassifying portions of the forest reserve thus, leading to the fragmentation of dense closely packed intact forest land in the CRNP (Mascia and Pailler, 2011).

3.3.1.3. Impacts. Forest fragmentation hinders the migration of the Cross River gorilla (*Gorilla gorilla diehli*) in the Okwangwo Division (Bergl et al., 2012; Imong et al., 2014). Its enclaves hinder their migration from the northern part of Okwangwo to the southern part (Bergl et al., 2012), which can have negative long term effects on the population (Bergl and Vigilant, 2007). In combination with hunting, forest fragmentation can be devastating for the Cross River gorilla and other species (Adetola and Adetoro, 2014). Forest fragmentation negatively influences water cycling, carbon sequestration (Onojeghuo and Blackburn, 2011) and climate mitigation (Adetola and Adetoro, 2014) in both divisions. Furthermore, the region is a "hot-spot" for emerging zoonotic diseases like the Lassa Fever due to increased human-wildlife contact caused by deforestation (Friant et al., 2020).

3.3.1.4. Responses. The above-mentioned ICDP and resettlement programmes were the main Responses to prevent and reduce forest fragmentation and were aimed directly at Drivers and Pressures of forest fragmentation. But both the ICDP and resettlement programmes failed or are yet to be implemented (Enuoh and Bisong, 2014). Moreover, a Regional Action Plan aimed to promote the conservation of the Cross River gorilla in the Okwangwo Division (Imong et al., 2014), to generate knowledge and information concerning the conservation of the Cross River gorilla and suggest possible conservation interventions. Further, according to Nigeria's National Biodiversity Strategy and Action Plan (NBSAP), a transboundary agreement was brokered by the World Conservation Society (WCS) in 2008 between Nigeria (CRNP) and Cameroon (Takamanda National Park) to protect the habitat of the endangered Cross River gorilla (Federal Ministry of Environment, 2015). The agreement includes, inter alia, combating illegal logging and increasing community involvement in conservation efforts.

4. Discussion

4.1. Fragmentation analysis

For the entire CRNP, including both Divisions (but without considering the buffer zone and enclaves), 4 of 5 class-level pattern metrics indicate that forest fragmentation is occurring, both between 2000 and 2015 and between 2015 and 2020. MPS is decreasing, which indicates a more fragmented forest (McGarigal and Marks, 1995). The increasing NP combined with a decreasing TA indicates ongoing fragmentation as well (Armenteras et al., 2003; Sharma et al., 2017), likewise the increased TE (Fahrig, 2003). Only the LDI stays approximately the same, which means that isolation is not yet occurring at a measurable intensity. Considering the Oban Division independently, the metrics

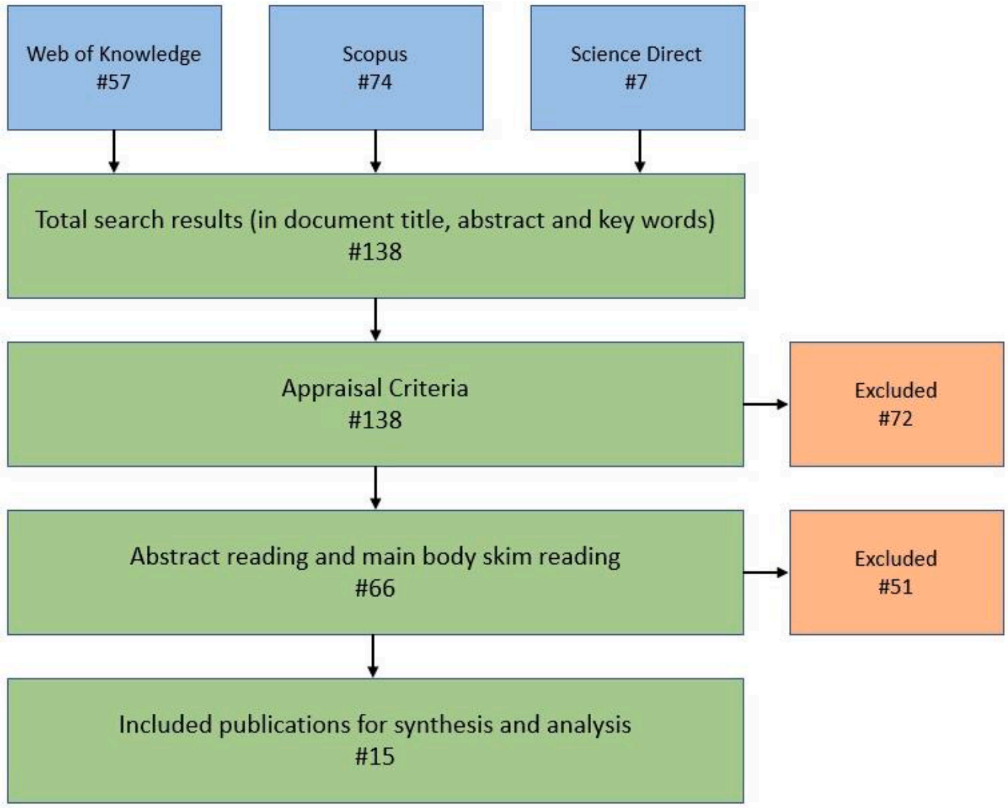

Fig. A1. Search- and appraisal-procedure of the Systematic Literature Review.

Table A4
Error matrix of the land use and land cover classification of the year 2000.

Ground Truth / Classified	Forest	Built-up / Bare Land	Agriculture / Shrub-cover / Disturbed Forest	Cloud	Water	Total	User Accuracy
Forest	115	0	2	0	0	117	98.29
Built-up / Bare Land	2	23	5	0	0	30	76.67
Agriculture / Shrub-cover / Disturbed Forest	8	0	22	0	0	30	73.33
Cloud	0	4	0	26	0	30	86.67
Water	0	0	0	0	30	30	100.00
Total	125	27	29	26	30	237	
Producer Accuracy	92.00	85.19	75.86	100.00	100.00		

Table A5
Error matrix of the land use and land cover classification of the year 2015.

Ground Truth / Classified	Forest	Built-up / Bare Land	Agriculture / Shrub-cover / Disturbed Forest	Cloud	Water	Total	User Accuracy
Forest	120	0	2	0	0	122	98.36
Built-up / Bare Land	1	27	5	0	2	35	77.14
Agriculture / Shrub-cover / Disturbed Forest	12	1	22	0	0	35	62.86
Cloud	0	0	0	0	0	0	–
Water	0	0	0	0	35	35	100.00
Total	133	28	29	0	37	227	
Producer Accuracy	90.23	96.43	75.86	–	94.59		

behave similarly. TA, MPS, NP and TE indicate that fragmentation is happening during both periods, while the LDI stays roughly the same. The buffer zone of the Oban Division experienced fragmentation as well: during 2015 – 2020, 3 of 5 metrics indicate fragmentation, while TA and LDI do not signal that fragmentation is happening. In the second time-step (2015 – 2020) all five metrics indicate that forest fragmentation is intensively occurring.

In contrast, fragmentation metrics in Okwangwo Division are different: TA and MPS increase in the first time-step (2000 – 2015), while NP and TE decrease, indicating a less fragmented and degraded

Table A6
Error matrix of the land use and land cover classification of the year 2020.

Ground Truth / Classified	Forest	Built-up / Bare Land	Agriculture / Shrub-cover / Disturbed Forest	Cloud	Water	Total	User Accuracy
Forest	114	0	1	0	0	115	99.13
Built-up / Bare Land	5	19	5	1	0	30	63.33
Agriculture / Shrub-cover / Disturbed Forest	4	1	25	0	0	30	83.33
Cloud	0	0	0	30	0	30	100.00
Water	0	0	0	0	30	30	100.00
Total	123	20	31	31	30	235	
Producer Accuracy	92.68	95.00	80.65	96.77	100.00		

Table A7
Literature used from the Systematic Literature Review.

Reference	Section in DPSIR
(Adetola and Adetoro, 2014)	Pressure, Impact
(Bergl and Vigilant, 2007)	Impact
(Bergl et al., 2012)	Impact
(Enuoh and Bisong, 2014)	Driver, Pressure, Response
(Ezebilo, 2010)	Driver
(Ezebilo, 2011)	Driver
(Ezebilo, 2012)	Driver
(Ezebilo and Mattsson, 2010)	Driver
(Friant et al., 2020)	Pressure, Impact
(Imarhiagbe et al., 2020)	Pressure
(Imong et al., 2014)	Pressure, Impact, Response
(Ite, 1998)	Driver
(Ite, 1997)	Driver
(Schoneveld, 2014)	Driver, Pressure
(Onojeghuo and Blackburn, 2011)	Impact

Table A8
Class-level pattern metrics for Oban Division for 2000, 2015 and 2020. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020
TA [km^2]	2660.20	2648.42	2608.74
NP [#]	48	73	233
MPS [km^2]	55.42	36.28	11.20
TE [km]	1074.96	1155.24	1776.00
LDI [0–1]	0.01	0.01	0.01

Table A9
Class-level pattern metrics for Okwangwo Division for 2000, 2015 and 2020. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020
TA [km^2]	592.15	593.62	591.15
NP [#]	19	18	24
MPS [km^2]	31.17	32.98	24.63
TE [km]	431.52	379.56	476.16
LDI [0–1]	$<$0.00	$<$0.00	$<$0.00

forest area. However, in the second time-step (2015 – 2020), fragmentation again increases and overtakes the state in 2000. All metrics except the LDI indicate, that the Okwangwo Division is more fragmented in 2020 than in 2015 and 2000. Fragmentation of its buffer zone is similar. In the first time-step, all metrics indicate that fragmentation is declining. However, in the second time-step (2015 – 2020), all metrics signal increasing forest fragmentation. Considering the metrics in the enclaved communities, the enclaves in both Oban and Okwangwo Division experienced almost no change in the first time-step, except for a strong decrease in TE in the Okwangwo enclaves. In the second time-step, TA,

Table A10
Class-level pattern metrics for Oban Division buffer zone for 2000, 2015 and 2020. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020
TA [km^2]	671.90	673.50	636.81
NP [#]	122	126	242
MPS [km^2]	5.51	5.35	2.63
TE [km]	1518.42	1595.04	2034.42
LDI [0–1]	0.67	0.53	0.75

Table A11
Class-level pattern metrics for Okwangwo Division buffer zone for 2000, 2015 and 2020. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020
TA [km^2]	240.26	244.89	236.59
NP [#]	63	61	85
MPS [km^2]	3.81	4.01	2.78
TE [km]	747.78	523.20	772.32
LDI [0–1]	0.06	0.05	0.53

Table A12
Class-level pattern metrics for Oban Division enclave for 2000, 2015 and 2020. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020
TA [km^2]	20.55	20.60	19.83
NP [#]	1	1	3
MPS [km^2]	20.55	20.60	6.61
TE [km]	33.66	33.96	51.06
LDI [0–1]	0.00	0.00	0.01

Table A13
Class-level pattern metrics for Okwangwo Division enclaves for 2000, 2015 and 2020. TA: Total Area; NP; Number of Patches; MPS: Mean Patch Size; TE; Total Edge; LDI: Landscape Division Index.

Metric	2000	2015	2020
TA [km^2]	61.86	62.86	59.37
NP [#]	2	2	4
MPS [km^2]	30.93	31.43	14.84
TE [km]	116.94	79.80	174.36
LDI [0–1]	0.48	0.48	0.48

NP, MPS and TE indicate that fragmentation is occurring in the enclaves in Oban and Okwangwo Division. The exception is again the LDI, which stays approximately the same.

Overall, the metrics indicate that forest fragmentation, induced by the LULC change (Fig. 3a and 3b), occurs in form of a reduction of the area-size in total, an increasing number of patches, a decrease in average patch size and an increase of edge for the entire CRNP, its buffer zone and enclaves. The LDI, which represents the effect of isolation, is the only metric that shows little change, except in the buffer zones. This implies that isolation is not yet significantly occurring in the park itself. This result supports findings from Bergl et al. (2012), who state that connectivity is still existent in the Okwangwo Division. This development is also evident in the fragmentation map (Fig. 3b): most of the forest remain intact, while the forest at the borders of the CRNP, the forest in the enclaves and the forest in the buffer zone experience high fragmentation. Moreover, it should be highlighted, that all investigated areas experienced a greater degree of fragmentation in the second time-step (2015 – 2020), although the second time-step is almost 3 times shorter than the first. This finding implies an upward trend of forest fragmentation in recent years. In addition to the induced forest fragmentation, the assessed LULC change can directly affect biodiversity and lead to land degradation as previous studies in PAs have shown (Dimobe et al., 2015; Maitima et al., 2009).

4.2. Drivers, Pressure, Impacts of fragmentation and Responses

With the establishment of the CRNP in 1991 and its borders, the local communities lost their rights to legally use the forest's resources. As the ICDP and resettlement programs failed to provide alternative livelihoods, the local communities are left with no alternatives but to continue using the CRNP's resources, however now illegally. Consequently, the local communities are turned into the Drivers of forest fragmentation in the CRNP. Cases in other PAs around the world show a similar development, where local communities experience restrictions to their traditional livelihoods with a consequent decline in their well-being due to the establishment and exclusivity of the PA (Anaya and Espírito-Santo, 2018). According to Andrade and Rhodes (2012), participation of the local people is key to the long term integrity of PAs and studies in the CRNP show, that the local communities are willing to participate in wildlife conservation (Ilori et al., 2015). Also, the IUCN calls for better involvement and participation of local communities to reach equity and an effective conservation (Borrini-Feyerabend et al., 2004).

Together with population growth and an increasing (external) socioeconomic demand, Pressure in the form of agricultural activities, illegal logging and building infrastructure is exerted on the CRNP. Here, external demands mean demands from outside the region of the CRNP itself. Agricultural activities do not only comprise self-sufficient farming but also the cultivation of cash crops for export (Agaldo et al., 2017). Similarly, logged timber (mostly for export) and its associated road-networks constitute Pressure on the forest (ibid.). Furthermore, large-scale infrastructural development like the Cross River Superhighway would have devastating impacts on the integrity of the CRNP and its surrounding forest (Laurance et al., 2017). Although the project is heavily criticized and alternative routes have been proposed (Mahmoud et al., 2017), it remains unclear if the project will be halted or continued.

Underling these drivers are government decisions in the form of a local policy shift around the CRNP which encourages plantation economy at the expense of the smallholder farmers. According to Schoneveld (2014), these historical and political factors date back to pre-independence Nigeria till the present and have made the CRNP a flashpoint for agribusiness expansion of forest frontiers. For instance, government policy on privatization promotes the sale of state-owned agricultural assets, including investment and partnership with the private sector in value chains (Adesina, 2012). According to Schoneveld (2014), the government through various privatization programs directly encouraged several large concessions in sections in or neighboring the CRNP such as to the Dangote business conglomerate, Obasanjo Farms, Dansa Food, Real Oil Mills, Brazilian energy company Petrobras to produce palm-based biodiesel. Thus, the interaction of economic investments in land and supportive government policies are non-negligible factors driving forest fragmentation.

The resulting State of forest fragmentation has Impacts on biodiversity and Ecosystem Services (ES). The Cross River gorilla is potentially threatened by fragmentation, mainly in the Okwangwo Division (Dunn et al., 2014). Its possible loss could have implications for cultural services like ecotourism, as the gorilla is the flagship species of the CRNP (ibid.). Likewise are further faunal species in the Oban Division threatened by the impairment of their habitat (Agaldo et al., 2017). ES like water cycling, climate mitigation, carbon sequestration and disease regulation are negatively affected in both divisions (Adetola and Adetoro, 2014; Onojeghuo and Blackburn, 2011).

The foreseen main Responses to forest fragmentation were the ICDP and the resettlement of enclaved communities. However, the ICDP, designed as a top-down development intervention and mainly depending on external funding, failed to fulfil its promise, despite being "attractive on paper" (Ite and Adams, 2000: 340). Likewise, the planned resettlement of enclaved communities is yet to be implemented. However, Diaw and Tiani (2010) highlight, that resettlement would separate conservation and development and not integrate them.

The Regional Action Plan (2007 – 2012 and revised 2014 – 2019) (Dunn et al., 2014) provides valuable information and recommendations concerning conservation, but it is species-limited to the Cross River gorilla and spatially limited to the Okwangwo Division. Furthermore, it inadequately addresses forest fragmentation, and its recommendations have yet to be implemented. Likewise, the transboundary agreement between Nigeria (CRNP) and Cameroon (Takamanda National Park) is yet to be officially signed and declared. In general, Enuoh and Ogogo (2018b: 405) state, that "colonial forest policy failures [and] poor public forest management practices" such as logging bans, fail to adequately address forest loss in Nigeria and the Cross River Rainforest.

A possible future Response to forest fragmentation in the CRNP is REDD+ (Reducing Emissions from Deforestation and Forest Degradation plus sustainable forest management). Several REDD + pilot sites were implemented in community forests surrounding the CRNP in the Cross River State, as Nigeria is preparing to achieve REDD + readiness. However, concerns abound regarding REDD + implementation as it leads to "reinforce[d] state control, […] re-specification of local forest governance through clustering, the militarization of the forests landscape, the widespread exclusion of local resources users from the forest economy, and elite capital accumulation" and "carbonized exclusion" (Asiyanbi, 2016: 155). Studies in current REDD + pilot sites in the Cross River State already show that REDD + fails to address environmental concerns and even denies local people access to environmental benefits (Krause et al., 2019).

4.3. Fragmentation analysis and SLR combined in the DPSIR

The combined results of the forest fragmentation analysis and the SLR in the DPSIR are shown in Fig. 4. The results of the fragmentation analysis, as discussed above, are supported by the findings of the SLR: Onojeghuo and Blackburn (2011) and Onojeghuo and Onojeghuo (2015) state that the Niger Delta Region, including the Cross River State and its PA, experience high levels of deforestation and fragmentation. However, these studies cover the situation only until the year 2014, whereas our study provides more recent results. The main Pressures revealed by the SLR, are agricultural activities and logging, and are complementary to the results of the LULC classification, where agriculture / shrub-cover / disturbed forest are the most increasing LULC classes.

According to the SLR, the main Drivers of forest fragmentation are the surrounding and enclaved local communities, together with population growth and an increasing (external) socioeconomic demand. These findings cannot be directly linked with results from the fragmentation analysis, as it is not possible to know who is responsible for changes in LULC based on satellite imagery. The metrics and the fragmentation map show, that fragmentation primarily takes place in the buffer zones and inside the park itself. However, studies reveal inadequate considerations of justice, tenure rights and local values as environmental policy instruments often disadvantage indigenous and local peoples (Aggarwal et al., 2021; Guibrunet et al., 2021; Isyaku et al., 2017). Discourses about forest fragmentation and degradation also tend to disproportionately criminalize local resource users (Ayari and Consell, 2017; Dressler et al., 2021). There is thus a need for a critical analysis of the social-ecological interactions related to forest fragmentation in the CNRP, the roles of the various involved actors, the considerations of justice and local values, to identify pathways for equitable and just use, management and governance of the CNRP. Moreover, natural drivers such as drought and pest infestation should be considered in further studies if data availability allows.

Information regarding Impacts are rather sparse and are mostly restricted to a single species, the Cross River gorilla, or general processes like climate mitigation. This deficit calls for an improved investigation on Impacts of forest fragmentation in the CRNP specifically and tropical forests generally, as it might have a more diverse outcome. For instance, Mitchell et al. (2015) state that although fragmentation is generally connoted with negative impacts such as land degradation or restricted ES provision, fragmentation or LULC change could also have positive effects, especially on the flow of ES to people. Friant et al. (2019) for example, state that an intermediate stage of deforestation and land-use change for agricultural expansion could improve and diversify diets of local communities in and around the CRNP and enable them to capitalize on forest goods and access to markets.

The Response to forest fragmentation, such as the Revised Regional Action Plan for the Conservation of the Cross River gorilla (2014 – 2019) (Dunn et al., 2014) and the planned transboundary agreement between Nigeria and Cameroon, seem ineffective, considering the results of the fragmentation analysis. If these Responses were successful, fragmentation should be less intensive in the second time-step (2015 – 2020), which is not the case as the fragmentation analysis shows. However, the Responses may show noticeable effectiveness only after a longer time. Last, Responses aimed directly at the State of the CRNP, such as reforestation, are missing (dotted red arrow in Fig. 4).

5. Conclusion

Forest fragmentation threatens the effectiveness of protected areas around the world. The present study investigated forest fragmentation in the Cross River National Park in Nigeria with the Driver-Pressure-State-Impact-Response framework. The fragmentation analysis showed that forest fragmentation is occurring in the form of a reduction in the total area of forest, a decreasing average size of forest patches, an increasing number of forest patches and an increasing amount of edge. Only the isolation of forest patches has not yet reached a measurable intensity, except in the buffer zone. Moreover, the spatio-temporal analysis indicates an upward trend of fragmentation from 2015 to 2020. Further investigation with a systematic literature review revealed the surrounding and enclaved communities, the growing population and (external) socioeconomic demand as the main Drivers of forest fragmentation. They exert Pressure in the form of agricultural activities, illegal logging and infrastructure building. The resulting forest fragmentation has negative Impacts on the Cross River gorilla and various regulating and supporting services. Responses have failed, are yet to be implemented or have yet to prove their effectiveness. These findings reveal that the park is not adequately fulfilling its functions. The alarming upward trend in fragmentation must be addressed on a regional level together with the local communities. Thus, further research needs to investigate fragmentation through field work that includes local actors, their perception of the drivers, perspectives and values to build a more robust indicator system. Such knowledge will provide a basis for identifying inclusive options that support the CRNP to effectively fulfil its conservation and development goals.

CRediT authorship contribution statement

Juri Fitz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Resources, Visualization, Writing – original draft, Writing – review & editing. **Ademola. A. Adenle:** Conceptualization, Investigation, Supervision, Resources, Funding acquisition, Project administration, Writing – review & editing. **Chinwe Ifejika Speranza:** Conceptualization, Investigation, Supervision, Resources, Funding acquisition, Project administration, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

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