Environ Monit Assess (2022) 194:60
https://doi.org/10.1007/s10661-021-09729-0

Urbanization influences small mammal composition, but not species richness in forest fragments in Accra, Ghana

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Received: 12 July 2021 / Accepted: 23 December 2021

Abstract The Accra Plain of Ghana is experiencing rapid urbanization, but there is scant information on its impact on local biodiversity. We assessed the changes in land use/land cover of the Accra Plain since 1991 and evaluated how the observed changes have influenced local small mammals in forest fragments. We applied supervised classification and intensity analysis time-series Landsat imagery data to assess land use/land cover changes between 1991 and 2017. Small mammals were surveyed in two forest fragments, the Pinkwae and Adumanya forests from June 2019 to January 2020, using capture-mark-recapture technique. We compared our data with baseline data gathered in 1991–1992, when large areas of the city remained mostly undeveloped. Our data revealed that the urban area has increased by 832%, while the forest area declined by 85% between 1991 and 2017. The Pinkwae and Adumanya forests, which covered 120 and 1.5 ha, respectively, in 1991 have each been reduced to < 1 ha. We found changes in the small mammal species composition in the forest fragments, but not species richness due to species turnover. *Grammomys poensis* and *Dephomys defua* are first records for the Accra Plain. Our data suggested that small forest fragments within the urbanizing landscape are important for maintaining the local small mammal species. For the conservation of local small mammals in urbanizing landscapes, it is important to maintain the greatest possible number of small forest fragments and establish policies that prevent forest remnants from being further depleted.

Keywords Beta diversity · Biotic homogenization · Connectivity · Land-cover change · Rodents · Sacred groves · Shrews

Introduction

Anthropogenic conversion of natural habitats into human-dominated landscapes is a major driver of global biodiversity loss. Land use/land cover change such as deforestation, agricultural intensification, and urbanization have dramatically altered natural habitats, causing declines in species diversity and alterations in community composition (Newbold et al., 2015; Hansen et al., 2016). Urbanization directly causes habitat loss; declines in species richness, abundance, and genetic diversity (Fischer & Lindenmayer, 2007); simplification of trophic structure; and alterations in biotic interactions (Mullu, 2016). The process of urbanization and urban expansions permanently transforms natural ecosystems (Jiménez-Peñuela et al., 2019), breaking up continuous forest habitats into increasingly smaller and isolated forest patches (Lindenmayer, 2019) and creating altered environments where only reduced numbers of synanthropic

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Published online: 06 January 2022

species can survive (Ofori et al., 2018; Salomão et al., 2018; Jiménez-Peñuela et al., 2019).

Naturally, many forest wildlife species occur at low densities and require large contiguous areas of intact forest to sustain viable populations (Ancrenaz et al., 2021). Consequently, international and local conservation policies and strategies have prioritized the conservation of large contiguous forests to the neglect of small forest fragments (Sodhi et al., 2010). However, recent habitat loss and fragmentation due to expansive development for urbanization, agriculture, and resource extraction imply that most contiguous forests are becoming increasingly fragmented and surrounded by human modified landscape (Urech et al., 2012; Wintle et al., 2019). Although small forest fragments may be sensitive to microclimatic, anthropogenic, and biological edge effects (Arroyo-Rodríguez et al., 2020), they serve as important habitat and stepping stones for dispersal for many species, particularly in human-dominated landscape (Baguette et al., 2013; Watling et al., 2020). Therefore, many international projects are advocating to preserve forest fragments and to transfer their management to local communities (Urech et al., 2012).

Indeed, the persistence of species in small forest fragments depends on the connectivity relationships dictated by dispersal capacity and distances between forest patches (Manning et al., 2009; de Oliveira et al., 2020). Extensive transformation of the landscape matrix surrounding forest fragments can increase the distance between forest patches and reduce their connectivity. Forest fragments that lack connectivity to other forest patches become isolated and tend to lose rare species through local extinction events (Beca et al., 2017). Therefore, any land use change or anthropogenic activities that tend to isolate forest fragments will have negative consequences for the species richness and composition of these forest fragments.

The Accra Plain of Ghana is experiencing rapid urbanization and urban expansion (Songsore & Staphens, 2008; Owusu, 2015). As a result of urbanization and a high population growth rate, coupled with economic development over the last few decades, most of the natural landscape has been transformed into built-up areas (Asongu et al., 2020). The Ghana Statistical Service (GSS) estimates that the population of the Greater Accra Metropolitan Area increased from about 1.5 million in 1984 to ~ 3 million in 2000, and then to 4 million in 2010. Although land cover and land use changes in some regions of Ghana are linked to mining, farming, lumbering, and fuelwood collection, the main driver of landscape transformation in the Accra Plain is urbanization (Benza et al., 2016; Akubia & Bruns, 2019).

Despite the rapid urbanization and urban expansion of the Accra Plain and the subsequent conversion of natural habitats to build up areas (Owusu, 2015; Agyeman, 2018), there is scant information on its effect on local biodiversity. To help bridge this knowledge gap, we assessed the rate of urban expansion of the Accra Plain and its influence on the small mammal communities in forest fragments. We considered small mammals as good model organisms for this study because of their high fecundity, reproductive rates and turnover, low dispersal capacity, and quick response to disturbances in their habitat (Pearce & Venier, 2005; Chavel et al., 2017; Cobo-Simón et al., 2019). We hypothesized that the increased human population and land use changes in the Accra Plain due to rapid urbanization, which has led to the reduction and isolation of forest fragments, will cause significant declines in small mammal species richness and abundance, and alteration in community composition in the forest fragments. The findings of our study can reveal the importance of small forest fragments in maintaining native small mammal species in rapidly urbanizing landscape and could inform urban land use planning and development.

Materials and methods

Study area

Small mammals were surveyed in the Pinkwae forest (5°45′N, 0°08′W) and Adumanya forest (05°54′N, 00°07′W) located in the Shai-Osudoku District of the Greater Accra of Ghana (Fig. 1). The Pinkwae forest has been protected by the local people since the Ga-Ashante war in 1826. The Adumanya forest is protected by the local community of the Adumanya village at the foot of the Akuapim escarpment near the Dodowa township (Decher & Bahian, 1999). The Pinkwae and Adumanya forests covered an area of 120 ha and 1.5 ha, respectively, at the time they were studied in 1991 by Decher and Bahian (1999). Urbanization and human encroachment due to the

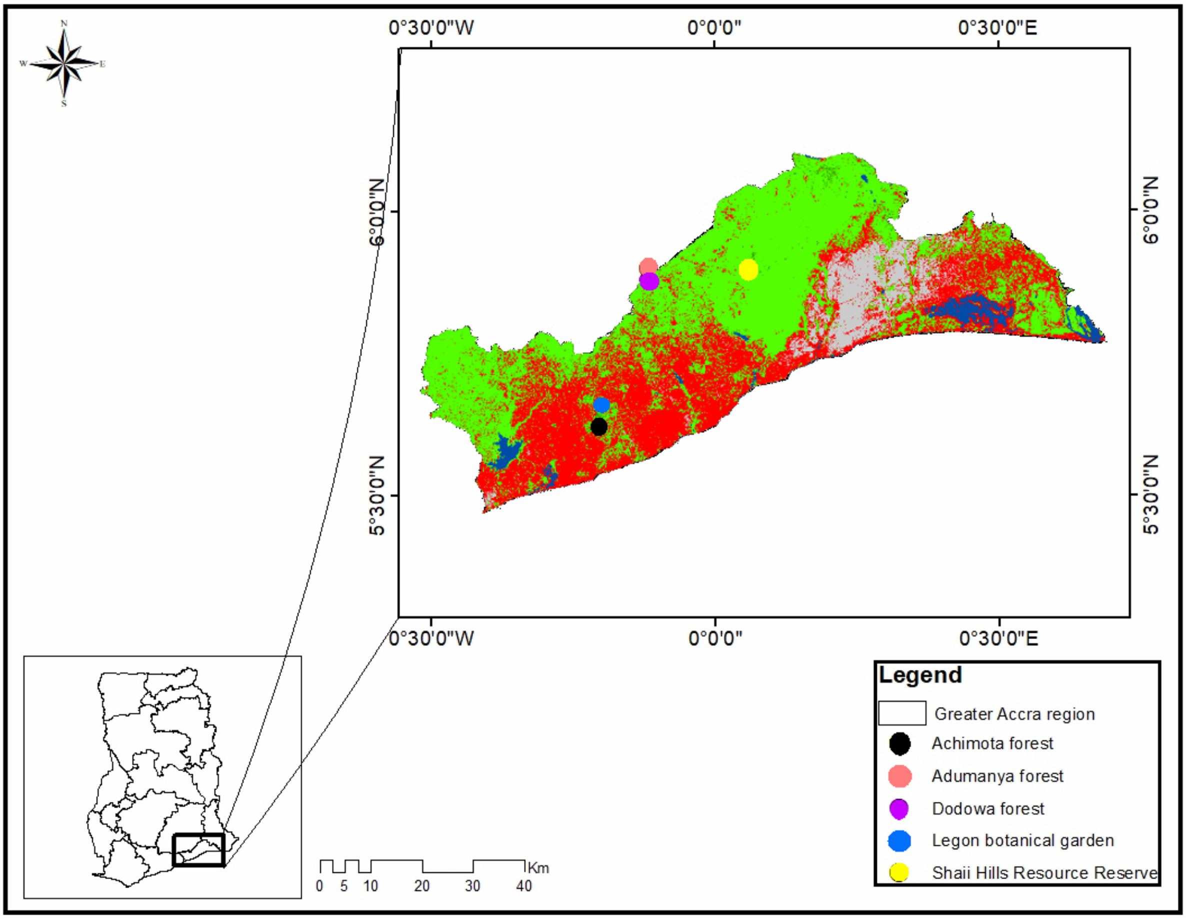

Fig. 1 Small mammal sampling locations and other green areas within the Accra Plain of Ghana

burgeoning human population of the Accra Plains have reduced the size of each forest to about 1 ha. The rainfall pattern of the Shai-Osudoku district is bimodal with a mean annual rainfall of 762.5 mm. The mean annual temperature of the area ranges from 25 to 28 °C. The average annual relative humidity is 81% and average monthly relative humidity ranges from 77% in February to 85% in June.

The Pinkwae forest is a remnant of the South-east Outlier dry forest (Hall & Swaine, 1981). The dominant tree species include *Capparis* sp., *Cissus* sp., *Diospyros abyssinica*, *Drypetes oribunda*, *Grewia* sp., *Lannea nigritana*, *Millettia thonningii*, *Strophanthus* sp., and *Uvaria ovata*. The Adumanya forest is a remnant of the high forest, with *Antiaris africana*, *Bambusa vulgaris*, *Ceiba pentandra*, *Cola gigantea*, *Elaeis guineensis*, *Trichilia prieuriana*, and *Triplochiton scleroxylon* being the dominant tree species (Decher & Bahian, 1999). The forest fragments harbor many species of mammals, birds, reptiles, and amphibians. The forests are also home to different kinds of butterflies, ants, spiders, and land snails. Large mammals such as *Tragelaphus scriptus* (Bushbuck), *Civettictis civetta* (African civet), *Nandinia biotata* (Palm civet), *Cephalophus* spp. (duikers), and *Neotragus pygmaeus* (royal antelope) were once present in the forest (Ntiamoa-Baidu, 2008), but have been extirpated due to intense hunting pressure and decline in the forest area.

Assessment of urban expansion and land use/land cover change

We assessed the rate of urban expansion and other land use/land cover change in the Accra Plain using

Landsat imagery data. Landsat images for the years 1991, 2005, 2010, and 2017 acquired during the dry season (i.e., between March and April) were downloaded from United States Geological Survey. The processing of the images, including geometric and atmospheric corrections, were made using ERDAS IMAGINE 14. The images were all georeferenced to UTM WGS 1984 projection system. A set of 100 points were collected by random sampling to represent the different LULC types using handheld GPS to train and validate the classified maps. Seventy percent of the points was used for training and the remaining points were used for validation following Abdi (2020). A supervised classification was performed with five main categories of land use/land cover types identified and classified including forest, shrubland, bareland, water bodies, and settlement. The accuracy assessment of the classification was checked by computing the confusion matrix, overall accuracy, and kappa coefficient for each year as well as the errors of omission and commission. To minimize classification errors due to image registration, all the classified maps were subjected to 3×3-pixel filtering to have a good homogeneity. Stepwise, a post classification comparison was used for land use/land cover change (LUCC) detection. Once the land use/land cover classification was established, the intensity analysis method was applied. We used appropriate equations to perform interval and category level analyses following Aldwaik and Pontius (2012).

Live-trapping of small mammals

Approval for the present study was granted by the University of Ghana College of Basic and Applied Sciences Animal Care and Research Ethics Committee (Ref. No. ECBAS 024/18–19). Live-trapping and handling protocols followed guidelines of the American Society of Mammalogists (Sikes & Mammalogists, 2016). The small mammal abundance, richness, and composition in the selected forest fragments were first studied from December 1991 to June 1992 (Decher & Bahian, 1999). In the baseline study small mammals were sampled on 1-ha grids of 10×10 trap stations 10 m apart in each of the two forests. At the Pinkwae forest two grid were established at 500 m apart, while only one grid was established at the Adumanya forest probably due to its size. Each trap station was supplied with 2 standard Sherman live traps (7.6×8.9×22.9 cm) baited with fresh palmnut shavings. Traps were set on the ground, on fallen logs, and in tree branches along the transects for three consecutive nights, with one trapping session in the dry season (December 1991 to January 1992) and another in the rainy season (May to June 1992), giving a total of 2400 trap-nights in the Pinkwae forest and 1200 trap-nights in the Adumanya forest.

We followed similar trapping protocol in the present study, but we set the Sherman traps (7.6×8.9×22.9 cm) along two line transects placed about 40 m apart in each forest fragment. At the time of the present study, the trap lines established during the baseline study was still present at the Adumanya forest, but not for the Pinkwae because that portion of the forest had been lost to urban land development. Along each transect we placed 25 Sherman traps baited with a mixture of groundnut paste, cornmeal, and palm shavings that were set on the ground, on fallen logs, and in tree branches along the transects, with inter-trap distance of 10 m. Two traps were placed at each trap station, except for the last trap station of each transect which had one trap (from experience, placing two traps per station increases the trapping success). Traps were set between 1600 and 1700 h GMT and checked the following morning between 0700 and 0800 h GMT for seven consecutive nights. Like the baseline study, there were two trapping sessions — one in the wet season (June 2019) and the other in the dry season (January 2020).

Captured individuals were transferred from the trap to a mesh handling bag and identified to species level. Standard morphometrics, such as weight (WT), head+body length (HB), tail length (TL), hind foot length (HF), and ear length (EL), sex, and reproductive status, were recorded. They were then marked and released at the point of capture. Taxonomy followed Wilson and Reeder (2005).

Data analysis

Species richness The species richness was estimated as the number of species captured at each site. We also constructed species accumulation curves using Chao1, Chao2, Jacknife1, and Bootstrap to estimate the expected species richness at each forest fragment. The species diversity and evenness were estimated using the Shannon's H' and Pielou's J' indices, respectively, as follows:

$H' = \sum_{i=1}^{R} pi \ \log_2 pi$ and

$J' = ^{H'} /_{log(s)}$,

where s is the number of species and pi is the proportion of species i in the community.

Proportional abundance This was estimated as the ratio of the number of individuals of that species to the total number of individuals of all the species captured in a particular site multiplied by 100%.

Relative abundance This was estimated as the number of individuals of a particular species captured (excluding recaptures) per 100 trap-nights. This measure is standardized and allows for comparison between different sites and time interval.

Similarity of species composition The Sorensen's similarity index was used to compare the species composition between the sites and between the present and baseline data.

The significance of differences between baseline data and present data for each species was determined using a binomial test at alpha level of 0.05. Statistical significance was defined as two-tailed p-value < 0.05. All the analyses were done using the Primer 6 software (Version 6.1.13) and R Software (Version 14.0.5).

Results

Land use/cover change over the period 1991–2017

The land use/land cover maps of 1991, 2002, 2010, and 2017 of the Accra Plain are shown in Fig. 2, while their respective land use/land cover changes are shown in Table 1. Forest and shrubland constituted the major land cover types in the year 1991. However, by 2017, settlement as a result of population growth,

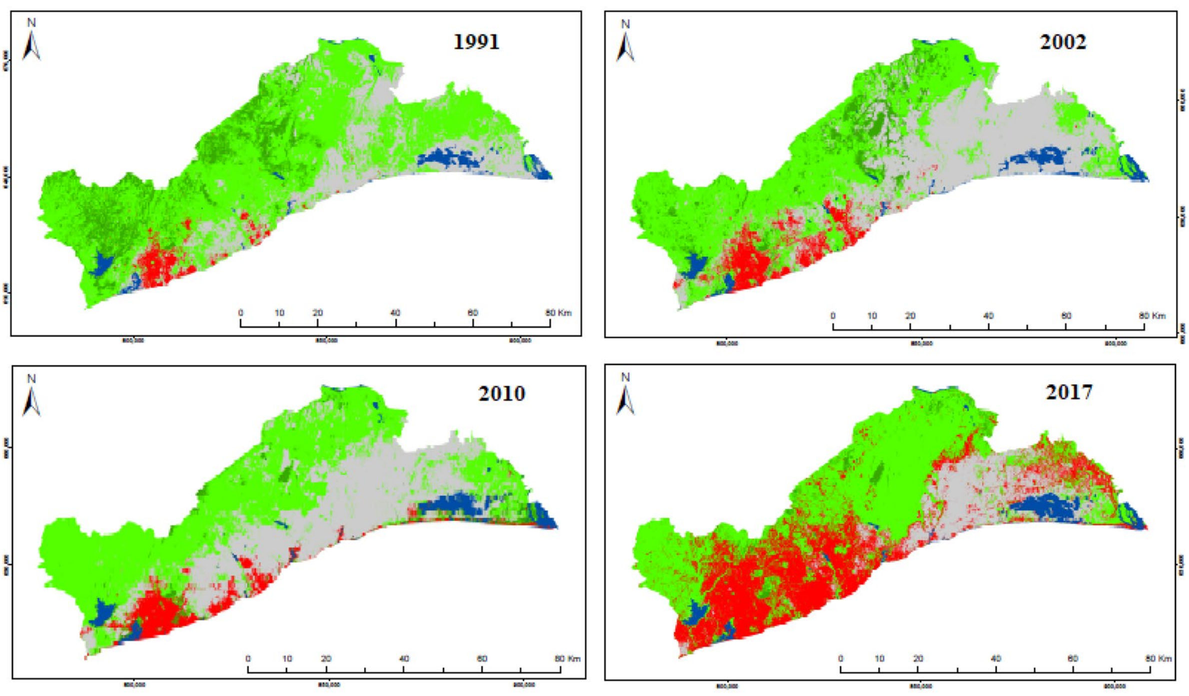

Fig. 2 Landsat imagery of the land use/land cover of the Accra Plain from 1991 to 2017 (deep green = dense forest, light green = shrubland, blue = wetland, red = settlement, grey = bareland)

Table 1 Land use/land cover changes in the Accra Plain between 1991 and 2017

Area in km^2				
Cover type	1991	2002	2010	2017
Dense forest	293.03	131.97	84.2	44.12
Settlement	114.38	230.92	240.22	1066.05
Shrubland	2103.60	1756.98	1744.959	1570.16
Water	119.94	145.31	127.53	150.42
Bareland	868.1	1373.95	1408.15	593.62
Land use land cover change (%)				
Cover type	1991–2002	2002–2010	2010–2017	1991–2017
Dense forest	−55	−36	−48	−85
Settlement	102	4	344	832
Shrubland	−16	−1	−10	−25
Water	21	−12	18	25
Bareland	58	2	−58	−32

urbanization and urban expansion, experienced the largest gain of 832%, whereas the forest declined by 85%. The fastest annual area of increase in settlement (344%) and decrease in forest (48%) occurred between 2010 and 2017. The bareland area also decreased by 58% between 2010 and 2017 (Table 1).

Small mammal abundance, diversity, and species composition

Overall, 95 individual small mammals belonging to two orders (Rodentia and Eulipotyphla) and eight species (seven rodents and one shrew) were captured in the Pinkwae and Adumanya forests in 1400 trap-nights. The overall relative abundance and species diversity (H') were 6.8% and 1.58, respectively. Seventy-six individuals of six species were captured in the Pinkwae forest, while 19 individuals of three species were captured in the Adumanya forest (Table 2). The relative abundance of small mammals was therefore 10.9% in the Pinkwae forest and 2.7% in the Adumanya forest. The Chao1, Chao2, Jacknife1, and Bootstrap species richness estimators all estimated eight species for the Pinkwae forest and three species for the Adumanya forest (Figs. 3 and 4). The species diversity (H') and evenness (J') were 1.360 and 0.86, respectively, in the Adumanya forest and 1.155 and 0.45, respectively, in the Pinkwae forest (Table 2).

The species captured in the Pinkwae forest were *Dasymys incomtus* (African marsh rat), *Hylomyscus aleni* (Allen's wood rat), *Dephomys defua* (Defua rat), *Grammomys poensis* (Shining thicket rat), *Mus musculoides* (Temminck's mouse), and *Praomys tullbergi* (Tullberg's soft-furred mouse). In Adumanya forest, *Hybomys trivirgatus* (Temminck's striped mouse), *P. tullbergi*, and *Crocidura olivieri* (African giant shrew) were captured. *Praomys tullbergi* was the most abundant species in the Pinkwae forest with 77.6% (59 out of 76 individuals) of the total captures, while *C. olivieri* was the most abundant species (52.6%; 10 out of 19 individuals) in the Adumanya forest. Also, *P. tullbergi* was the only species common to the two forest fragments, giving a low similarity index of species composition (22.2%) between the two forest fragments.

Seasonal variation in abundance, diversity, and composition

In the Pinkwae forest, 49 individuals of six species were captured in the wet season, while 26 individuals of three species were captured in the dry season. The species captured during the wet season are *D. incomtus*, *H. alleni*, *Dephomys defua*, *G. poensis*, *M. musculoides*, *P. tullbergi*, and *A. niloticus.* During the dry season only *D. defua*, *G. poensis*, and *P. tullbergi* were captured. At the Adumanya forest, 12 individuals of three species were captured during the wet season, while seven individuals of three species were captured during the dry season. The same set of species, *C. olivieri*, *P. tullbergi*, and *H. trivirgatus*, were captured during both the wet and dry seasons. The similarity of species composition between the wet and dry seasons was 73% at Adumanya forest and 63% at Pinkwae forest.

Comparison between the present and baseline data

In the baseline study, Decher and Bahian (1999) recorded 200 individuals of seven species, comprising three rodent species and four shrew species in 3600 trap-nights within the two forest fragments. The overall relative abundance and species diversity (H') were 5.6% and 1.263, respectively (Table 2). At Pinkwae forest, 93 individuals of four species was captured in 2400 trap-nights, giving a relative abundance of 3.9%, whereas at Adumanya forest, 107 indiviuals

Table 2 Abundance, diversity, and species composition of small mammals in the Pinkwae (PF) and Adumanya (AF) forests during the present study and baseline study (Decher & Bahian, 1999)

Species	PF wet	PF dry	PF total	AF wet	AF dry	AF total	Overall
Present study							
Dasymys incomtus	1	0	1 (1.3%)	0	0	0	1 (1.1)
Hylomyscus alleni	1	0	1 (1.3%)	0	0	0	1 (1.1)
Dephomys defua	6	4	10 (13.2%)	0	0	0	10 (10.5)
Hybomys trivirgatus	0	0	0	1	1	2 (10.5%)	2(2.1)
Grammomys poensis	2	1	3 (3.9%)	0	0	0	3 (3.2)
Mus musculoides	2	0	2 (2.6%)	0	0	0	2 (2.1)
Praomys tulbergi	37	22	59 (77.6%)	3	4	7 (36.8%)	66 (69.5)
Crocidura olivieri	0	0	0	8	2	10 (52.6%)	10 (10.5)
Number of individuals	49 (64.5%)	27 (35.5%)	76	12 (63.2%)	7 (36.8%)	19	95
Trap-nights	448	350	798	448	350	798	1,596
Trap success	10.90%	7.70%	9.50%	2.70%	2%	2.40%	6%
Species richness	6	3	6	3	3	3	8
Evenness (*J′*)	0.496	0.521	0.447	0.75	0.87	0.858	0.526
Diversity (*H′*)	1.283	0.825	1.155	1.189	1.379	1.36	1.579
Baseline study							
Hylomyscus alleni	0	0	0	23	5	28 (26.2)	28 (14)
Mus musculoides	2	4	6 (6.5)	0	3	3 (2.8)	9 (4.5)
Praomys tullbergi	46	32	78 (83.9)	35	37	72 (67.3)	150 (75)
Crocidura buettikoferi	0	0	0	0	1	1 (0.9)	1 (0.5)
Crocidura crossei	0	8	8 (8.6)	0	0	0	8 (4)
Crocidura lamottei	0	1	1 (1.1)	0	0	0	1 (0.5)
Crocidura poensis	0	0	0	0	3	3 (2.8)	3 (1.5)
Number of individuals	48 (51.6%)	45 (48.4%)	93	58 (54.2%)	49 (45.8%)	107	200
Trap-nights	1200	1200	2400	600	600	1200	3600
Trap success	4%	3.80%	3.90%	9.70%	8.20%	8.90%	5.60%
Species richness	2	4	4	2	5	5	7
Evenness (*J′*)	0.25	0.613	0.421	0.969	0.538	0.535	0.45
Diversity (*H′*)	0.25	1.225	0.843	0.969	1.25	1.243	1.263

of five species were captured in 1200 trap-nights, giving a relative abundance of 8.75%. Although the present study recorded higher relative abundance, diversity, and species richness than the baseline study at Pinkwae forest, the differences were not statistically significant (Table 3). Also, in the Adumanya forest, we found no statistically significant differences in the species richness, relative abundance, and diversity between the present and baseline studies (Table 3). However, we found changes in the species composition. The shrews *Crocidura crossei*, *C. lamottei* (in Pinkwae forest) and *C. buettikoferi*, *C. poensis* (in Adumanya forest) that were captured in the baseline study were not recorded in the present study. Also, the rodents *Grammomys poensis*, *Dephomys defua*, *Dasymys incomtus* (in Pinkwae), and *Hybomys trivirgatus* and the shrew *C. olivieri* (in Adumanya) that were captured in the present study were not recorded during the baseline study. The rodents *Praomys tullbergi*, *Hylomyscus alleni*, and *Mus musculoides* were common to both the present and baseline studies. Therefore, the similarity of species composition (Sorensen's index) between the present and baseline studies was 40% for the Pinkwae forest, 25% for Adumanya forest, and 40% for the two forest fragments combined.

All the small mammals recorded in this study are common and widespread across the country and are

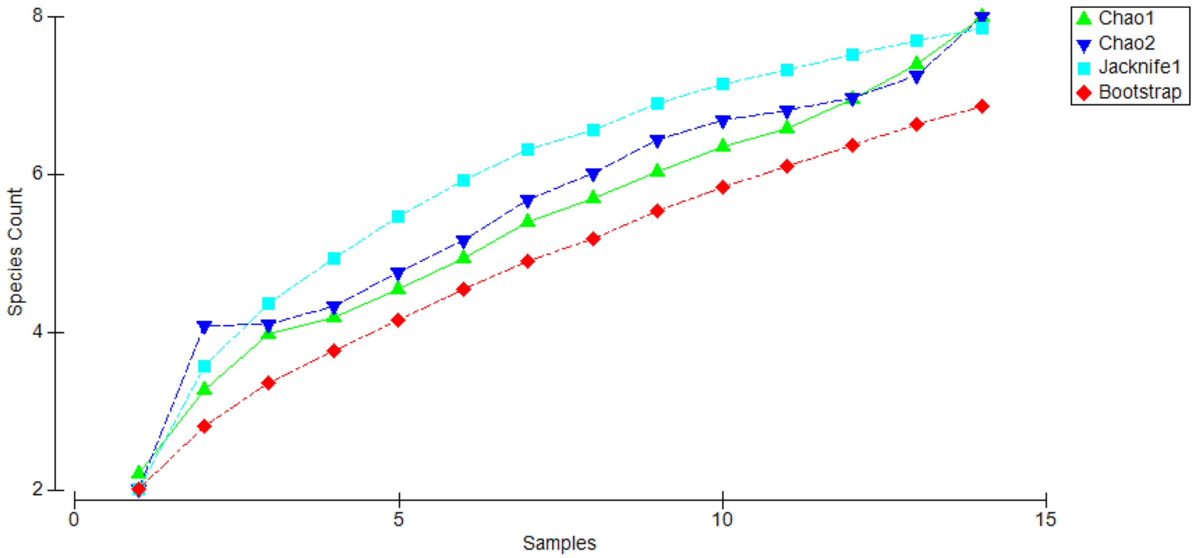

Fig. 3 Species accumulation curves of the different species richness estimators for the Pinkwae forest

listed as Least Concern by the IUCN Red List. They are also endemic to the Upper Guinean forest. Similarly, the shrews that have disappeared from the study area are endemic to the West African rainforest, but are common and known from several localities in the country. They are also listed as Least Concern because widespread distribution across their range and there is no evidence to suggest that their populations are declining.

Discussion

We assessed the land use/land cover change in the Accra Plain of Ghana between 1991 and 2017 and the influence of urbanization on the small mammals in two forest fragments by comparing the diversity, abundance, and species composition with baseline data collected in 1991–1992 (Decher & Bahian,

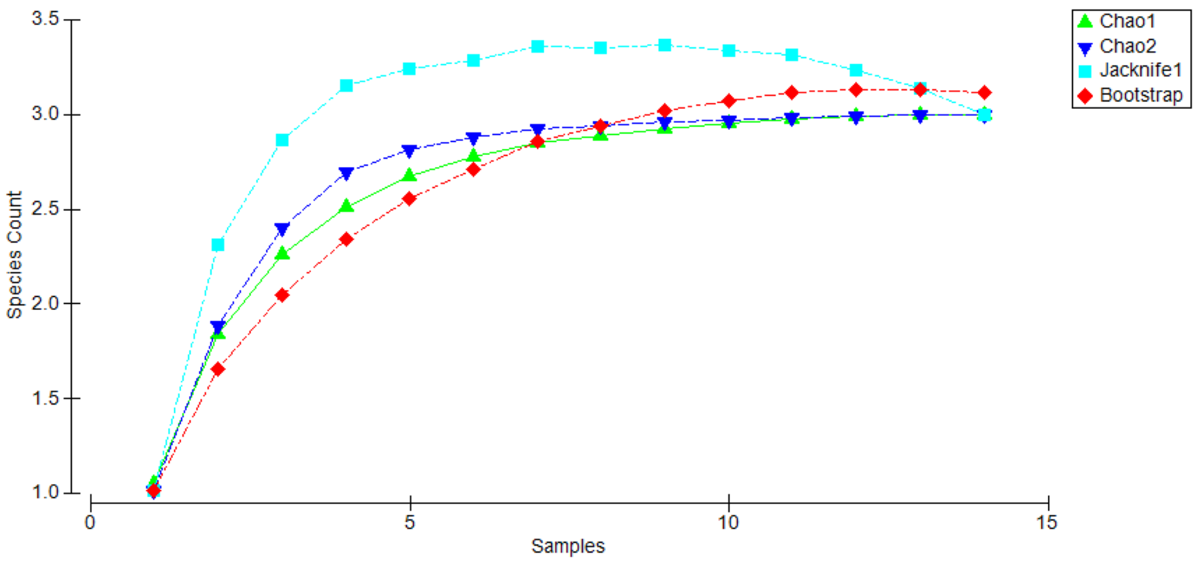

Fig. 4 Species accumulation curves of the different species richness estimators for the Adumanya forest

Table 3 Differences in relative abundance, species richness, and diversity of small mammals between the baseline (1991–1992; Decher & Bahian, 1999) and present (2019–2020) studies. The significance of differences between the baseline and present data was determined by a binomial test and indicated by a *P*-value

Species	Pinkwae				Adumanya			
	Baseline	Present	Overall	*P*-value	Baseline	Present	Overall	*P*-value
Crocidura buettikoferi	0	0	0	-	0.08	0	0.05	0.78
Crocidura crossei	0.33	0	0.25	0.57	0	0	0	-
Crocidura lamottei	0.04	0	0.03	0.84	0	0	0	-
Crocidura olivieri	0	0	0	-	0	1.25	0.5	0.26
Crocidura poensis	0	0	0	-	0.25	0	0.15	0.62
Dasymys incomtus	0	0.13	0.03	0.72	0	0	0	-
Dephomys defua	0	1.25	0.31	0.26	0	0	0	-
Grammomys poensis	0	0.38	0.09	0.54	0	0	0	-
Hybomys trivirgatus	0	0	0	-	0	0.25	0.1	0.62
Hylomyscus alleni	0	0.13	0.03	0.72	2.33	0	1.4	0.13
Mus musculoides	0.25	0.25	0.25	1	0.25	0	0.15	0.62
Praomys tulbergi	3.25	7.39	4.28	0.2	6	0.88	3.95	0.05
Trap success	3.88	9.52	5.28	0.12	8.92	2.38	6.31	0.05
Species richness	4	6	8	0.53	5	3	6	0.05
Diversity (*H′*)	0.843	1.155	-	0.83	1.243	1.36	-	0.092
Evenness (*J′*)	0.421	0.447	-	0.98	0.535	0.858	-	0.078

1999), when large areas of the Accra Plain remained mostly undeveloped. We hypothesized that increased human populations and its associated urban expansion of the Accra Plain will cause significant declines in species richness and abundance, and alteration in community assemblages in the forest fragments. Our data indicated that the urban area as measured by settlement increased by 832%, whereas the forest declined by 85% between 1991 and 2017. As expected, our results showed alteration in the small mammal species composition in the forest fragments, but contrary to our expectation, we found no significant changes in the species richness and abundance. The change in species composition observed in this study supports the findings of several studies that suggest that urbanization is a major driver of alterations in local species composition (e.g., Pauchard et al., 2006; McKinney, 2008; Shochat et al., 2010; Seto et al., 2012; Scherner et al., 2013; Seto et al., 2013; Sushinsky et al., 2013; Aronson et al., 2014; McPhearson et al., 2016; Ofori et al., 2018).

The Chao1, Chao2, Jacknife1, and Bootstrap species richness estimators all estimated eight species for the Pinkwae forest and three species for the Adumanya forest (Figs. 3 and 4), which suggests that our trapping effort was just enough to include most, if not all, of the species currently harbored by the two forest fragments. The change in small mammal species composition, but not species richness and abundance, may be due to species turnover, i.e., the disappearance of a set of species and their subsequent replacement by another set with unique composition. This assertion is supported by the low similarity of species composition (≤ 40%) between the present and baseline studies for the two forest fragments. For instance, the forest specialist species *H. alleni*, *Crocidura poensis*, and *C. buettikoferi* that occurred at the Adumanya forest in the past were not captured in the present study. Interestingly, the habitat generalist species *Crocidura olivieri* that form the bulk of the captures at the Adumanya forest in the present study was not recorded in the baseline study. Also, at the Pinkwae forest, the ground-dwelling forest obligate shrew species *Crocidura crossei* and *Crocidura lamottei* seem to have been replaced by *Dephomys defua* and *Grammomys poensis*, which are also forest obligate, but arboreal rodent species. We also found low similarity of species composition between the two forest fragments.

Change in species composition over geographical time and space is a typical characteristic of community structure (Kelt et al., 1996). The distinctiveness or dissimilarity of species composition among habitats (beta diversity) is generated broadly by geographical distance and environmental differences among the habitats (Steinitz et al., 2006). Restrictions on dispersal may produce autocorrelated distributions of individuals of each species, causing distant areas to harbor different sets of species because of dispersal limitations (Nekola & White, 1999; Melo et al., 2009). In contrast, ecological theory predicts that species are limited in space by their niche requirements, so that areas with contrasting environmental conditions would harbor different sets of species (Steinitz et al., 2006). Therefore, differences in floral composition and structure of habitats in geographically similar or different areas or the same habitat over different time periods could result in dissimilarity of their faunal composition (Reed & Clockie, 2000; Webala et al., 2006). Similarly, differences in environment conditions (abiotic and biotic variables) of the same habitat over time may influence its faunal composition. The fragmentation of the forest might have decreased the number of tree species and produced substantial changes in the forest community attributes, including abiotic and biotic variables. Therefore, it is fair to say that the changes in the small mammal community composition of the forest fragments over time could be a reflection of the changes in the forest structure and quality of the habitat over the two study periods.

Although the Pinkwae and Adumanya forests are within the same geographic location and experience a more similar abiotic conditions, particularly the amount of rainfall and solar radiation, they had only one species (*Praomys tullbergi*) in common. The low similarity of species composition between the two forest fragments may reflect subtle environmental differences between them rather than dispersal limitation given that the two sites are not too far apart. The Pinkwae forest had a lot of bigger and taller trees, lianas, ground litter cover, and fallen logs than the Adumanya forest. The Adumanya forest also looked more homogeneous in terms of the size (diameter at breast height) and height of trees, as well as the canopy structure compared to the Pinkwae forest. Arboreal species normally use lianas to reach tree branches and canopies; thus, it was not a surprise to record the arboreal rodents *D. defua*, *G. poensis*, and *H. alleni* at the Pinkwae forest.

The rodent *Hylomyscus alleni* that disappeared from the Adumanya forest is a primary forest specialist that dwells in the canopies of emergent tress. Thus, the felling of mature timber trees at the Adumanya forest, which happen to be the emergent trees, might have destroyed the habitat of this rodent species, driving it out of the forest. The shrews that disappeared from the two forest fragments are of the genus *Crocidura* (family Soricidae, order Eulipotyphla), which is the most speciose among African mammal genera (Happold, 2013). *Crocidura poensis*, *C. crossei* and *C. lamottei*, and *C. buettikoferi* are primary forest specialists that have an ecological preference for closed canopy forests with dense understorey and ground litter cover (Nicolas et al., 2009). They dwell and forage mainly among the leaf litter and on the surface of the ground. They prey primarily on arthropods, earthworms, and mollusks, and are thus ecologically important as secondary consumers (Churchfield et al., 2004). Although they may be locally abundant, they have short life span, restricted dispersal capacity, and respond quickly to anthropogenic changes in their environment (Igbokwe et al., 2019). Most *Crocidura* spp. have been shown to respond to canopy height, canopy cover, and density of trees (Nicolas et al., 2009). Therefore, the shrews that disappeared from the forest fragments signify the increasing human presence in and disturbance of the forest, including the felling of emergent trees at the Adumanya forest and removal of the understorey vegetation at the two sites.

The actual mechanism driving the local disappearance of the species, although unknown, could be explained by the extinction vortices. According to Gilpin and Soulé (1986), as populations decline, an insidious mutual reinforcement can occur among biotic and abiotic processes such as environmental stochasticity, demographic stochasticity, and inbreeding, driving population size downward to extinction. The destruction and fragmentation of the habitats of *C. poensis*, *C. crossei* and *C. lamottei*, and *C. buettikoferi* caused declines in their population size and a corresponding increase in variability, making the populations patchy and vulnerable. The small populations, which exhibited low genetic diversity, might have increased the risk of inbreeding depression and population genetic load, and a decrease in the populations' adaptive potential, eventually resulting in their local extinction.

The current occurrence of the shrew *C. olivieri* (in Adumanya) and rodents *Grammomys poensis*, *Dephomys defua*, *Dasymys incomtus* (in Pinkwae), and *Hybomys trivirgatus* (in Adumanya) in the study area may be in direct response to the changes in the structure of the forests and disappearance of the suitable habitats that they once occupied within the rapidly urbanizing Accra Plain. *Crocidura olivieri*a are habitat generalist species with preference for openings within forests (Barrière et al., 2009). Their movement into the Adumanya forest is therefore an indication of the openness of the forest canopy due to the felling of the emergent trees. Despite the logging of some emergent trees in the Pinkwae forest, the site still has quite a number of mature tall trees that provide suitable habitat for *G. poensis*, *D. defua*, and *H. alleni*. Also, because the now ~ 1-ha forest is the only fragment left of the then ~ 120-ha forest, these species have now moved from their previous locations into the only available suitable habitat within their dispersal range.

Our data showed that urbanization has decreased the size and connectivity and altered the environmental conditions of the two forest fragments, causing changes in the small mammal species community. Our findings also revealed that the two forest fragments complemented each other in terms of sustaining the native small mammals of the Accra Plain. A previous study of the small mammals in the University of Ghana botanical garden (Ofori et al., 2018) provided a list of 10 species of small mammals — of which only two species were shared with the Pinkwae forest (*Dasymys incomtus* and *P. tullbergi*) and Adumanya forest (*P. tullbergi* and *C. olivieri*). Also, recent studies at the Shai Hills Resource reserve and Achimota forest in the Accra Plain (Fig. 1) recorded 10 and eight species, respectively. Five species that were common to the Shai Hills Resource reserve and Achimota forest, including *Gerbilliscus* (*Tatera*) *kempi*, *Arvicanthis rufinus niloticus*, *Mastomys natalensis*, *Lemniscomys striatus*, and *Atelerix albiventris*, were not recorded at the Pinkwae and Adumanya forests, obviously due to the grassland habitat association of these species. This suggests that forest fragments and other green areas within the rapidly urbanizing landscape have a complementary effect and are all important for the conservation of native small mammals in the Accra Plain.

The species that disappeared from the forest fragments are all endemic to the Upper Guinean forest, but listed as Least Concern by the IUCN Red List because they are common and widespread across their distributional range. Also, there is no evidence to suggest that their populations are declining in any part of their range. Although they are known from several localities in Ghana, their presence in urban areas are threatened by the conversion of forests into impervious landscape. It is therefore important that urban developers and land use planners incorporate forest fragments into their development processes and establish policies that will protect and preserve forest remnants in the urban landscape.

Acknowledgements We thank John Mensah Bosu, Charles Achina, Faustina Adu-Boahene, Patience Darko, and Caleb Frimpong for their assistance in the field. We are very grateful to Jones Quartey for assisting with the data analyses.

Funding This research was supported by the BaNGA-Africa Seed Research Grant (UG-BA/PD-010/2017–2018).

Data availability Most of our data are included in the manuscript. However, any data not included in the manuscript will be made available upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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