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RESEARCH ARTICLE

The savannization of tropical forests in mainland Southeast Asia since 2000

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Abstract
Context Tropical forests in mainland Southeast (MSEA) have important conservation values and provide critical ecosystem functioning and services. With climate change and increasing anthropogenic activities, these forests can be lost to other land use types or degraded.
Objectives We aim to understand how these forests have changed under the context of MSEA's rapidly changing physical and socioeconomic environments in recent decades.
Methods We employed satellite-derived tree cover products, primarily the MODIS-based Vegetation continuous field (VCF) data, to investigate changes in forest cover with a focus on potential forest degradation to savannah since 2000 for the four MSEA countries, i.e., Thailand, Laos, Cambodia, and Vietnam.
Results We found an overall increasing trend of savannah (defined as places with tree cover between 10 and 55%) during the period 2000–2020. However, the sources of the increased savannah area differed significantly between 2000–2009 and 2009–2020: In the earlier decade, the positive trend of the savannah area was primarily attributed to tree regeneration from grasslands; while during the more recent decade, the degradation (savannization) of forests was the major cause. Fire disturbance primarily controlled interannual variation in tree cover for the savannah gain during the period of 2000–2009, while high atmospheric water demand drove the degradation of forests during the period of 2010–2020.
Conclusions Our analysis sheds light on the understanding of changing forest landscapes in a globally important region of tropical forests, which is critical for informing land management and tropical forest protection.

Keywords Tropical forest · Savannization · Vegetation continuous field (VCF) data · Southeast Asia · Drought · Fire disturbance

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Introduction

Tropical forests across the globe are important carbon pools and have played as a key atmospheric carbon sink in recent decades by absorbing a net of 7.6 Gt CO_2 per year (Harris et al. 2021). The high capacity

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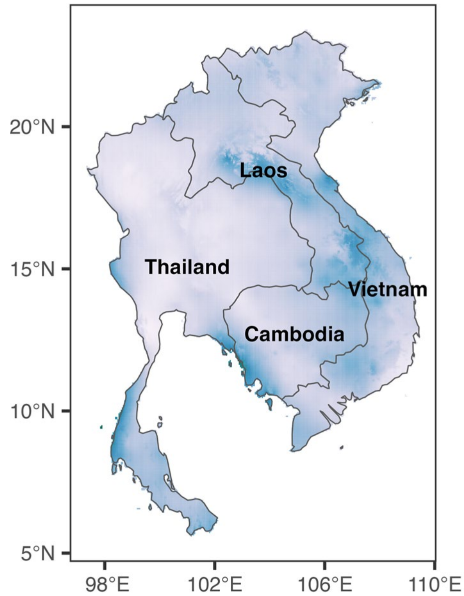

Fig. 1 The study is focused on four countries of mainland Southeast Asia (MSEA): Thailand, Laos, Cambodia, and Vietnam. The filling values indicate mean annual precipitation (MAP)

of carbon storage in tropical forests is important for climate mitigation (Mitchard 2018) but can change under climate change and disturbance. Mainland Southeast Aisa (MSEA; Fig. 1) is one of the world's biodiversity hotspots (Pletcher et al. 2022) under the threat of rapid land use and land cover changes (LULCC) in recent years. In particular, several studies have revealed widespread forest loss with crop expansion in MSEA (Chen et al. 2022; Feng et al. 2022; Zeng et al. 2018a, b). This type of forest loss, i.e., deforestation, is often in the form of clear-cut and complete loss of tree cover. On the other hand, some other changes in tropical forests may not involve the complete loss of tree cover, but rather the decrease in tree cover, a process often referred to as savannization. Yet tropical savannahs can also arise naturally, as has been shown in tropical Africa and Australia (Lehmann et al. 2014; Staver et al. 2011a, b). While the existence and evolutionary origin of tropical savannahs in MSEA has long been a topic of debate, a definition of savannah simply by tree cover thresholds (usually 10–55% tree cover, e.g., Zeng et al. 2014) offers a convenient chance to examine forest-savannah dynamics (often driven by deforestation and forest recovery) with remote sensing tools. However, few studies have examined the distribution and formation of savannahs in the forest-savannah mosaic system in MSEA, as well as how climate change and anthropogenic activities may have shaped their temporal and spatial variations.

Earlier studies suggested that savannah distributions are mainly constrained by mean annual precipitation (MAP) (Pletcher et al. 2022; Staver et al. 2011a, b). Savannahs may be found in places with MAP from 250 mm (e.g., in Africa and Australia) to 2500 mm (e.g., in South America) (Staver et al. 2011b). At intermediate rainfall, between 1000 and 2000 mm MAP, savannahs and forests can coexist (Staver et al. 2011b). This coexistence can persist until disturbance (e.g., fire) interrupts the stable state. Fire regimes are likely to influence the distributions of savannahs by adjusting the rainfall constraint (Staver et al. 2011b). In addition, precipitation seasonality (i.e. dry season length) may also constrain the presence of savannahs (Lehmann et al. 2011, 2014). However, most of these studies focus on drivers of the spatial pattern in tree covers, but not their temporal changes. The interannual variation in the greenness of tropical forests has been found correlated with interannual variation in climates (e.g., radiation, vapor pressure deficit, and precipitation) (Brando et al. 2010; Zhang et al. 2016), which suggests potential climate constraints on the transition of land cover types (Scheiter et al. 2020). Identifying these drivers of the forest–savannah dynamics in MSEA can improve our understanding of how the forest cover changes over time in MSEA during the early 21st century.

Tree cover data derived from remote sensing provides us with a powerful tool to detect both forest and savannah distributions and their spatial and temporal changes over large regions and across time (Hirota et al. 2011; Staver et al. 2011b; Zeng et al. 2014). In this study, we leveraged remotely sensed tree cover data to identify the distribution of the forest–savanna-grass mosaic system across MSEA and asked the following questions: (1) What is the spatial and temporal variation in grasslands, savannahs, and forests derived from tree cover data in MSEA? (2) What are the environmental drivers of potentially observed tree cover changes, especially for the forest-to-savannah transition? We first identified yearly land covers of grasslands, savannahs and forests based on the tree cover data and investigated interannual changes in their areas in MSEA during 2000–2020. We separated the entire study period into two sub-periods, i.e., 2000–2009 and 2010–2020, due to a breakpoint detected in the time series of savannah areas. During each sub-period, we examined changes in the spatial distribution of savannahs and forests and found hot-spot regions of their conversions. Furthermore, we associated the spatial patterns of fire frequency, dryness changes, and climatic dryness with that of land cover conversions and provided insight into the driving factors for the savannization of tropical forests in MSEA.

Data and methods

Study area

Mainland Southeast Asia (MSEA) lies east of India and south of Mainland China. It is to the east coast of the Indian Ocean and the west of the Pacific Ocean (5.8°N–22.8°N and 97°E–109.8°E). The mean annual temperature ranges from 20° to 30° and the mean annual precipitation is generally greater than 1000 mm (Liu et al. 2018). Four countries are included in our study: Thailand, Laos, Cambodia, and Vietnam (Fig. 1).

Tree cover

We used a satellite-derived tree cover dataset from the Terra MODIS Vegetation Continuous Fields (VCF) product (MOD44B, Collection 6) to detect interannual changes in the region's savannah area (DiMiceli et al. 2015). The VCF product defines a tree as woody vegetation larger than 5 m tall and provides yearly continuous tree covers at a spatial resolution of 250 m × 250 m. The tree cover data at the annual step facilitate the detection of interannual changes in tree cover and the data from 2000 to 2020 are used in this study. We define forests, savannahs, and grasslands according to the tree cover values based on previous studies (Hirota et al. 2011; Staver et al. 2011b). Savannahs encompass areas where the tree cover fraction ranges between 10 and 55%, while forests having tree cover larger than 55% and grasslands less than 10%. We note that the classification based on the tree cover percentage for the ecosystems is different from the strict ecological definition and this may cause uncertainties in our final land cover map (Lehmann et al. 2011; Staver and Hansen 2015). After obtaining the land cover mask, we calculated the total area (km^2) for each land cover type by aggregating the pixel areas within the mask for each respective year. We then examined the interannual variation in areas for each land cover type.

Fire occurrence and frequency

We used the MODIS burned area product (MCD64A1, Version 6) to estimate fire occurrence and frequency in MSEA. The MCD64A1 product identifies the date of burns for each 500-m × 500-m pixel at a monthly step by combining 500-m MODIS surface reflectance imagery with 1-km MODIS active fire observations (Giglio et al. 2015). The data has been validated in tropical regions with high accuracy in tropical savannahs (Boschetti et al. 2019). In our analysis, the fire frequency (FF) for a given pixel is defined as the total number of times burns are detected by the monthly burned area product within each year (Pletcher et al. 2022). This generates a map of fire frequency at a 500-m resolution for each year during the period 2000–2020.

Meteorological factors

Three meteorological factors, i.e., climatic water deficit (CWD), downward surface shortwave radiation (SR), and vapor pressure deficit (VPD), were used to examine the impacts of environmental drivers on interannual variation in tree cover across MSEA. CWD is defined as the difference between precipitation (P) and potential evapotranspiration (PET) (Huang et al. 2018). Higher CWD indicates a higher water availability for plants. All the three factors are supposed to influence the interannual variation in vegetation activities of tropical forests (Brando et al. 2010). Here, we used CWD instead of precipitation as the driving factor because CWD can be better related to water availability for plants (Brando et al. 2010). We did not consider the precipitation seasonality here since it primarily influences the spatial distribution of savannahs but not the temporal transition in the short term (Lehmann et al. 2011). We also did not include temperature because the interannual variation in temperature is expected to be minor in tropical regions. The P, PET, SR, and VPD data were extracted from the TerraClimate dataset at a monthly temporal resolution and a spatial resolution of 1/24° × 1/24° (~4.6 km) (Abatzoglou et al. 2018). The TerraClimate is a dataset of monthly climate and climatic water balance for global terrestrial surfaces from 1958 to 2019 (Abatzoglou et al. 2018). We first calculated monthly CWD for each year and then aggregated them into the annual CWD. Annual mean SR and VPD were calculated as the mean of the monthly values in each year.

Statistical Analyses

We used Sen's slope to estimate the linear trend in savannah area during each period, i.e., the earlier period 2000–2009, the latter period 2010–2020, and the whole period 2000–2020. The Sen's slope uses the median of the slopes of all linear lines derived from pairs of data points (Sen 1968). This makes the slope insensitive to outliers of the data. We used the Mann–Kendall test to investigate whether the slope is equal to zero with statistical significance. The trend analysis was done in *R* software (version 4.1.2) by using the "sens.slope" function in the "trend" package (Pohlert 2020). In addition, we detected the breakpoint in the time series of areas of each land cover type in MSEA as well as each country by using the "breakpoints" function provided in the *R* package "strucchange" (Zeileis et al. 2002, 2003). The function can detect multiple changes within linear regression models and give when the break occurs in one time series (Zeileis et al. 2002).

To investigate conversions between savannahs and two other land cover types (i.e., forests and grasslands) during the two separated periods 2000–2009 and 2010–2020, we identified four types of conversions which influence area changes in savannahs: savannah gains from grasslands and forest; savannah losses to grasslands and forests. First, we obtained the maps of the land cover types at the beginning and the end of each period based on the tree cover data. To make robust estimations, we averaged tree cover data during the first and last 3 years of each period respectively: 2000–2002 and 2007–2009 for the first one; 2010–2012 and 2018–2020 for the second one. Based on the tree cover thresholds (see the "Tree cover"), we generated the land cover maps and estimated the conversions of land cover types accordingly.

To estimate the influences of environmental factors on the interannual variation in tree cover, we performed partial correlation analyses ("Spearman" method) between tree cover and the environmental factors (i.e., CWD, FF, SR, and VPD). The partial correlation provides the correlation between the interannual fluctuation in tree cover and that in each of the three factors while controlling for the other two. The analysis was performed for each type of land cover conversions for the two separate periods 2000–2009 and 2010–2020, respectively. Before conducting the statistical analysis, we upscaled all data (i.e., tree cover and fire frequency) into the same spatial resolution as that of the climate datasets (i.e., 4.6 km × 4.6 km) by averaging the pixel values. Then, we estimated the mean value of each variable for each type of land cover conversion in every year and removed the long-term linear trend from all variables for the partial correlation analysis. The function "pcor" in the *R* package "ppcor" was used to implement the analysis (Kim 2015).

Results

Interannual changes in savannahs

The linear trend for the total area of savannah in MSEA was 4800 km^2 yr^{-1} ($p<0.01$) during 2000–2020, but there were two distinct phases of the area change in 2000–2020. Before 2009 (the year inclued), the total trend for savannah areas was 16,200 km^2 yr^{-1} ($p<0.01$). However, the rate declined to 3100 km^2 yr^{-1} with no statistical significance ($p=0.16$) after 2009 (the year exclued).

Except in Cambodia where the savannah area showed no statistically significant trend (400 km^2 yr^{-1}; $p=0.32$), we found an increasing trend in savannah area for all the other three countries during 2000–2020 (Fig. 2). Thailand had the largest annual increase of 2200 km^2 yr^{-1} ($p<0.05$). A breakpoint (2009) in the time series of savannah area was found in Thailand and Vietnam (Fig. 3a and d). Before 2009, the savannah areas in these two countries had increasing rates of 8200 km^2 yr^{-1} ($p<0.01$) and 4100 km^2 yr^{-1} ($p<0.01$), respectively. After then, no statistically significant trends were found in both countries.

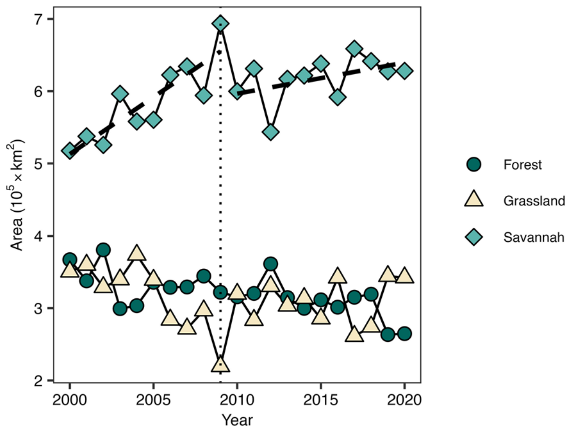

Fig. 2 Annual areas of forest, savannah, and grassland during 2000–2020 in mainland Southeast Asia (MSEA). Forest is indicated as dark green and circle points. Savannah is indicated as light green and diamond points. Grassland is indicated as yellow and triangle points. The vertical dotted line indicates the year (2009) where the breakpoint for the savannah area change is detected. The segmented dashed lines are the linear trend lines before and after the breakpoint

We found land cover conversions among grasslands, savannahs, and forests at different regions during the separate periods across MSEA (Fig. 4). During the earlier period (2000–2009), most of the conversions from grasslands to savannahs were found in central parts of Thailand, west Cambodia, and north Vietnam (Fig. 4a). The conversions from forests to savannahs mostly occurred at the northern part of Laos (Fig. 4a). During the latter period (2010–2020), however, the savannahs in central Thailand and north Cambodia suffered degradation to grasslands (Fig. 4b). The degradation also occurred in the northern parts of Vietnam. The savannization of forests continued in the northern parts of Laos and also spreaded across the center of Cambodia (Fig. 4b).

Spatial patterns in savannah gain and loss

Tree cover changes in savannahs indicated different magnitudes of degradation or regeneration from non-savannahs to savannahs across MSEA in both the earlier (2000–2009) and latter (2010–2020) periods. During the earlier period, the conversion rate of non-savannahs to savannahs ranged from −68.7 to 49.7% (Fig. 5a). The proportion of pixels with positive values (62.6%) was larger than that with negative ones (37.4%). Most of the regeneration (from grasslands) of savannahs were found in central Thailand (Fig. 5a), while large declines in tree covers occurred in Cambodia and northern parts of Laos. During the latter period, however, the proportion of conversions from grasslands to savannahs (i.e., positive values) decreased by 17.9%, even though the range of the tree cover changes was similar to that of the earlier period, i.e., from −66.7 to 52.3% (Fig. 5b). Large declines in tree covers also occurred in Cambodia.

Compared to the conversions from non-savannahs to savannahs, regions with the conversions from savannahs to non-savannahs were limited, especially during the earlier period (2000–2009) (Fig. 6a). The total area of conversions from savannahs to non-savannahs detected during the earlier period was less than 700 km^2. However, we still found large areas with decreased tree cover during the period 2010–2020. This implies large areas of degradation of savannahs to grasslands, which occurred in Cambodia, central Thailand, central Laos, and northern Vietnam (Fig. 6b).

Environmental drivers of savannah gain and loss

During the earlier period (2000–2009), all environmental variables showed statistically significant effects ($p < 0.05$) on the tree cover changes in regions with savannah gain from forests (Fig. 7a). The partial correlation coefficients for CWD, FF, SR, and VPD are 0.97, − 0.97, 0.92, and 0.96, respectively. This suggests that the tree cover change leading to the conversion from savannahs to forests is highly associated with environmental variations, especially the changes in water availability (i.e., CWD) and fire events (i.e., FF). However, in other types of land cover conversions, we rarely found a significant effect of the environmental factors on tree cover variation, except for FF which showed a negative impact on tree cover for areas experiencing the land cover conversion from savannahs to grasslands (Fig. 7a). This implies either limited effects of environmental factors on tree cover changes during the period 2000–2009 or factors not discussed here have played a more important role.

During the latter period (2010–2020), variations in aridity-related variables, especially VPD, showed significant effects ($p < 0.05$) on tree cover variation for pixels with savannah gains (Fig. 7b). The partial correlation coefficient between VPD and tree

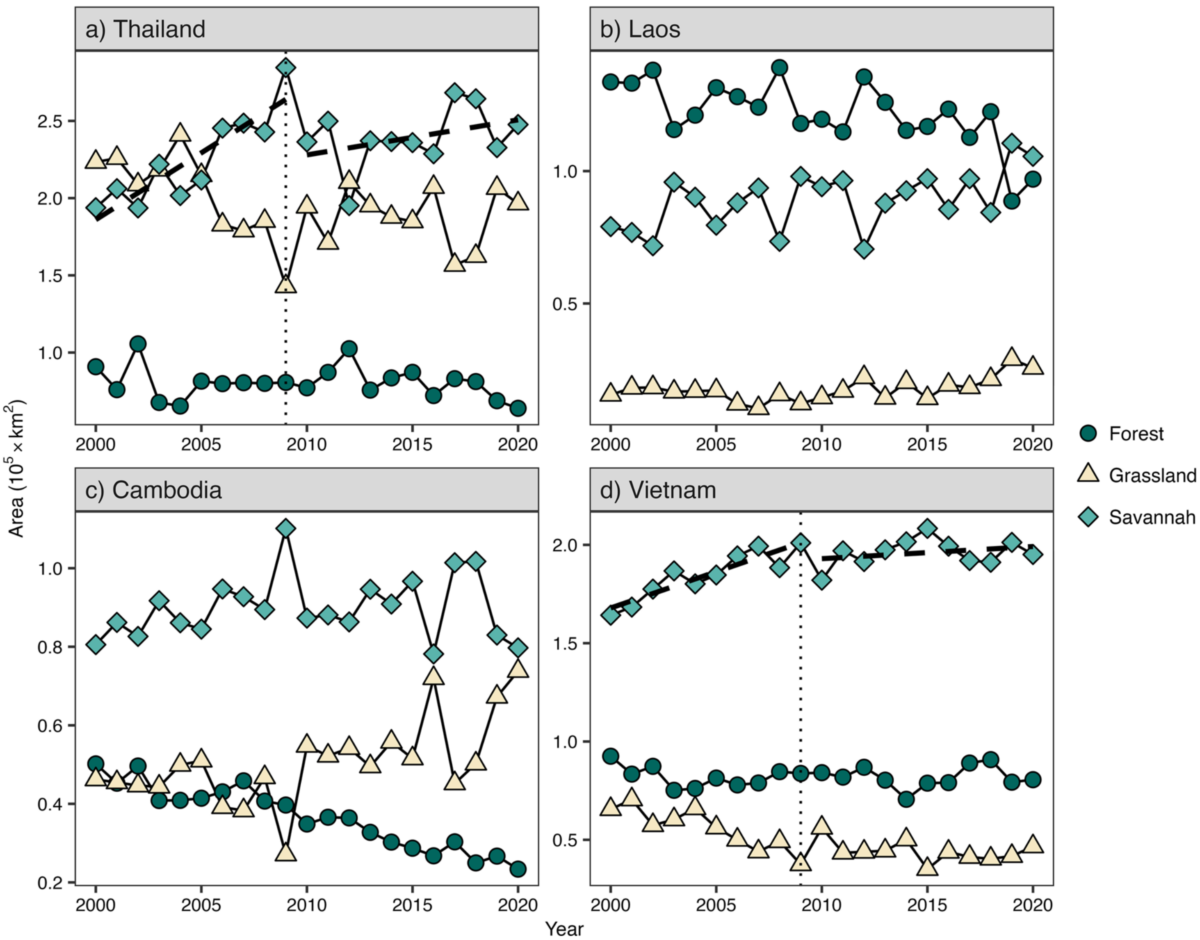

Fig. 3 Annual area of forest, savannah, and grassland during 2000–2020 in four countries of mainland Southeast Asia (MSEA): Thailand (**a**), Laos (**b**), Cambodia (**c**), and Vietnam (**d**). Forest is indicated as dark green and circle points. Savannah is indicated as light green and diamond points. Grassland is indicated as yellow and triangle points. The vertical dotted line in each figure indicates the year (2009) where the breakpoint for the savannah area change (present in Thailand and Vietnam) is detected. The segmented dashed lines are the linear trend lines before and after the breakpoint

cover was −0.72 and −0.85, respectively, for areas experiencing forest-to-savannah and grassland-to-savannah conversions. The negative effect of VPD on tree cover might be due to the tendency of stomatal closure under high water demand in the atmosphere (Novick et al. 2016). This was different from the dominant factors observed in the period 2000–2009, during which FF mainly influenced the variation in tree cover. The effect of FF on the tree cover variation during the period 2010–2020 was trivial except for its impact in the savannah-to-grassland areas (Fig. 7b).

Discussion

We observed two separate periods (i.e., 2000–2009 and 2010–2020) with distinguished patterns of changes in savannah areas in MSEA during the early 21st century (Fig. 2). The area in savannahs continuously increased in MSEA through 2009. This savannization corresponded to the decline in grassland areas (Fig. 2). This increase in savannah area from grassland can also be detected from the spatial distribution of positive tree cover changes during the earlier period (Fig. 5a). After 2009, forest areas in MSEA drastically decreased in 2010 and then showed no significant trends, while the area changes

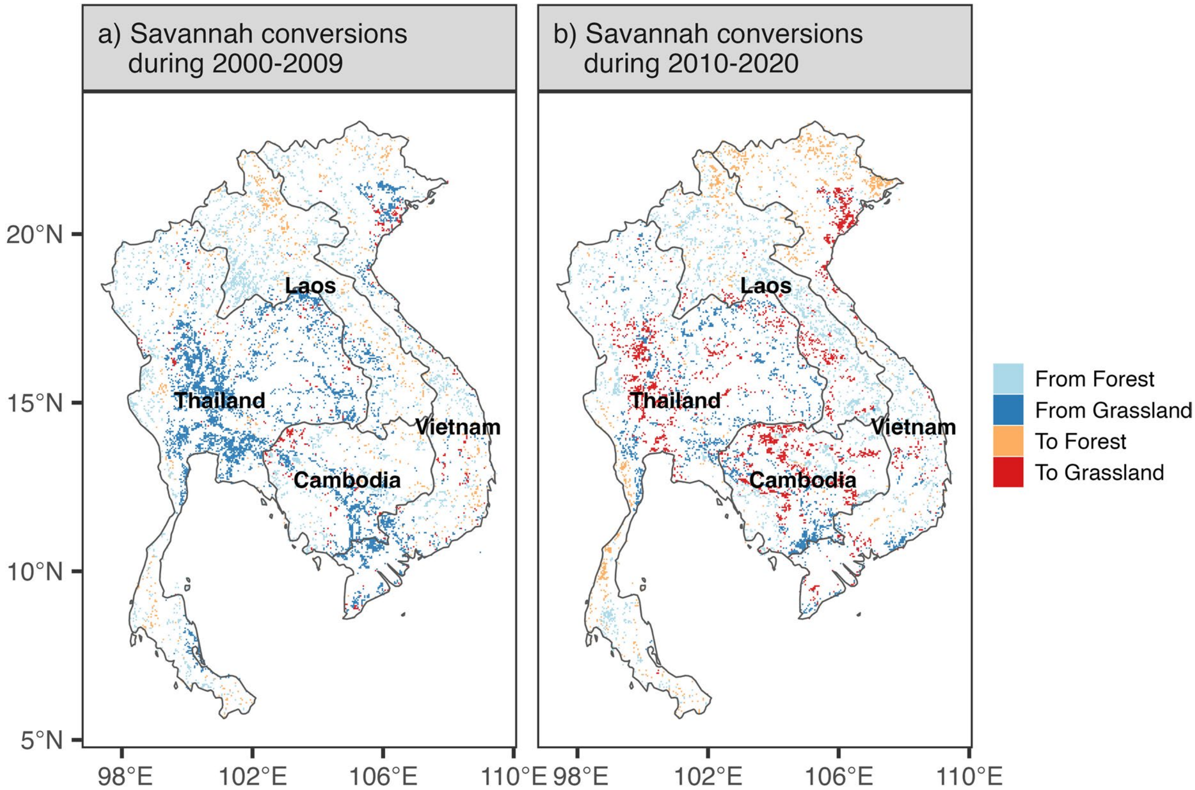

Fig. 4 Conversions between savannahs and other land cover types across mainland Southeast Asia (MSEA) during 2000–2009(**a**) and 2010–2020 (**b**). The savannah-related conversions include four types: gains from forests (dark blue) and grasslands (light blue); losses to forests (orange) and grasslands (red)

in grasslands vs. savannahs still compensated for each other despite their interannual variabilities (Fig. 2). The sharp decrease in savannah area in 2010 may be attributed to hot drought occurring in MSEA caused by El Nino and global warming (Thirumalai et al. 2017; Wang et al. 2022). The two-period pattern of tree cover changes is consistent with previous findings about forest carbon loss over MSEA (Feng et al. 2022). According to the map of forest carbon loss in Feng et al. (2022), a larger decrease in forest biomass in MSEA was found in 2015–2019 compared to the period of 2001–2005. The decrease in tree covers (i.e., from forests to savannahs and from savannahs to grasslands) implies the carbon loss in recent decades.

We found hotspots of forest-to-savannah conversions in Laos and Cambodia. Different from other countries, most of Laos is covered by savannahs and forests. Area changes in savannahs and forests generally compensate for each other (Fig. 3b). Thus, most of the savannah gain in Laos at the end of each period was from the forest loss (Fig. 4). In Cambodia, the forest area continuously decreased through 2020, but the savannah area did not show a similar trend. This is due to the strong dynamics between grasslands and savannahs (Fig. 3c). Especially during the latter period 2010–2020, large areas of savannahs were converted to grasslands over the country. This suggests serious degradations of both forests and savannahs in Cambodia (Fig. 4b), corresponding to the deforestation pressure found in other studies (Lohani et al. 2020; Chen et al. 2022). For example, deforestation has been found to continue around the largest freshwater lake in Cambodia since 2001 (Chen et al. 2022). A similar deforestation trend was also detected on the larger Srepok–Sesan–Sekong watershed (Lohani et al. 2020).

According to the partial correlation analysis, the two separate periods showed different dominant environmental factors (i.e., FF in 2000–2009 and VPD in 2010–2020) for tree cover variations, especially

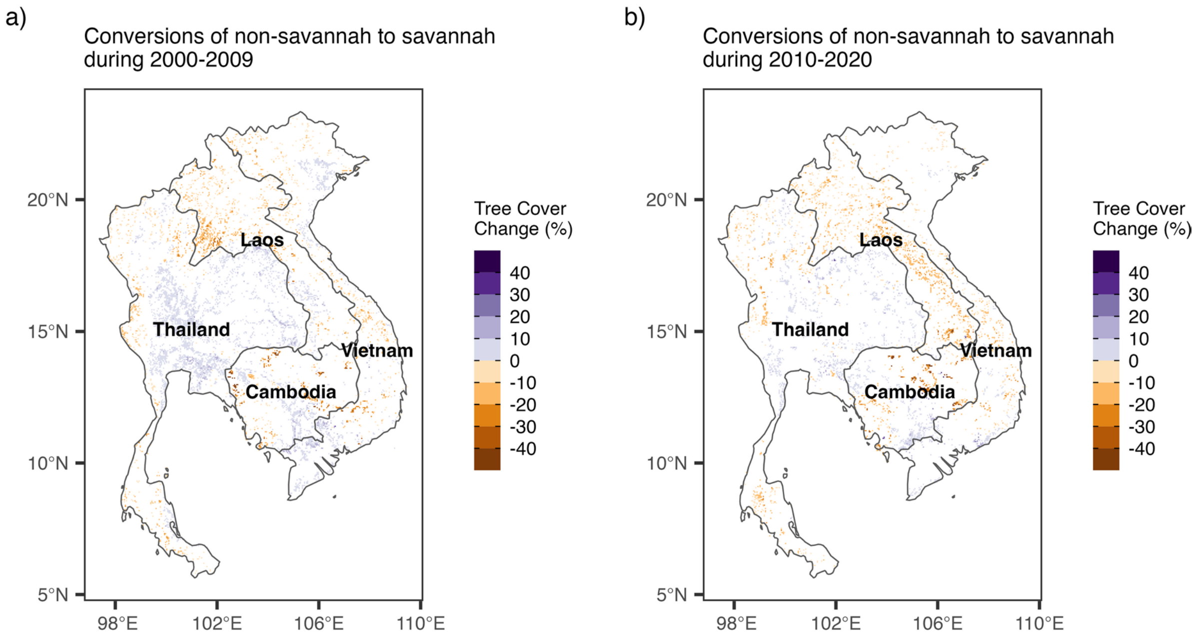

Fig. 5 Spatial distributions of forests and grasslands converting to savannahs and associated tree cover changes in mainland Southeast Asia (MSEA) during the earlier (**a**) and latter (**b**) periods. The earlier period is from 2000 to 2009 and the latter from 2010 to 2020

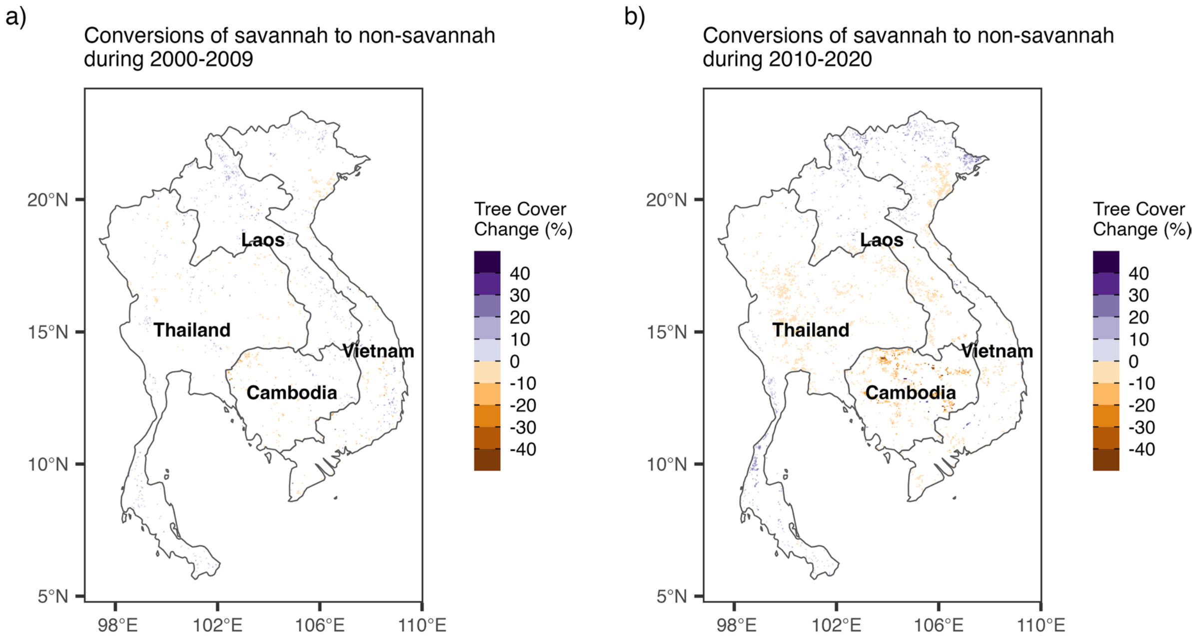

Fig. 6 Spatial distributions of savannahs converting to forests or grasslands and associated tree cover changes in mainland Southeast Asia (MSEA) during the earlier (**a**) and latter (**b**) periods. The earlier period was from 2000 to 2009 and the latter from 2010 to 2020

for the regions with savannah gain (Fig. 7). Fire is expected to suppress tree cover and thus influence the

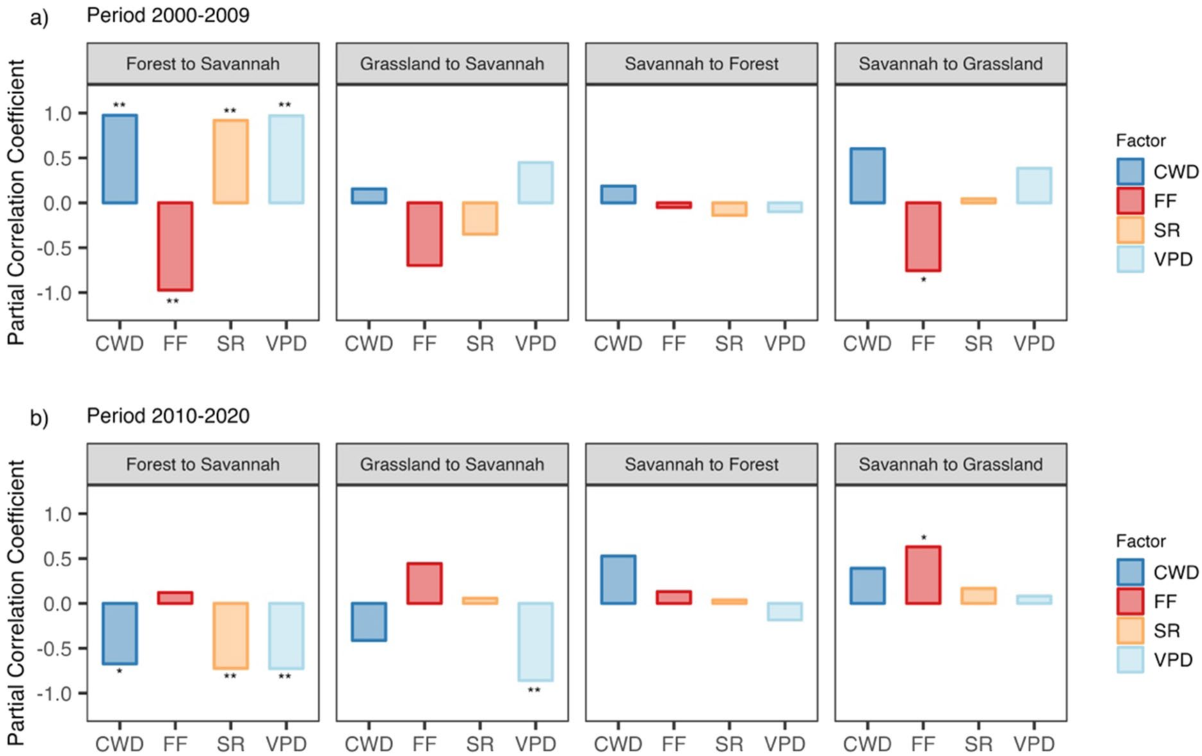

Fig. 7 Partial correlation coefficients between the tree cover and the environmental factors: climatic water deficit (CWD), fire frequency (FF), vapor pressure deficit (VPD), and downward surface shortwave radiation (SR). Subfigures (**a**) and (**b**) show partial correlation coefficients for the environmental factors in four types of land conversions during the periods 2000–2009 and 2010–2020, respectively. The four types of land conversions include conversions from forests to savannahs, grasslands to savannahs, savannahs to forests, and savannahs to grasslands. "**" indicates the significance level of 0.05. "*" indicates the significance level of 0.1

interannual variation of tree cover in MSEA, which is consistent with the fire effect on the spatial variation in tree cover across MSEA (Pletcher et al. 2022). The suppression of fires on tree growth facilitates the formation of savannahs or forest-savannah mosaics (Hoffmann et al. 2012; Pletcher et al. 2022). In the forest-savannah mosaic system, low tree covers in turn promote fire spread (Staver et al. 2011a). This feedback can expand the range of savannahs beyond their climate- (e.g., precipitation) defined boundaries (Staver et al. 2011b; Beckett et al. 2022). Meanwhile, we observed a significantly negative impact of VPD on tree cover variation in the recent decade (i.e., 2010–2020; Fig. 7b). Recent warming makes trees suffer more drought stress from atmospheric water demand (i.e., higher VPD) (Novick et al. 2016; Yuan et al. 2019). The higher VPD can decrease stomatal conductance and photosynthetic rates (Novick et al. 2016), and even trigger widespread tree mortality in the tropics with hydraulic failure (Bauman et al. 2022).

Furthermore, during the period 2000–2009, for areas with land cover conversion from forests to savannahs, water availability (i.e., CWD) is positively associated with tree cover changes (Fig. 7a), confirming the previous finding that higher mean annual precipitation corresponds to a larger tree cover (Hirota et al. 2011; Staver et al. 2011bPletcher et al. 2022). The interannual variation in CWD alters annual water availability for trees, which is responsible for the changes in open canopy structures, i.e., savannahs (Xu et al. 2015). Higher CWD increases water storage in tropical regions, which correlates with increased vegetation activities as well as tree covers (Brando et al. 2010; Guan et al. 2015). However, in other types of land cover conversions, the CWD effect is not significant or even negative (Fig. 7b), and other factors (e.g., VPD or biotic ones) dominate the interannual change in tree cover. For example, changes in canopy properties in tropical forests, specifically bursts of new leaves, can influence the variation in vegetation activities (Green et al. 2020). Even under higher atmospheric water demand, new leaves with high photosynthetic capacity flush and increase the canopy photosynthesis, compensating for the negative stomatal responses to increased dryness (Green et al. 2020). These biotic processes may cause decreased tree covers with high CWD or low VPD (Fig. 7).

In addition to the environmental changes and disturbance, human activities in MSEA can also contribute to the observed savannization (e.g., degradation of forests) and confound the impact of the environmental drivers (e.g., CWD and VPD) on tree cover changes. For example, forest clearing (e.g., firewood collection and logging) and agricultural farming were the primary causes for forest loss during 1992–2010 in Cambodia (Chen et al. 2022). Similar negative impacts of large-scale agriculture and forestry on forest carbon (i.e., forest carbon loss) were also found in MSEA (Feng et al. 2021, 2022). Anthropogenic activities can dramatically change the land cover, often leading to the degradation of forests. This impact may cause overestimations of the negative influence of the environmental drivers on tree cover change (e.g., the effect of CWD in Fig. 7b).

Conclusions

In this study, we investigated land cover changes, including grasslands, savannahs, and forests, based on remotely sensed tree cover fractions in mainland Southeast Asia (MSEA) during the early 21st century and found increased savannization of forests during the period. The interannual variation in the total savannah area can be generally divided into two periods: 2000–2009 and 2010–2020. During the earlier period, the area of savannahs indicated a positive trend due to tree regenerations from grasslands, while during the latter one, the savannization of forests enhanced. Two hotspots of the savannization were found in Laos and Cambodia. Dominant environmental drivers of tree cover changes were different between the two separate periods. Fire disturbance primarily contributed to the degradation of forests to savannahs during the period 2000–2009, while atmospheric water demand (i.e., VPD) controlled the savannization during the period 2010–2020. Coupled with the fire suppression, the drying climate could amplify the decrease in tree covers over MSEA in the future. While we do not analyze the impacts of human activities, this study still provides essential insight into how environmental drivers may influence temporal changes in tree covers and the savannization of forests throughout MSEA.

Author contributions AC designed the study. MW did the analysis, wrote the draft, and prepared the figures. All authors reviewed and edited the manuscript.

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Declarations

Conflict of interest The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.

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