様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　４ 年　 ７ 月 ２７ 日現在

機関番号：８２１０５
研究種目：若手研究
研究期間：2020～2021
課題番号：２０Ｋ１３２６２

研究課題名（和文）Global forest transitions: finding evidence for the forest transition theory and examining implications for SDG 15

研究課題名（英文）Global forest transitions: finding evidence for the forest transition theory and examining implications for SDG 15

研究代表者
ＥＳＴＯＱＵＥ　ＲＯＮＡＬＤＣ（ESTOQUE, Ronald Canero）

国立研究開発法人森林研究・整備機構・森林総合研究所・主任研究員 等

研究者番号：６０７６０１３９

交付決定額（研究期間全体）：（直接経費）　　2,300,000円

研究成果の概要（和文）：森林変化の時空間的パターンは森林遷移説を支持し、森林減少は主に熱帯の低所得国で、森林増加は熱帯外の高所得国で起こっている。さらに、経済成長と森林の純増加は、森林の純減よりも強い関連性を持っている。持続可能な開発課題（SDG15など）を達成するためには、世界に残る森林を保全し、劣化した森林景観を回復・再生することによって、世界の森林純減カーブを逆転させるか、少なくとも平坦にすることが非常に必要である。

研究成果の学術的意義や社会的意義
This research contributes to the study of the forest transition theory. The results highlight the need to address forest losses in the lower income countries especially in the tropics and for the higher income countries to reduce their dependence on imported tropical forest products.

研究成果の概要（英文）：The results revealed that over the past 60 years (1960-2019), the global forest area has declined by 81.7 million ha, with forest loss (437.3 million ha) outweighing forest gain (355.6 million ha). With this forest decline and the population increase (4.68 billion) over the period, the global forest per capita has decreased by over 60%, from 1.4 ha in 1960 to 0.5 ha in 2019. The spatiotemporal pattern of forest change supports the forest transition theory, with forest losses occurring primarily in the lower income countries in the tropics and forest gains in the higher income countries in the extratropics. Furthermore, economic growth has a stronger association with net forest gain than with net forest loss. To help achieve the sustainable development agenda (e.g., SDG 15), there is a profound need to reverse, or at least flatten, the global net forest loss curve by conserving the world's remaining forests and restoring and rehabilitating degraded forest landscapes.

研究分野：地理・林業

キーワード：forest transition　forest cover change　land change　sustainability　SDGs　forest loss displacement　GIScience/Remote Sensing　Earth observation

様　式　C－１９、F－１９－１、Z－１９（共通）

１．研究開始当初の背景

Today, monitoring of the world's forests is an integral part of various global environmental and social initiatives, including the Sustainable Development Goals (SDGs), the Paris Climate Agreement and the Post-2020 Global Biodiversity Framework[1–4].

In the early 1990s, geographer Alexander Mather proposed the forest transition theory (FTT)[5,6] based on the positive correlation he observed between forest expansion and economic growth. In particular, FTT hypothesizes that forest cover change is a function of social and economic development, and that forest cover generally declines as countries develop economically, but this trend eventually reverses with further economic development and industrialization, resulting in a U-shaped curve[5–7]. In a nutshell, forest transitions occur within countries or regions when net forest gain replaces net forest loss[8]. Among the direct causes that lead to forest transition are agricultural land abandonment[9–11] and forest restoration and rehabilitation[5,10].

Essentially, FTT suggests that if new policies that can accelerate forest transitions could be identified, then the corresponding forest gains and carbon sequestration might slow climate change, avert biodiversity losses, and prevent a further deterioration in ecosystem services[8]. For forest plantations, however, although they can also provide certain ecosystem services, their capacity to protect biodiversity and/or increase carbon sequestration is much less (especially non-native and/or monoculture plantations) when compared with natural forest ecosystems[12].

Although there have been a number of studies related to FTT, a quantitative assessment of evidence based on global and spatially explicit data with extensive temporal coverage is lacking; hence this study.

２．研究の目的

This study aimed to answer two critical questions. First, how has the extent of global forest change varied over space and time? Second, how do the detected trends in global forest change relate to FTT? To clarify these questions, both forest losses and gains at the global, regional and national levels across decades from 1960 to 2019 were detected and quantified. Here, a 'region' refers to a group of countries that belong to the same level of income and human development, and is not necessarily conterminous and can be composed of countries from multiple continents. This study evaluated whether there is evidence to show that the extent of forest change was related to the socioeconomic status of countries and regions and if the evidence supports FTT. The implications of the findings in the context of global sustainability were explored.

３．研究の方法

The data used in this study included the following: a time-series land use dataset of wide temporal coverage (1960-2019) (HILDA+[13,14]), a GIS country-level boundary dataset, a time-series country-level population and GDP dataset, and country classifications (regions) by the World Bank (WB) and United Nations (UN) based on income and level of human development, respectively.

The datasets were processed, analyzed and synthesized using ArcGIS and statistical analysis tools and techniques. Among the results produced are the following: percentage share of each WB region and UN region to the world's total forest loss and gain; percentage of forest loss and gain relative to the respective land areas of the countries across WB regions and UN regions; global and regional level time-series forest extent, forest per capita and GDP per capita and their changes from 1960 to 2019; and correlation between change in GDP and net forest loss/gain.

４．研究成果

(1) Global forest change over the past 60 years

Between 1960 and 2019, the world lost 437.3 million ha (Mha) (−10.4%) and gained 355.6 Mha (+8.5%) of forest. In terms of share to the world's total forest loss by the regions based on income (WB), the upper middle income region had the highest (30%), followed by the lower middle income region (27%) (Fig. 1a). Among the regions based on level of human development (UN), the second most developed (high) region had the highest share (33%), followed by the least developed region (27%) (Fig. 1b). By contrast, in terms of share to the world's total forest gain, about 59% and 43%

were contributed by the high income region and the most developed (very high) region, respectively.

The proportion of forest loss and gain relative to each country's land area varied considerably across income and human development levels (Figs. 1c, 1d). Despite the observed variability, however, the results reveal a clear pattern: on average, the lower income countries and countries with low levels of human development had higher proportions of forest loss, while the higher income countries and countries with higher levels of human development had higher proportions of forest gain.

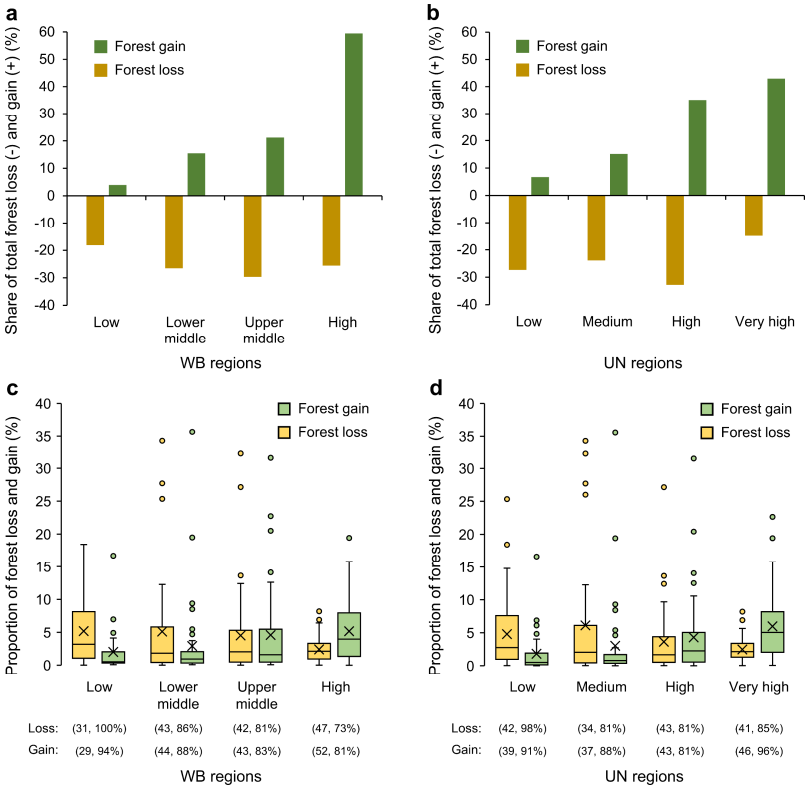

Fig. 1 | Regional characteristics of forest loss and gain between 1960 and 2019. a, b Percentage share of each WB region and UN region, respectively, to the world's total forest loss and gain. **c, d** Percentage of forest loss and gain, respectively, relative to the respective land areas of the countries across WB regions and UN regions, respectively. For **c** and **d**, the numbers at the bottom refer to the number of countries that recorded gross forest loss and gain in each region, respectively, with their corresponding percentages (%) relative to the total number of countries in each region.

(2) Global forest change and socioeconomic status

At the global level, while there was a net forest gain between 1960 and 1970, the world's forest has been continuously decreasing decade by decade since 1970, i.e., from 4195.6 Mha (32.2%) in 1970 to 4105.9 Mha (31.5%) in 2019 (Fig. 2a). While the inter-decadal rate of net forest loss slowed to about a half Mha per year during the 1980–1990 period, it continuously accelerated during the past three decades, reaching almost 4 Mha per year in the most recent decade (2010–2019). With the increase in the world's population from 3.03 billion in 1960 to 7.71 billion in 2019, forest per capita decreased from 1.4 ha in 1960 to 0.5 ha in 2019 (i.e., > 60% decrease).

A similar trend of a decreasing forest area was observed in the low, lower middle and upper middle income regions (Fig. 2b) (UN regions are not shown in the figure). By contrast, increasing forest area along with increasing GDP per capita was observed in the high income region. The low income region had the largest drop in forest per capita (−2.3 ha) over the past six decades, in contrast with its lowest rise in GDP per capita. The upper middle and high income regions had accelerating GDP rise per capita (especially the latter), accompanied by a relatively more stable (for the upper middle income region), or an increasing (for the high income region), forest extent.

Net forest gain and change in GDP were positively correlated across all six decades. All the correlation coefficients (i.e., r = 0.32–0.79) were statistically significant ($p < 0.005$). In contrast, net forest loss and change in GDP were positively and significantly correlated in only two decades (1970–1980 and 2000–2010).

In general, the detected spatiotemporal pattern of forest change supports FTT, with forest losses occurring primarily in the lower income countries in the tropics and forest gains in the higher income countries in the extratropics. Furthermore, economic growth has a stronger association with net forest gain than with net forest loss. To help achieve the sustainable development agenda (e.g., SDG 15), there is a profound need to reverse, or at least flatten, the global net forest loss curve by conserving the world's remaining forests and restoring and rehabilitating degraded forest landscapes. The results also highlight the need to strengthen the support given to lower income countries, especially in the tropics, to help improve their capacity to minimize or end their forest losses. To help address the

displacement of forest losses to the lower income countries in the tropics, higher income nations need to reduce their dependence on imported tropical forest products.

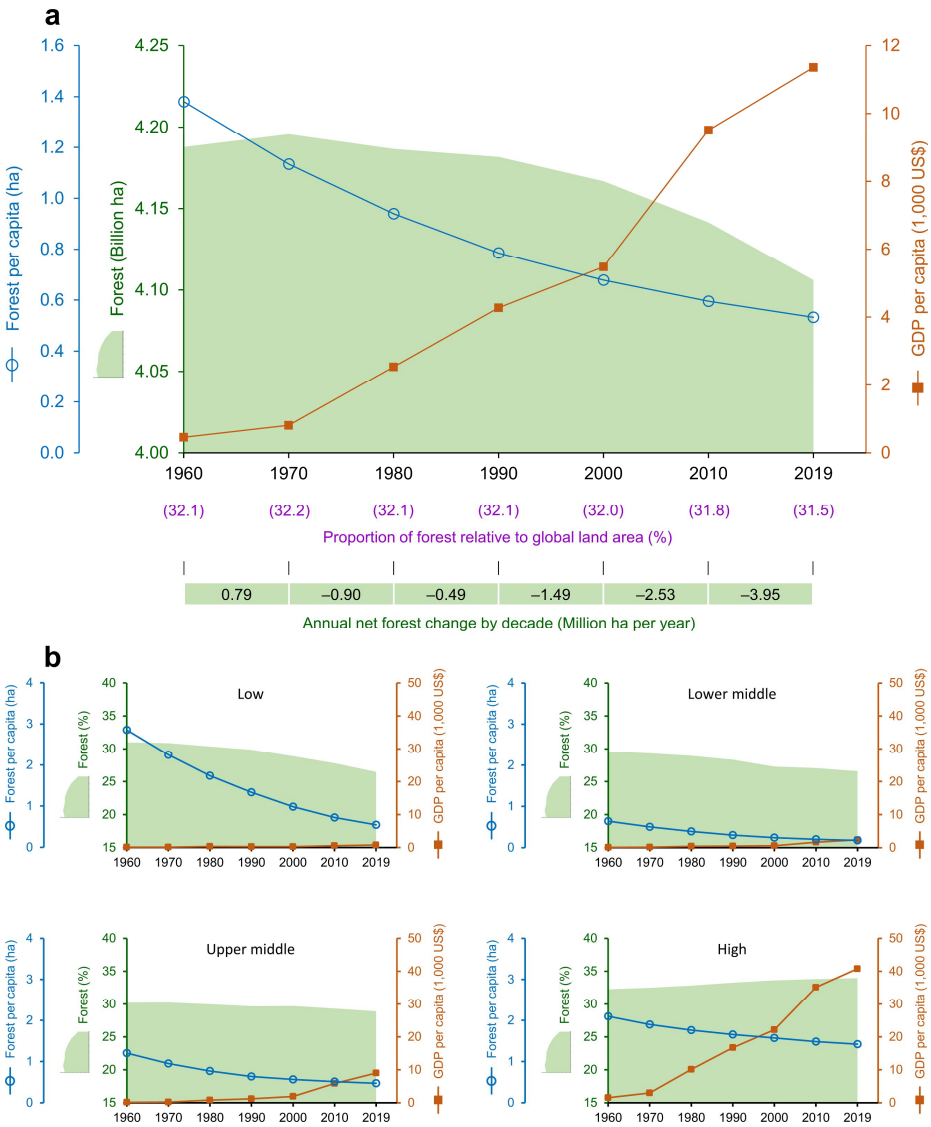

Fig. 2 | Forest extent, forest per capita and GDP per capita and their changes from 1960 to 2019. a Global data. The figure also lists the decadal percentage of global forest (purple) and annual net change by decade (green bar at the bottom). **b** Data for the WB regions. In **a**, forest extent is measured in area, whereas in **b**, it is measured as percentage of the total land area of countries in each region. Although not presented here, the results for the UN regions showed a comparatively similar pattern.

Notes:

This study has clarified the two research questions mentioned in the Introduction section. The results also provide answers to the key scientific questions this KAKENHI research project (20K13262) aims to clarify. A full research article presenting the primary results has been written and published:

Estoque RC, et al. (2022). Spatiotemporal pattern of global forest change over the past 60 years and the forest transition theory. *Environ. Res. Lett.* ***17,*** *084022.* https://doi.org/10.1088/1748-9326/ac7df5

References

1. Estoque, R. C. *et al.* The future of Southeast Asia's forests. *Nat. Commun.* **10**, 1829 (2019).
2. Oldekop, J. A. *et al.* Forest-linked livelihoods in a globalized world. *Nat. Plants* **6**, (2020).
3. Harris, N. L. *et al.* Global maps of twenty-first century forest carbon fluxes. *Nat. Clim. Chang.* **11**, 234–240 (2021).
4. Hansen, A. J. *et al.* Toward monitoring forest ecosystem integrity… *Conserv. Lett.* **14**, e12822 (2021).
5. Mather, A. S. The forest transition. *Area* **24**, 367–379 (1992).
6. Mather, A. S. Forest transition theory and the reforesting of Scotland. *Scottish Geogr. J.* **120**, 83–98 (2004).
7. Garcia, C. A. *et al.* The global forest transition as a human affair. *One Earth* **2**, 417–428 (2020).
8. Rudel, T. K. *et al.* Whither the forest transition?... *Ambio* **49**, 74–84 (2020).
9. Barbier, E. B., et al. The forest transition:… *Land use policy* **27**, 98–107 (2010).
10. De Jong, W. Forest rehabilitation and its implication for forestry transition. *Biotropica* **42**, 3–9 (2010).
11. Oduro, K. A., *et al.* Tracing forest resource development in Ghana… *Land use policy* **48**, 63–72 (2015).
12. Estoque, R. C. *et al.* Remotely sensed tree canopy cover-based indicators… *Environ. Res. Lett.* **16**, 044047 (2021).
13. Winkler, K., *et al.* HILDA+ Global Land Use Change between 1960 and 2019. *PANGAEA* (2020) doi:10.1594/PANGAEA.921846.
14. Winkler, K., *et al.* Global land use changes are four times greater than previously estimated. *Nat. Commun.* **12**, 2501 (2021).

５．主な発表論文等

〔雑誌論文〕　計6件（うち査読付論文　6件／うち国際共著　6件／うちオープンアクセス　4件）

１．著者名 Ronald C. Estoque	４．巻 12
２．論文標題 A review of the sustainability concept and the state of SDG monitoring using remote sensing	５．発行年 2020年
３．雑誌名 Remote Sensing	６．最初と最後の頁 1770
掲載論文のDOI（デジタルオブジェクト識別子） 10.3390/rs12111770	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Ronald C. Estoque, Brian A. Johnson, Yan Gao, Rajarshi DasGupta, Makoto Ooba, Takuya Togawa, Yasuaki Hijioka, Yuji Murayama, Lilito D. Gavina, Rodel D. Lasco, Shogo Nakamura	４．巻 16
２．論文標題 Remotely sensed tree canopy cover-based indicators for monitoring global sustainability and environmental initiatives	５．発行年 2021年
３．雑誌名 Environmental Research Letters	６．最初と最後の頁 44047
掲載論文のDOI（デジタルオブジェクト識別子） 10.1088/1748-9326/abe5d9	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Darshana Athukorala, Ronald C. Estoque, Yuji Murayama, Bunkei Matsushita	４．巻 13
２．論文標題 Ecosystem Services Monitoring in the Muthurajawela Marsh and Negombo Lagoon, Sri Lanka, for Sustainable Landscape Planning	５．発行年 2021年
３．雑誌名 Sustainability	６．最初と最後の頁 11463
掲載論文のDOI（デジタルオブジェクト識別子） 10.3390/su132011463	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Ronald C. Estoque, Makoto Ooba, Takuya Togawa, Yasuaki Hijioka, Yuji Murayama	４．巻 115
２．論文標題 Monitoring global land-use efficiency in the context of the UN 2030 Agenda for Sustainable Development	５．発行年 2021年
３．雑誌名 Habitat International	６．最初と最後の頁 102403
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.habitatint.2021.102403	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 Ronald C. Estoque, Brian Alan Johnson, Rajarshi Dasgupta, Yan Gao, Toshiya Matsuura, Takeshi Toma, Yasumasa Hirata, Rodel D. Lasco	4．巻 317
2．論文標題 Rethinking forest monitoring for more meaningful global forest landscape change assessments	5．発行年 2022年
3．雑誌名 Journal of Environmental Management	6．最初と最後の頁 115478
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.jenvman.2022.115478	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 Ronald C. Estoque, Rajarshi Dasgupta, Karina Winkler, Valerio Avitabile, Brian A. Johnson, Soe W. Myint, Yan Gao, Makoto Ooba, Yuji Murayama, Rodel D. Lasco	4．巻 17
2．論文標題 Spatiotemporal pattern of global forest change over the past 60 years and the forest transition theory	5．発行年 2022年
3．雑誌名 Environmental Research Letters	6．最初と最後の頁 84022
掲載論文のDOI（デジタルオブジェクト識別子） 10.1088/1748-9326/ac7df5	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

〔学会発表〕　計6件（うち招待講演　2件／うち国際学会　4件）

1．発表者名 Ronald C. Estoque
2．発表標題 Global forest cover changes in the past 60 years
3．学会等名 The 133 The Japanese Forest Society Conference
4．発表年 2022年

1．発表者名 Ronald C. Estoque, Brian A. Johnson, Yan Gao, Rajarshi DasGupta, Makoto Ooba, Takuya Togawa, Yasuaki Hijioka, Yuji Murayama, Lilito D. Gavina, Rodel D. Lasco, Shogo Nakamura
2．発表標題 Remotely sensed tree canopy cover-based indicators for monitoring progress towards global sustainability and environmental initiatives
3．学会等名 Japan Geoscience Union (JpGU) Meeting（招待講演）（国際学会）
4．発表年 2021年

１．発表者名
Darshana Athukorala, Yuji Murayama, Bunkei Matsushita, Ronald C. Estoque

２．発表標題
A scenario-based analysis of the impacts of urbanization on the ecosystem services of the Muthurajawela Marsh and Negombo Lagoon, Sri Lanka

３．学会等名
Japan Geoscience Union (JpGU) Meeting（国際学会）

４．発表年
2021年

１．発表者名
Estoque RC

２．発表標題
Global forest cover changes in the past 60 years

３．学会等名
The 133 The Japanese Forest Society Conference

４．発表年
2021年

１．発表者名
Estoque RC, Ooba M, Johnson BA, Gao Y, DasGupta R, Togawa T, Hijioka Y, Murayama Y, Gavina LD, Lasco RD, Nakamura S

２．発表標題
Remotely sensed tree canopy cover-based indicators for monitoring progress towards global sustainability and environmental initiatives

３．学会等名
Japan Geoscience Union (JpGU) Meeting（招待講演）（国際学会）

４．発表年
2021年

１．発表者名
Darashna A, Murayama Y, Matsushita B, Estoque RC

２．発表標題
A scenario-based analysis of the impacts of urbanization on the ecosystem services of the Muthurajawela Marsh and Negombo Lagoon, Sri Lanka

３．学会等名
Japan Geoscience Union (JpGU) Meeting（国際学会）

４．発表年
2021年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

The following publication was selected for Press Release by the Publisher (IOP Publishing Company).

Estoque RC, et al. (2022). Spatiotemporal pattern of global forest change over the past 60 years and the forest transition theory. Environ. Res. Lett. 17, 084022. https://doi.org/10.1088/1748-9326/ac7df5

Title of the Press Release:
"New study finds global forest area per capita has decreased by over 60%"

６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関