Global vegetation change is more affected by direct human activity than by climate change (#37648)

First submission

Guidance from your Editor

Please submit by **17 Jun 2019** for the benefit of the authors (and your $200 publishing discount).

Structure and Criteria
Please read the 'Structure and Criteria' page for general guidance.

Author notes
Have you read the author notes on the guidance page?

Raw data check
Review the raw data. Download from the location described by the author.

Image check
Check that figures and images have not been inappropriately manipulated.

Privacy reminder: If uploading an annotated PDF, remove identifiable information to remain anonymous.

Files
Download and review all files from the materials page.

4 Figure file(s)
1 Table file(s)

Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. **BASIC REPORTING**
2. **EXPERIMENTAL DESIGN**
3. **VALIDITY OF THE FINDINGS**
4. General comments
5. Confidential notes to the editor

You can also annotate this PDF and upload it as part of your review

When ready submit online.

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your guidance page.

BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Figures are relevant, high quality, well labelled & described.
- Raw data supplied (see PeerJ policy).

EXPERIMENTAL DESIGN

- Original primary research within Scope of the journal.
- Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

- Impact and novelty not assessed. Negative/inconclusive results accepted. *Meaningful* replication encouraged where rationale & benefit to literature is clearly stated.
- All underlying data have been provided; they are robust, statistically sound, & controlled.
- Speculation is welcome, but should be identified as such.
- Conclusions are well stated, linked to original research question & limited to supporting results.

Standout reviewing tips

The best reviewers use these techniques

Tip	*Example*
Support criticisms with evidence from the text or from other sources	*Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.*
Give specific suggestions on how to improve the manuscript	*Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).*
Comment on language and grammar issues	*The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult.*
Organize by importance of the issues, and number your points	*1. Your most important issue 2. The next most important item 3. … 4. The least important points*
Please provide constructive criticism, and avoid personal opinions	*I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC*
Comment on strengths (as well as weaknesses) of the manuscript	*I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.*

Global vegetation change is more affected by direct human activity than by climate change

Xianliang Zhang Corresp., [1], **Xuanrui Huang** [1]

[1] College of Forestry, Hebei Agricultrual University, Baoding, China

Corresponding Author: Xianliang Zhang
Email address: zhxianliang85@gmail.com

Human activity and climate change both affect the global vegetation distribution. Few studies were conducted to address their relative contributions on vegetation change. We aim to separate the influences of human activity and climate changes on the vegetation changes in this study. Potential vegetation reflects the vegetation distribution without human influences, while climatic vegetation indicates the vegetation distribution under human influences. The impact of human activity on the vegetation distribution can be identified by comparing the climatic vegetation changes with the potential vegetation changes. The results showed that climate-induced vegetation changes only occurred in a few grid cells for the period 1982-2013. Vegetation changes caused by human activities occurred worldwide from 1982 to 2013, except in the polar and desert regions. About 3% of total vegetation distribution was transformed by human activities during the period 1982-2013. We can conclude that human activities caused more severer damage to global vegetation change than climate change. The regions where vegetation experienced both human activity and climate change are eco-fragile regions, where should be well preserved in the future.

Global vegetation change is more affected by direct human activity than by climate change

Xianliang Zhang[1*], Xuanrui Huang[1]

[1]College of Forestry, Hebei Agricultural University, Baoding 071001, China

Correspondence Author:
Xianliang Zhang
289 Lingyusi street, Lianchi District, Baoding, 071001, China
Email address: zhxianliang85@gmail.com

Abstract. Human activity and climate change both affect the global vegetation distribution. Few studies were conducted to address their relative contributions on vegetation change. We aim to separate the influences of human activity and climate changes on the vegetation changes in this study. Potential vegetation reflects the vegetation distribution without human influences, while climatic vegetation indicates the vegetation distribution under human influences. The impact of human activity on the vegetation distribution can be identified by comparing the climatic vegetation changes with the potential vegetation changes. The results showed that climate-induced vegetation changes only occurred in a few grid cells for the period 1982-2013. Vegetation changes caused by human activities occurred worldwide from 1982 to 2013, except in the polar and desert regions. About 3% of total vegetation distribution was transformed by human activities during the period 1982-2013. We can conclude that human activities caused more severer damage to global vegetation change than climate change. The regions where vegetation experienced both human activity and climate change are eco-fragile regions, where should be well preserved in the future.

Keywords: vegetation types, climatic effects, human activity, Climate change, vegetation change.

1 Introduction

Vegetation is the most important component of the global terrestrial ecosystem. However, the global vegetation distribution has shifted from a semi-wild terrestrial biosphere to a mostly anthropogenic biome (Ellis et al., 2010), mainly caused by human activity and climate changes. The land surface the Earth has been modified by human activities (e.g. farming, building and grazing) for centuries, and it has been significantly changed by human activities (Foley et al., 2005; Ellis and Ramankutty, 2008; Defries et al., 2010). More of the land surface is being transformed as the human population continues to increase (Goldewijk et al., 2011; Eills et al., 2013). This new geological epoch has been referred to as the Anthropocene (Lewis and Maslin 2015) and the period in which biomes have been severely transformed by human activity is referred to as an anthrome (Eills and Ramankutty, 2008). As human settlements have developed and expanded, the distribution of vegetation types across the globe has changed markedly compared with the potential distribution of vegetation types which reflect vegetation distribution in the absence of anthropogenic influences.

The anthropogenic transformation of biomes and the terrestrial biosphere has been investigated to reflect vegetation distribution changes by comparing different biomes at century intervals (Ellis et al., 2010, 2011). However, Climate changes also caused shifts in the vegetation distribution (Kelly et al., 2008), which is difficult to be examined in these earlier studies which were only focus on the anthropogenic transformation of the vegetation distribution. Climate change had strong influences on the transformation of the vegetation distribution. Tropical rainforest and arctic tundra have experienced boundary changes as a result of climatic change (Diaz and Eischeid, 2007; Cook and Vizy, 2010; Zhang and Yan, 2014a). Widespread forest die-off from drought and heat stress increased with climate changes (Allen et al., 2010; Anderegg et al., 2013). Some dying forests were likely to be replaced by other vegetation types. Boreal forests are experiencing strongest warming among forest ecosystems, and large area of boreal forest are expected to be replaced by other biomes (Gauthier et al., 2015). Vegetation distribution change would be severer with continuous climate warming.

Human activities and climate change are the two main factors that determine changes in regional vegetation distribution. However, few studies evaluated the separated contribution of the two factors on vegetation changes. Climate data (1700–2000) used to detect the anthropogenic transformation of biomes was almost 20 years ago (Ellis et al., 2010). In this study, we delimit the influence of human activity and climate on the distribution of vegetation based on updated data. Accordingly, our main goals were to (1) delineate the influence of human activity and climate on the vegetation distribution, and (2) identify those regions most susceptible to human activity in recent period.

2 Data and methods

2.1 Climate and vegetation data

Global gridded monthly mean temperature and total precipitation data were obtained from the CRU TS 3.40 dataset at 0.5°×0.5° resolution (Harris et al., 2014). This dataset interpolates climate data from meteorological stations distributed throughout the world to the global land area, grid-by-grid, for the period 1901–2013 and has been used in previous climate classifications (Zhang and Yan, 2014a). We used climate data for the period 1982–2013 as this period reflected the availability of the vegetation data.

The normalized difference vegetation index (NDVI) has been used to indicate the greenness of vegetation in numerous vegetation studies (e.g. Breshears et al., 2005, Tucker et al., 2005, Zhou et al., 2014). It is defined as

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED})/(\mathrm{NIR} + \mathrm{RED}),$$

where NIR and RED are the amounts of radiation in the near-infrared and red regions, respectively. The NIR and RED reflectances should be corrected for atmospheric effects. The NDVI values range from −1 to 1, where negative values correspond to an absence of vegetation and positive values indicate vegetated land.

Monthly mean NDVI data at 0.0833°×0.0833° spatial resolution were retrieved from the Advanced Very High Resolution Radiometer (Pinzon and Tucker, 2014) based Global Inventory Modelling and Mapping Studies dataset (http://ecocast.arc.nasa.gov/data/pub/gimms/3g/) for the period 1982–2013. The NDVI data were up-scaled by calculating the arithmetic mean of the nearest neighbor grids over a six-by-six window to give the same resolution as for the climate data (0.5°×0.5°).

2.2 Separation of climate- and anthropo- driven vegetation changes

Regional vegetation might succeed to the climax vegetation community without the influence of human activity. The climax vegetation types could be represented by potential vegetation types, which indicate the vegetation distribution without human influences. The potential vegetation changes are mainly caused by climate changes. Therefore, the climate-driven vegetation changes could be reflected by the changes in potential vegetation types over different periods.

The vegetation changes are influences by both human activities and climate changes in the real world. The vegetation distribution in the real would could be represented by climatic vegetation types which reflected the vegetation distribution under human influences (Zhang et al., 2017a). Climatic vegetation types include effects of human influences while potential vegetation types exclude these effects. Hence, the anthropo-driven vegetation changes can be identified by the difference between the changes in potential and climatic vegetation. This method is similar to the observation minus reanalysis method reported by Kalnay and Cai (2003) which was used to test the climatic effect of changes in land use. In their method, the observations include the effects of changes in land use on climate, whereas the reanalysis excludes the effects of changes in land use on climate.

2.3 Potential vegetation distribution

The potential vegetation was generally defined based on climate variables (Koeppen 1936; Holdridge 1947; Box 1996; Ramankutty and Foley, 1999; Beck et al., 2005; Baker et al., 2010; Ellis et al., 2010; Levavasseur et al., 2012), therefore, the potential vegetation types could be represented by corresponding climate types. Climate types could be objectively classified to different global climate types based on the monthly attributes using the K-means clustering method (Mahlstein and Knutii, 2010; Zhang and Yan, 2014a, b; Zhang and Yan, 2016; Zhang et al., 2017b). Monthly mean temperature and monthly total precipitation were used as input multivariables that consisted of an n×24 matrix **X**:

$$\mathbf{X} = \begin{bmatrix} T_{11} & \cdots & T_{1m} & P_{11} & \cdots & P_{1m} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ T_{n1} & \cdots & T_{nm} & P_{n1} & \cdots & P_{nm} \end{bmatrix}$$

where T is monthly mean temperature, P is monthly mean precipitation, m is 12, and n is the number of all the grid cells in the global land area, except the Antarctic. The rows in **X** represent the monthly attributes, while the columns represent the number of grid cells. The names of vegetation types were designated by referring to the Koeppen classification (Kottek et al., 2006).

2.4 Climatic vegetation distribution

The climatic vegetation types were classified based on climate and NDVI data using the K-means method (Zhang et al., 2017a). An n×36 matrix **X** was constituted by monthly mean temperature, monthly total precipitation and monthly mean NDVI:

$$\mathbf{X} = \begin{bmatrix} T_{11} & \cdots & T_{1m} & P_{11} & \cdots & P_{1m} & \mathrm{NDVI}_{11} & \cdots & \mathrm{NDVI}_{1m} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ T_{n1} & \cdots & T_{nm} & P_{n1} & \cdots & P_{nm} & \mathrm{NDVI}_{n1} & \cdots & \mathrm{NDVI}_{nm} \end{bmatrix}$$

where T is monthly mean temperature, P is monthly mean precipitation, NDVI is monthly mean NDVI, m is 12, and n is the number of all the grid cells in the global land area, except the Antarctic.

2.5 Temporal changes in the influences of human activity and climate change on vegetation distribution

Fraedrich et al., (2001) suggested that an interval of at least 15 years is required to detect temporal changes in the geographical distribution of climate types. Thus, the period from 1982 to 2013 was split into two periods (1982–1996 and 1997–2013), and the climatic and potential vegetation types were classified over the two periods to check the temporal changes in the influences of human activity and climate change on vegetation distribution.

The actual changes in vegetation type could be identified by the differences between the climatic vegetation distributions over two periods. The potential vegetation changes were indicated by the changes in climate types over the two periods. However, the actual vegetation may not be influenced by changes in climate over such a short period. When changes were detected in both the potential and climatic vegetation types, they were identified as the influence of climate changes on vegetation. The impacts of human activity on the vegetation distribution could be identified by the differences between the climatic vegetation changes and the potential vegetation changes.

3 Results

Global climatic vegetation types were defined over the period 1982–1996 and 1997-2013 (Fig. 1). Changes in the distribution of climatic vegetation were found worldwide, except in the polar and desert regions, from the period 1982–1996 to the period 1997–2013 (Fig. 1). The largest changes in climate vegetation types were found in central Africa, eastern China, western America and Australia.

Changes in potential vegetation mainly occurred on the boundaries between adjacent types of vegetation from the period 1982–1996 to the period 1997–2013 (Fig. 2). Obvious boundary changes were seen between tropical rainforests and tropical dry forests, between tropical deserts and the Sahel, and between temperate deciduous and evergreen forests. However, the impacts of climate change on vegetation could not be detected over such a short period of time. After compared with the climate vegetation changes, actual changes in potential vegetation caused by climate variations were only detected in a limited number of grid cells (Fig. 2D).

The impact of human activity on the vegetation distribution was identified from the period 1982–1996 to the period 1997-2013 (Fig. 3). The changes in vegetation type caused by human activity were not only seen at the boundaries of different vegetation types, but also within the regions of vegetation types. About 3% of total vegetation distribution was transformed by human activities during the period 1997-2013.

Eastern China was selected to verify our results (Fig. 4). The NDVI changed from −0.04 to 0.04 in the grid cells where vegetation changes occurred (Fig. 4B). The changes in vegetation type mainly occurred in the regions where the NDVI changed was detected (Fig. 4C). The actual vegetation changes were compared with the land use change between 1990 and 2000 (Liu et al., 2002, Fig. 4D). The vegetation changes were mainly concentrated in similar regions. The changes in area of certain vegetation types were similar to those obtained using Liu's land use data (Table. 1). Larger changed areas of vegetation types were detected in this study than in Liu et al., (2002), because more detailed changes in land use could be detected with the land use data as a result of higher resolution and more detailed vegetation types (24 types).

4 Discussion

We separated the relative contributions of human activity and climate change on the vegetation distribution changes. Potential vegetation distribution in our study was similar to potential natural vegetation in 1700 as defined by Ramankutty and Foley (1999) and Ellis et al., (2010). Vegetation types have previously been defined based on NDVI data derived from satellite imagery (DeFries and Townshend 1994; Lu et al., 2003), but the connection of vegetation with climate is weakly reflected by this classification. The climatic vegetation types were therefore classified based on both vegetation and climate data to reflect the connection between vegetation and climate. Potential vegetation types and their corresponding climatic vegetation types were easily compared because they were classified by the same method.

Human activity has influenced vegetation for several centuries. The transformations of vegetation caused by human activities mainly through farming, building and grazing. The vegetation was mainly transformed into cropland, pasture and buildings due to human activities (Ellis et al., 2011). The impacts of human activity on vegetation were seen worldwide over the period 1982–2013, except for the polar and desert regions. The areas that were most affected by human activity were those with the highest population densities, including Europe, western North America, Central Africa, southern South American, eastern Australia and eastern China. Transitions in land use before 1900 mainly occurred in China, India, Europe, North America and Australia (Ellis et al., 2010). Transformations in the distribution of vegetation accelerated after the industrial revolution when rapid growth in the human population increased the pressure to expand the amount of pasture and farmland. The expansion of pasture mainly took place in central Asia, Australia, southern Africa and in the tropical Sahel and subsequent overgrazing led to transformations in the vegetation cover. The amount of cropland has expanded markedly in North and South America, Europe, southern Australia, northeast China and southern Asia. Grassland has been replaced by farmland in Europe and in North and South America. Cropland has expanded into the shrublands of Australia. The main change in land use in eastern China has been the replacement of forest and grassland with cropland (Zhang et al., 2016; Zhang et al., 2017c). These regions are the key zones with respect to the anthropogenic transformation of vegetation from the no human influence period to the period 1982–2013.

The influence of climate change on vegetation distribution was limited over the period 1982–1996 because vegetation shift caused by climate changes was not viable over short periods, except when there was an abrupt climate shift. In addition, climate warming and hot drought caused structure changes of regional vegetation (Breshear et al., 2005; Allen et al., 2011), not vegetation type change (e.g. forest to grassland). These vegetation changes caused by climate changes could not be visible over a short period. Nevertheless, the boundaries of some potential vegetation types were altered by climate changes, suggesting that the vegetation in these regions was under pressure and would show further changes over time. Widespread increased tree mortality has been found in some forest ecosystems because of climate warming (Adams et al., 2010; Van Mantgem et al., 2009). The impact of climate change on vegetation would be more visible in these regions over a longer period (e.g. 200 years).

By referring to the potential vegetation types, we can understand which regions will return to its climax community in the absence of human activity, for instance, abandoned farmland in northeast China can transform back to forest cover. These transformations caused fundamental changes in vegetation, and could be reflected in our results. However, it was not possible to identify all the shifts in vegetation distribution that had been affected by human activity. The dominant species of vegetation did not change in regions with a low intensity of human activities. The potential vegetation type can restore itself over a period with either low intensity or no human interference. Therefore, human disturbances on vegetation which only influenced the vegetation structure could not be reflected by our results because no shift in vegetation types could be detected.

The effects of human activity and climatic change on the distribution of global vegetation types could be separated using the proposed method. Human activity caused server vegetation changes than climate change, which is consistent with a study in northern forest (Danneyrolles et al. 2019). However, the influences of climate changes on vegetation distribution could not be ignored. The regions that were influenced by both human activity and climate change are vulnerable to vegetation changes in the future. The method presented in this study can also be used to identify the influences of human activity and climate changes on the past and future distribution of vegetation.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

X.Z conceived the idea, X.Z performed the analysis, and wrote the original manuscript, X.H, X.Z. revised and edited the manuscript.

Funding

This work was funded by the National Key Research and Development Program of China (2017YFD060040301), and the National Natural Science Foundation of China (grant numbers 41601045, 31570632, 41571094).

References

Adams, H.D., Macalady, A.K., Breshears, D.D., Allen, C.D., Stephenson, N.L., Saleska, S.R., Huxman, T.E. (2010), Climate-induced tree mortality: Earth system consequences, Eos, Transactions American Geophysical Union, 91, 153-154,

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., Mcdowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D. D., and Hogg, E. H. (2010), A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests, Forest Ecol Manag, **259,** 660-684,

Anderegg, W. R. L.and Kane, J. M. and Anderegg, L. D. L. (2013), Consequences of widespread tree mortality triggered by drought and temperature stress, Nat Clim Change, 3**,** 30-36,

Baker, B., H. Diaz, W. Hargrove, and F. Hoffman (2010), Use of the KoppenTrewartha climate classification to evaluate climatic refugia in statistically derived ecoregions for the People's Republic of China, Climatic Change, 98(98), 113-131.

Beck, C., J. Grieser, M. Kottek, F. Rubel, and B. Rudolf (2005), Characterizing global climate change by means of Koeppen climate classification, Beitrage zur globalen Klimatologie von Wolken und Niederschlag, 51.

Box, E.O. (1981), Macroclimate and plant form. Junk, The Hague.

Box, E. O. (1996), Plant functional types and climate at the global scale, J. Veg. Sci., 7(3), 309-320.

Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme,

J. H. Kastens, M. L. Floyd, and J. Belnap (2005), Regional vegetation die-off in response to global-change-type drought, P. Natl Acad. Sci. Usa, 102(42), 15144-15148.

Danneyrolles, V., Dupuis, S., Fortin, G., Leroyer, M., De Romer, A., Terrail, R., Vellend, M., Boucher, Y., Laflamme, J., Bergeron, Y., and Arseneault, D. (2019). Stronger influence of anthropogenic disturbance than climate change on century-scale compositional changes in northern forests. Nat Commun 10, 1265.

DeFries, R. S., Hansen, M. C., Townshend, J., Janetos, A. C., and Loveland, T. R. (2000), A new global 1-km dataset of percentage tree cover derived from remote sensing, Global Change Biol, 6**,** 247-254.

DeFries, R. S., and J. Townshend (1994), NDVI-derived land cover classifications at a global scale, Int. J. Remote Sens., 15(17), 3567-3586.

DeFries, R. S., T. Rudel, M. Uriarte, and M. Hansen (2010), Deforestation driven by urban population growth and agricultural trade in the twenty-first century, Nat. Geosci., 3(3), 178-181.

Ellis, E. C. (2011), Anthropogenic transformation of the terrestrial biosphere, Philosophical Transactions of the Royal Society A, 369(1938), 1010-1035.

Ellis, E. C., J. O. Kaplan, D. Q. Fuller, S. Vavrus, K. K. Goldewijk, and P. H. Verburg (2013), Used planet: A global history, P. Natl Acad. Sci. U S. A., 110(20), 7978-7985.

Ellis, E. C., K. Klein Goldewijk, S. Siebert, D. Lightman, and N. Ramankutty (2010), Anthropogenic transformation of the biomes, 1700 to 2000, Global Ecol. Biogeogr., 19(5), 589-606.

Ellis, E. C., and N. Ramankutty (2008), Putting people in the map: anthropogenic biomes of the world, Front. Ecol. Environ., 6(8), 439-447.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, and H. K. Gibbs (2005), Global consequences of land use, Science, 309(5734), 570-574.

Fraedrich, K., F. W. Gerstengarbe, and P. C. Werner (2001), Climate shifts during the last century, Climatic Change, 50(4), 405-417.

Gauthier, S., Bernier, P., Kuuluvainen, T., Shvidenko, A.Z., Schepaschenko, D.G. (2015), Boreal forest health and global change, Science, 349, 819-822

Goldewijk, K. K., A. Beusen, G. Van Drecht, and M. De Vos (2011), The HYDE 3.1 spatially explicit database of human - induced global land - use change over the past 12,000 years, Global Ecol. Biogeogr., 20(1), 73-86.

Harris, I., Jones, P. D., Osborn, T. J., and Lister, D. H. (2014), Updated high-resolution grids of monthly climatic observations-the CRU TS3. 10 Dataset, Int J Climatol, 34**,** 623-642

Holdridge, L. R. (1947), Determination of world plant formations from simple climatic data, Science, 105, 267-268.

Holdridge, L. R. (1967), Life zone ecology, Tropical Science Center, San Jose, Costa Rica.

Kelly, A. E., and M. L. Goulden (2008), Rapid shifts in plant distribution with recent climate change, P. Natl Acad. Sci. U S. A., 105(33), 11823-11826.

Köppen, W. (1936), Das geographische system der klimate

Kottek, M., Grieser, J., Beck, C., Rudolf, B., and Rubel, F. (2006), World map of the Köppen-Geiger climate classification updated, Meteorol Z, 15, 259-263

Lewis, S. L., and M. A. Maslin (2015), Defining the anthropocene, Nature, 519(7542), 171-180.

Levavasseur, G., Vrac, M., Roche, D. M., and Paillard, D. (2012), Statistical modelling of a new global potential vegetation distribution, Environ Res Lett, 7, 044019,

Liu, J., Liu, M., Deng, X., Zhuang, D., Zhang, Z., and Luo, D. (2002), The land use and land cover change database and its relative studies in China, J Geogr Sci, 12, 275-282,

Loveland, T. R., Reed, B. C., Brown, J. F., Ohlen, D. O., Zhu, Z., Yang, L., and Merchant, J. W. (2000), Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data, Int J Remote Sens, 21, 1303-1330,

Lu, H., M. R. Raupach, T. R. McVicar, and D. J. Barrett (2003), Decomposition of vegetation cover into woody and herbaceous components using AVHRR NDVI time series, Remote Sens. Environ., 86(1), 1-18.

Mahlstein, I., J. S. Daniel, and S. Solomon (2013), Pace of shifts in climate regions increases with global temperature, Nat. Clim. Change, 3(8), 739-743.

Pan, Y., X. Li, P. Gong, C. He, P. Shi, and R. Pu (2003), An integrative classification of vegetation in China based on NOAA AVHRR and vegetation-climate indices of the Holdridge life zone, Int. J. Remote Sens., 24(5), 1009-1027.

Pinzon, J. E. and Tucker, C. J. (2014), A non-stationary 1981–2012 AVHRR NDVI3g time series, Remote Sens-Basel, 6, 6929-6960

Ramankutty, N., and J. A. Foley (1999), Estimating historical changes in global land cover: Croplands from 1700 to 1992, Global Biogeochem. Cy., 13(4), 997-1027.

Tucker, C. J., J. E. Pinzon, M. E. Brown, D. A. Slayback, E. W. Pak, R. Mahoney, E. F. Vermote, and N. El Saleous (2005), An extended AVHRR 8 - km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data, Int. J. Remote Sens., 26(20), 4485-4498.

Van Mantgem, P.J., Stephenson, N.L., Byrne, J.C., Daniels, L.D., Franklin, J.F., Fulé, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H. (2009), Widespread increase of tree mortality rates in the western United States, Science, 323, 521-524

Zhang, X., Wu, S., Yan, X., and Chen, Z. (2017a). A global classification of vegetation based on NDVI, rainfall and temperature. International Journal of Climatology 37, 2318-2324.

Zhang, X., Z. Xiong, X. Zhang, Y. Shi, J. Liu, Q. Shao, and X. Yan (2016), Using multi-model ensembles to improve the simulated effects of land use/cover change on temperature: a case study over northeast China, Clim. Dynam., 46(3), 765-778.

Zhang, X., and X. Yan (2014a), Spatiotemporal change in geographical distribution of global climate types in the context of climate warming, Clim. Dynam., 43(3-4), 595-605.

Zhang, X., and X. Yan (2014b), Temporal change of climate zones in China in the context of climate warming, Theor. Appl. Climatol., 115(1-2), 167-175.

Zhang, X., and X. Yan (2016), Deficiencies in the simulation of the geographic distribution of climate types by global climate models, Clim. Dynam., DOI: 10.1007/s00382-015-2727-6.

Zhang, X., Yan, X., and Chen, Z. (2017b). Geographic distribution of global climate zones under future scenarios. International Journal of Climatology 37, 4327-4334.

Zhang, X., Xiong, Z., Zhang, X., Shi, Y., Liu, J., Shao, Q., and Yan, X. (2017c). Simulation of the climatic effects of land use/land cover changes in eastern China using multi-model ensembles. Global and Planetary Change 154, 1-9.

Zhou, L., R. E. Dickinson, Y. Tian, R. S. Vose, and Y. Dai (2007), Impact of vegetation removal and soil aridation on diurnal temperature range in a semiarid region: Application to the Sahel, P. Natl Acad. Sci. U S. A., 104(46), 17937-17942.

Zhou, L., Y. Tian, R. B. Myneni, P. Ciais, S. Saatchi, Y. Y. Liu, S. Piao, H. Chen, E. F. Vermote, and C. Song (2014), Widespread decline of Congo rainforest greenness in the past decade, Nature, 509(7498), 86-90.

Figure and table captions

Fig. 1. Geographical distribution of climatic vegetation types for (A) the period 1982–1996 and (B) the period 1997–2013 and (C) the differences between them. The black regions are those that have undergone transformations in vegetation type.

Fig. 2. Geographical distribution of potential vegetation types for (A) the period 1982–1996 and (B) the period 1997–2013 and (C) the potential and (D) actual changes between them. The colors used for the potential vegetation types represent the same meanings as in Fig. 2. The black regions are those that have undergone transformations in vegetation type.

Fig. 3. Impact of human activity on the distribution of vegetation types over the period 1982–2013. The black regions are those that have undergone transformations in vegetation type as a result of human activity.

Fig. 4. (A) The regions in which changes in the climatic vegetation type have occurred, (B) changes in the NDVI in these regions, (C) changes in the NDVI over the whole region, and (D) changes in land use in eastern China detected using the land use data of Liu et al., (2002).

Table 1. Comparison of changes in area of vegetation types in eastern China detected in this study to those detected using the land use data of Liu et al., (2002).

Table 1 (on next page)

Comparison of changes in area of vegetation types in eastern China detected in this study to those detected using the land use data of Liu et al., (2002).

Table 1. Comparison of changes in area of vegetation types in eastern China detected in this study to those detected using the land use data of Liu et al., (2002).

	Area of changed vegetation types ($10^4 km^2$)	
	This study	Liu's land use
Temperate grassland	7.5	6.4
Temperate Evergreen broadleaf forest	7.7	6.1
Temperate Deciduous forest	6.7	4.6
Sub-frigid mixed forest	6.4	4.9
Frigid evergreen coniferous forest	3.3	2.5

Figure 1

Geographical distribution of climatic vegetation types for (A) the period 1982–1996 and (B) the period 1997–2013 and (C) the differences between them. The black regions are those that have undergone transformations in vegetation type.

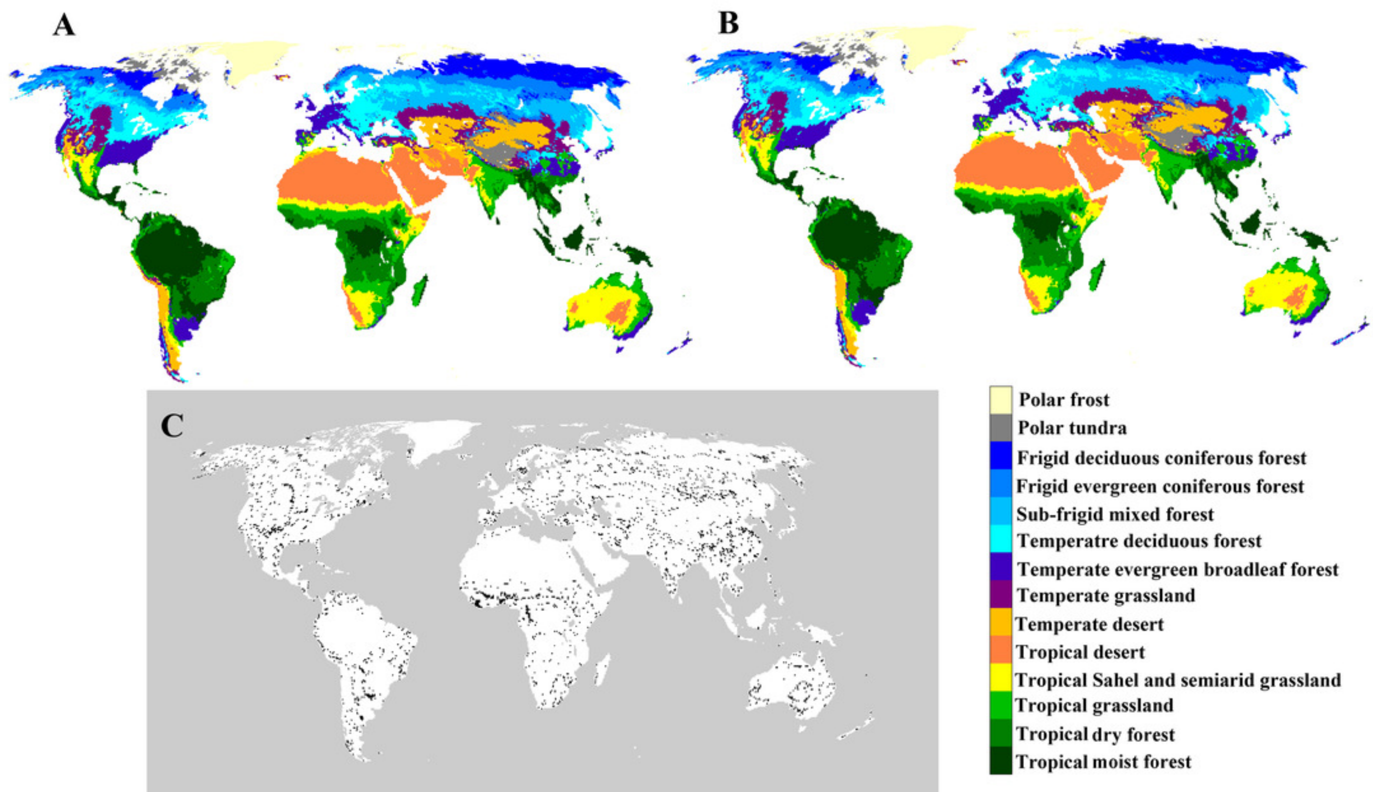

Figure 2

Geographical distribution of potential vegetation types for (A) the period 1982–1996 and (B) the period 1997–2013 and (C) the potential and (D) actual changes between them.

The colors used for the potential vegetation types represent the same meanings as in Fig. 2. The black regions are those that have undergone transformations in vegetation type.

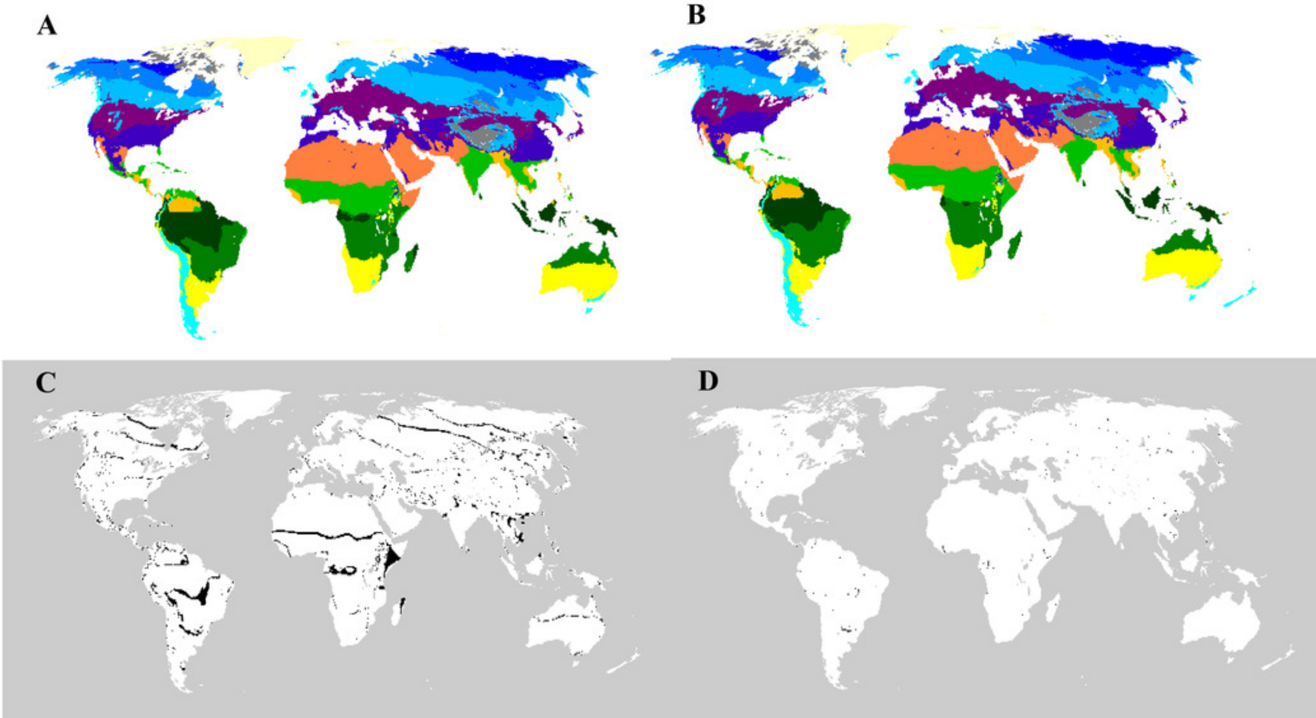

Figure 3

Impact of human activity on the distribution of vegetation types over the period 1982–2013

The black regions are those that have undergone transformations in vegetation type as a result of human activity.

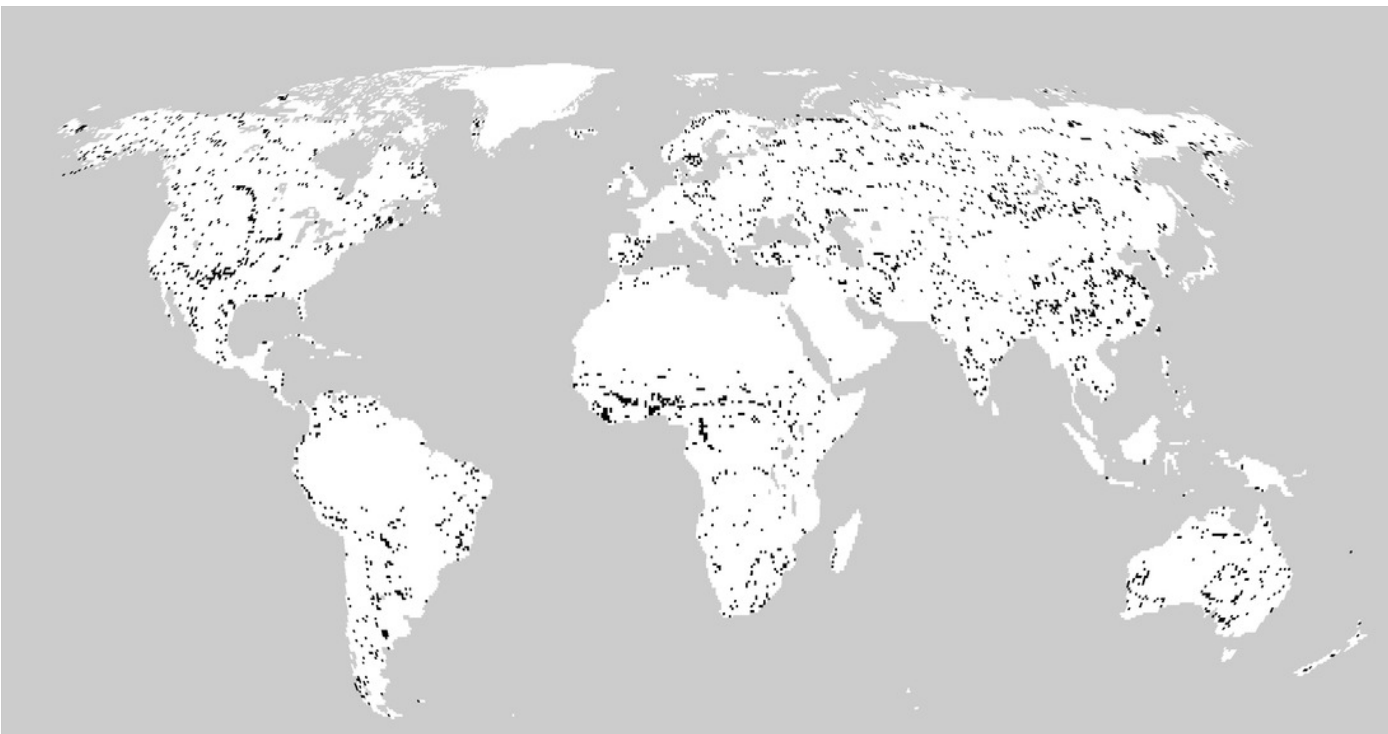

Figure 4

(A) The regions in which changes in the climatic vegetation type have occurred, (B) changes in the NDVI in these regions, (C) changes in the NDVI over the whole region, and (D) changes in land use in eastern China detected using the land use data of Liu e