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Research article

Global forestry areas, deforestation and mental health: A worldwide ecological study

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ABSTRACT

Background: - Forests are important for planetary and human health, but deforestation is increasing. Poor mental health is increasingly affecting the world's population. This study aims to investigate the association between forestry area, deforestation and mental health, at country level, worldwide.
Methods: - Forestry area in each country was sampled in 2016 and 2006; the country prevalence of mental health disorders or substance abuse was sampled in 2006 and 2016; and the relative disability-adjusted life years (DALYs) in 2010 and 2016. Crude and multivariate linear regression analyses were run, adjusting for peace index, wealth and inequalities, and urbanization at country level. A sensitivity analysis including sanitation and food security was run. Interaction with country gross domestic product per capita was assessed.
Results: - Based on data for 230 countries, country forestry area is negatively associated with the prevalence of mental health disorders in 2016 (β -0.02 (195% C.I. -0.04/-0.01). This association was maintained in sensitivity analyses, and found mainly in lower- and upper-middle income countries. Change in forestry area is not associated with mental health prevalence nor estimated DALYs due to mental health.
Conclusion: - This is the first study showing that forestry area at country level is associated with a lower prevalence of mental health disorders. If these results are replicated at individual level, this would suggest that public health implications should play a strong role in weighting ecological decisions, such as optimising forestry area coverage.

Introduction

Forests cover around 30% of the world's land surface area [1] and provide a habitat for various organisms, contributing to worldwide biodiversity. The world's population is rapidly increasing, creating a greater demand for agricultural land and putting more pressure on the way we use land provoking the forests to disappear at an alarming rate. Deforestation, the direct human-induced conversion of forested land to non-forested land, is most commonly caused by farming, grazing of livestock, drilling, mining and urbanization. Deforestation also results in a loss of habitat for various organisms, as well as impacting human health [2].

Mental health disorders affect one billion of the world's population [3]. These disorders are the leading cause of disability worldwide with around 23% of all years lost to disability due to these conditions [4]. Mental health disorders affect a person's day-to-day life, impacting employment, education, relationships and even increasing the risk of illness from other diseases [5]. The social stigma surrounding mental health prevents those affected from seeking help and hinders their recovery [6]. Improvements in mental health have numerous benefits, not only on physical health but also on economic growth and reduced healthcare costs [5].

Previous literature suggests that spending time in the natural environment can improve mental health [7,8]. Visits to forests improve both physical and mental health whereas an abundance of vegetation and bird wildlife reduces levels of stress, anxiety and depression [9]. Furthermore, research on a country level indicates how the loss of natural environments depletes biodiversity, posing a threat to health [10]. Biodiversity plays an important role in gut flora which has been demonstrated to impact health and mental health outcomes via the gut-brain axis [11].

A number of other factors can also affect mental health, at a population level. Conflict is shown to be strongly associated with poor

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mental health [12], with rates of mental health disorders doubling after an armed conflict and also associated with higher rates of deforestation [13]. Deforestations rates are indirectly driven by poverty, prompted by the increased land requirement needed for farming and livestock grazing [14]. Conversely, poverty is also associated with poorer mental health where those with lower socioeconomic status are at a higher risk for mental health disorders [15]. Urbanization increases the rate of deforestation due to city expansion into forestry area and the use of timber for infrastructure [16]; countries with higher rates of deforestation were found at increased risk of poor sanitation [17], which conversely has been shown to cause psychosocial distress [18,19]. Poor food security is found to be strongly associated with poor mental health, on a country level [20] and increased levels of deforestation in low- and middle-income countries affects the ability to grow food [21,22].

This study aims to assess the association between proportion of land covered by forest and deforestation, at a country level, and the burden of mental health conditions, accounting also for potential confounders such as conflict, poverty, urbanization, poor sanitation and food security, and exploring the interaction with country income level.

Methods

Information at country level, collected from a series of publicly available databases was used for this analysis. Specifically, data were collected for the exposure variable, deforestation; the outcome variable, measures of mental health at population level; and confounder variables, conflict, poverty, urbanization, poor sanitation and food security.

Deforestation

Forestry data, measured as forestry area as a percentage of land area of each country, were sampled through the World Bank database [1]r, for the years 2016 and 2006. Data in 2016 were the most current data available, and a 10-year period was chosen to analyse the long-term effect. For the purpose of this analysis, two variables were derived: forestry area as a percentage of land area in 2016; and change in forestry area as a percentage of land area between 2006 and 2016. The change is calculated by deducting the value in 2006 from the value in 2016, thus a positive value indicates reforestation and a negative value indicates deforestation. Forestry data were unavailable for 23 countries out of 230.

Mental health

Two variables were used in this study as a proxy for mental health: [1] age-standardised prevalence of mental health or substance abuse disorders; and [2] estimated disability-adjusted life years (DALYs) due to mental health and substance use disorders. Data of both variables were collected on two points in time (the most recent being 2016 in both cases), in order to calculate the change, in addition to the prevalence, as described below.

The prevalence of mental health disorders or substance abuse, derived from Our World in Data, encompasses the broad range of all mental health disorders including depression, anxiety, bipolar disorder, eating disorders, schizophrenia, intellectual development disability, and alcohol and drug use disorders [3]. In countries where raw data were lacking, epidemiological data and meta-regression models were used based on the data available from neighbouring countries [23]. The most recent values of age-standardised prevalence data were available for the year 2016; prevalence data were also collected for the year 2006, to calculate the 10-year change in prevalence. A positive value of the change variable indicates an increase in prevalence, while a negative value a decrease of prevalence, in the 10-year time period considered (34 countries had missing values).

Estimated DALYs due to mental health and substance use disorders provides a metric best suited for assessing mental health burden. One DALY equals the equivalent healthy year's loss due to early death or disability, capturing the impact of mental health on a person's wellbeing and combining mortality and morbidity [4]. The most recent data on DALY, expressed in DALYs per 1000 population available, were extracted for the year 2010, from the WHO Data Repository [4]. Given that data on DALY were not available for the year 2006 covering the same 10-year period as prevalence, it was collected for the nearest year available: 2010. Change in DALYs was calculated as values in 2016 minus values on 2010, where a positive value indicates an increase in DALYs, and a negative value indicates a decrease in DALYs over the 6-year period. In total, 47 countries had missing values. The distribution of both DALYs due to mental health and substance abuse disorders and its 2010−2016 change were found to be skewed (mean (SD): 933 [3,287], median (p25-p75): 214 (59 −596); and mean (SD): 61 (218), median (p25-p75): 12 (0.7−54), respectively), therefore the variables have been log-transformed before being added to the models leading to more normally distributed values (mean (SD): 5.1 (1.9), median (p25-p75): 5.4 (4.1−6.4); and mean (SD): 5.0 (4.2), median (p25-p75): 5.4 (2.4−8.0), respectively).

Overall, four outcome variables were analysed for an association with forestry areas and deforestation: the two cross-sectional measures in 2016 of prevalence of mental health and substance abuse disorders and DALYs due to mental health and substance use disorders; and their 10-year and 6-year changes, respectively.

A number of potential confounders of the association at country level were identified at the analysis planning stage and data were extracted, accordingly.

Conflict

Data on conflict were sampled using the 2016 Global Peace Index Report [24] which produces a score that is used to measure a nation's peacefulness based three domains: conflict, harmony and country militarization. This takes into account the level of safety and security in a country, as well as the ongoing internal and external conflict. It ranges from 1.192 in Iceland to 3.806 in Syria with higher scores representing higher level of conflict.

Poverty and income inequality

Poverty is assessed using Gross Domestic Product (GDP) per capita, and income inequality using the Gini coefficient. GDP per capita, sampled for the year 2016 from the World Bank Indicators [1], presented a skewed distribution (mean (SD): 15,117 [23,686], median (p25-p75): 5360 [1,987-17,493]) and was successfully log-transformed (mean (SD): 8.7 (1.5), median (p25-p75): 8.7 (7.6−9.8)). This is used in the analysis as proxy for absolute wealth of a country; and to categorise the countries into low- (<$1005.99), lower-middle- ($1006-$3955.99), upper-middle- ($3956-$12,235.99) and high- (> $12,236) income [1] for the analysis of the effect modification. The Gini coefficient, extracted from the World Bank database [1], is a measure of wealth distribution across the country population, and it is expressed as a percentage where the higher the index, the higher the inequality within that country [25]. Data for the most current Gini index available from 2006 through 2016 were extracted. Information on GDP per capita was highest in Monaco (168,011$) and lowest in South Sudan (237$), and was missing for 33 out of 230 countries; the GINI coefficient was highest in South Africa (63) and lowest in Ukraine [25], it was missing for 82 out of 230 countries.

Urbanization

Urbanization is measured using urban percentage which assesses the percentage of a population residing in urban areas. The indicator relies on a country's definition of urban centres. This data were sampled for the year 2016 from the World Bank Indicators [1] and was highest in Singapore (100%) and lowest in Burundi (12.4%); it was missing for 19 countries out of 230.

Sanitation

Overall country sanitation was assessed using the percentage of people using safely managed sanitation as an indicator. This data were collected for the year 2015 from the World Bank Indicators [1]. Data were only available for 81 countries, and was therefore not included into the main final models.

Food security

Data on food security were obtained from the Global Food Security Index (GFSI) 2016 [26]. Each country is assigned a score out of 100 according to a number of parameters based on affordability, availability, quality and safety of food. The higher the score, the higher the food security in a country, the GFSI varied from 86.6 in the United Stated to 24.0 in Burundi. Data were only available for 113 countries, and was therefore not included into the main final models.

Statistical analysis

Distribution of each of the variables was studied, checked for normality and log-transformed if skewed. The two main exposure (forestry area and forestry change) and four outcome variables (prevalence and DALYs due to mental health and substance abuse disorders and their changes) were mapped to explore geographical distribution. Crude and multivariable linear regression models were built in order to explore a total of six associations: the cross-sectional association between forestry area and the two mental health variables in 2016 (two models); the association between 10-year change in forestry area the two mental health variables in 2016 (two models); and the association between the change in forestry and the change in the two mental health variable (two models). The multivariable linear regression models included the confounding variables of peace index, GDP per capita, Gini index and urbanization . Sanitation and food security restricted the sample to 47 countries out of 230, so a sensitivity analysis was conducted separately. A likelihood ratio test was used to assess the interaction between the exposure variable and the World Bank income categories using the Likelihood ratio test, allowance being made for $p<0.05$. Where interaction was detected, associations were described by income category. Statistical analyses were conducted on Stata V.15.1, and maps were created using QGIS V.3.4.5.

The present papers used only publicly available data; therefore no external Ethical Committee approval was sought.

Results

Worldwide, 230 countries were sampled for the analysis. **Fig. 1** shows tertiles of the distribution of the forestry area as a percentage of land area in 2016, by country level; and **Fig. 2** shows the distribution of change in forestry area from 2006 to 2016. In 2016, forestry area was highest in Suriname (98%) and lowest in Greenland (0.0005%). Change in the forestry area (% of land area) varied from a loss of forestry area by 10.72% in Honduras to a gain of forestry area by 11.96% in Montenegro. Between 2006 and 2016, 82 countries increased in their forestry area (in green on the map in **Fig. 2**), 44 countries had no change in their forestry area (yellow) and 82 countries lost forestry area (orange). The overall mean change in forestry area during this time frame was a loss of forestry area by 0.23% (SD 2.64%).

Fig. 3 displays the distribution of the mental health variables. Greenland experienced the highest prevalence of mental health and substance abuse disorders in 2016 (22.1%) and Colombia the lowest (12.6%) with an overall mean of 15.7 (SD 1.7). From 2006 to 2016, there was an average decrease of prevalence by 0.1 (SD 0.2), with the greatest reduction in prevalence in Brazil (−0.9%) and the greatest increase in Iran (0.5%). Conversely, DALYs for mental health and substance abuse disorders in 2016 was highest in China (31,095 per 1000 population) and lowest in Tonga (1.7 per 1000 population) with an overall mean of 933.1 (SD 3278.0). From 2010 to 2016, there was a mean increase in DALYs of 60.6 (SD 217.7), with Russia experiencing the greatest reduction of DALYs (−503 per 1000) and India the greatest increase (2544.3 per 1000).

The results for the crude and adjusted linear regression analyses are displayed in **Table 1.** Forestry area measured as a percentage of land area in 2016 was cross-sectionally negatively associated with prevalence of mental health and substance abuse disorders in crude and adjusted models (β −0.02, 95% C.I. −0.04/−0.01). For every unit increase in the proportion of land covered by forestry area, the nation's prevalence of mental health and substance abuse disorders is decreased by 0.02 percentage points. Conversely, the crude association observed between forestry area and DALY for mental health and substance abuse disorders (β −0.02, 95% C.I. −0.04/−0.01) is lost after adjustment for confounders. Both the Peace Index and GDP per capita were associated with change in DALYs due to mental health and substance abuse disorders in the fully adjusted model. The change in forestry area (deforestation/reforestation) was not found to be associated neither with the prevalence or DALYs of mental health and substance abuse disorders in 2016, nor with their change (**Table 1**).

Evidence of an interaction between forestry area and prevalence of mental health and substance abuse disorders with categories of income per capita was found (p-interaction < 0.001). The beta coefficients from the regression analyses repeated across World Bank income groups are plotted in **Fig. 4**. After stratification, forestry area is negatively associated with the prevalence of mental health and substance abuse disorders only in lower-middle-income countries, examples include India, Kenya and Vietnam (β −0.2, 95% C.I. −0.04/−0.004) (**Fig. 4**).

Sensitivity analysis

Results of the sensitivity analysis conducted on 47 countries and including also information on sanitation and food security, are shown in **Supplementary Table 1**. Also, in this subset of countries, forestry area was associated with the prevalence of mental health and substance abuse disorders after accounting for all the other variables as confounders (β = −0.03, CI −0.06 to −0.01). Conversely, reforestation was not associated with any of the outcome variables. Food security was associated with both the prevalence and DALY from mental health and substance abuse disorders.

Discussion

This is the first study exploring the ecological association between forestry area, deforestation, and indicators of mental health at country level, worldwide. Country forestry areas were found to be associated with prevalence of mental health and substance abuse disorders: for a 10% increase in the proportion of land covered by forestry area the nation's prevalence of mental health and substance abuse disorders is decreased by 0.2 percentage points. This

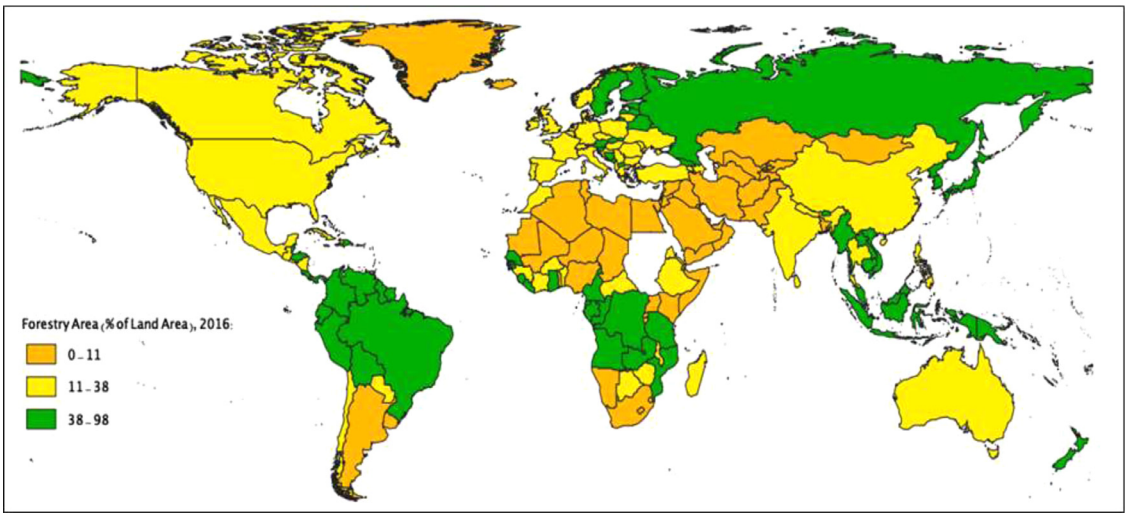

FIG. 1. World map showing the distribution of the forestry area as a percentage of land area, by country level in 2016. Adapted from the World bank. Categories calculated according to tertiles of distribution.

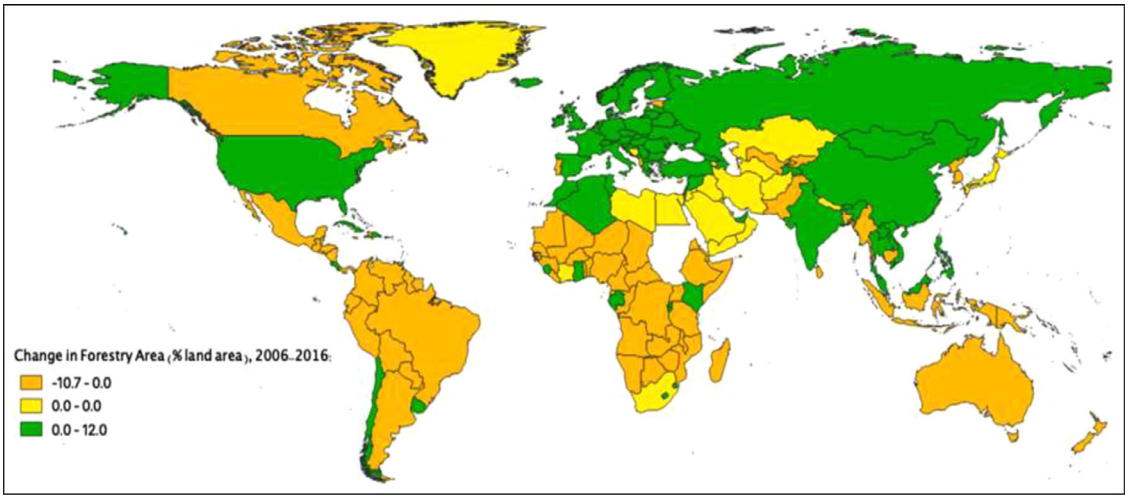

Fig. 2. World map showing the distribution of the change in forestry area as a percentage of land area, by country level from 2006 to 2016. Adapted from the World Bank. Categories calculated according to tertiles of distribution.

association is maintained even after adjusting for potential confounders, peace index, GDP per capita, Gini coefficient, and urbanization, and was replicated in the sensitivity analysis after accounting for access to safe sanitation and food security in fewer countries. The association seems particularly strong on lower-and upper-middle income countries. Conversely, no association was found between forestry area and DALYs due to mental health and substance abuse disorders.

Similarly, the pattern of deforestation/reforestation in the last 10 years was found not to be associated with any of the mental health outcomes. This suggests that either the deforestation changes are not large enough to be detected in association with mental health variables, or that the 10-year time interval was not long enough to detect an effect, or that in fact human activity around forests is not associated with the burden of mental health of the population.

When measuring the health outcomes, no association was found between forestry variables and the DALYs due to mental health and substance abuse disorders, while these were present for the prevalence of the same conditions. This suggested that the association existed with the actual prevalence, not with the severity of these diseases impacting on the disability and/or the mortality composing the DALYs.

Strengths and weaknesses of the study

This ecological analysis conducted at country level worldwide is designed to capture distribution of variables and their association at a global level. As such, the study suffered from the main limitation of ecological fallacy [27], by which any association found would need to be confirmed at individual level. Nonetheless, the present results observed at country level can be regarded as able to generate hypotheses at individual level and are corroborated by the consistency of findings after adjusting for confounders and in sensitivity analyses.

Mental health diagnoses are culturally diverse and therefore vary for each country [28] which could impact these results. Data collection for mental health prevalence is often underreported worldwide, and poorly representative of the population as a whole so relying on mental health diagnoses alone might be an underestimation of the true picture [29]. When sampling forestry data, 23 countries were missing, which could lead to information bias. However, this is only 10% and on closer inspection, the missing countries had small populations, and some are defined as cities e.g. Hong Kong. Urbanization relied on each country's definition so could lead to a discrepancy and the Institute for Health Metrics Evaluation uses the neighbouring country's data to collect missing values on prevalence. By only using

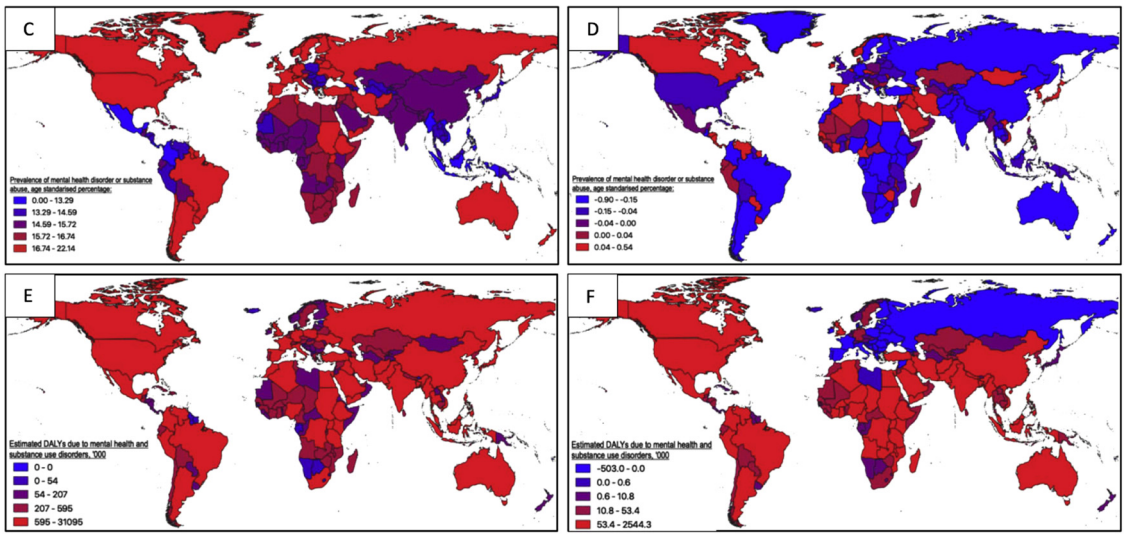

Fig. 3. World maps showing the distribution of the four proxy variables assessing mental health: (A) prevalence of mental health and substance abuse (PMHSA) disorders as age standardised percentages by country level in 2016; (B) change in PMHSA as age standardised percentages by country level from 2006 to 2016; (C) estimated DALYs due to mental health and substance abuse (EDMHSA), per 1000 population, by country level in 2016; and (D) change in EDMHSA, per 1000 population, by country level from 2010 to 2016. Unreported countries are missing. Categories calculated according to quintiles of distribution, adapted from Our World in Data.

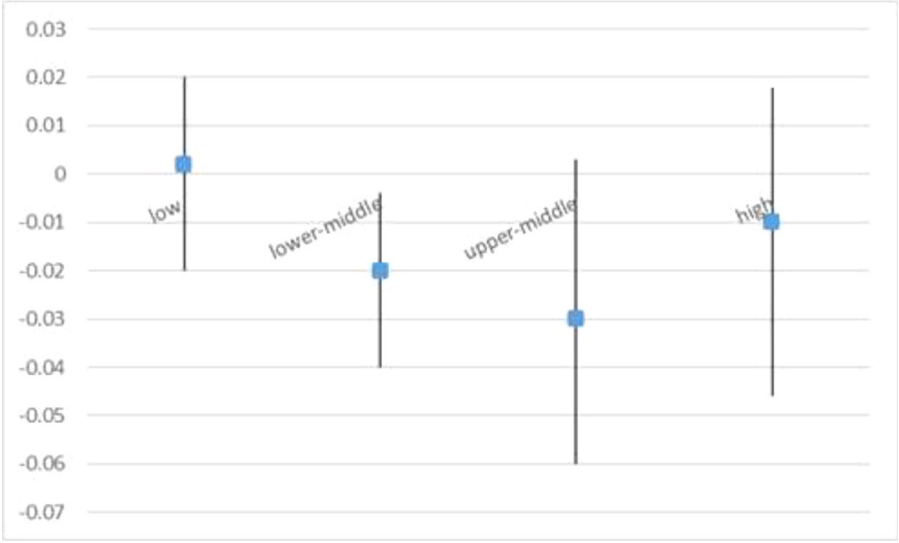

Fig. 4. Fully adjusted beta coefficients and relative 95% Confidence Intervals (C.I.) of the association between forestry area and age-standardised prevalence of mental health and substance abuse disorders by country income categories as measured by Gross Domestic Product (GDP) per capita.

publicly available data, it limits data sampling and the years sampled for mental health variables had to be adapted accordingly. This study was strengthened by sampling data on forestry area over 10 years to allow the investigation of the long-term effects of mental health. However, there lack of the association between deforestation/reforestation with mental health outcome variables might be due to the fact that longer periods are required to observe an effect.

Contextualisation of the results

One possible interpretation of the present findings is that proximity to green areas and forests is associated with better mental health. Despite the fact that it is not possible to examine this at an individual level with the present data, the fact that the association remains after adjusting for country-level urbanization reinforces this interpretation. Consistently, previous studies suggested an association between exposure to forestry areas and better mental health in individual countries [30]. One study revealed a positive linear association between the density of urban street trees and self-reported stress recovery [31]. Natural England published a report stating that nature-based interventions aid mental health recovery, lowering levels of anxiety, stress, and depression [32]. A health questionnaire in Toronto discovered that those residing in urban areas on blocks with more trees had reduced stress hormones in their blood as well as greater cardiac and metabolic health [33]. Furthermore, forestry areas are environmentally protective, sequestering carbon from the atmosphere and reducing air pollution. Deforestation results in a poorer air quality locally which is strongly associated with poor mental health including higher suicide rates [9].

Another explanation to these findings is that the reduced biodiversity of the environment caused by lack of forests affects the gut microbial abundance and increases the risk of poor physical and

Table 1
Crude and adjusted linear regression coefficient and relative 95% CI assessing the association between forestry area IN 2016, its change from 2006 to 2016 and mental health outcome variables (*N* = number of countries).

	Crude β coefficient	Adjusted β coefficient	Crude β coefficient	Adjusted β coefficient
	Prevalence of mental health and substance abuse disorders in 2016		**Log DALYs due to mental health and substance abuse disorders 2016**	
		N = 129		**N = 129**
Forestry area (% of land area) 2016	**-0.02**	**-0.02**	**-0.02**	0.0004
	(-0.03 to -0.01)	**(-0.04 to -0.01)**	**(-0.03 to -0.01)**	(-0.01 to 0.01)
Peace index score 2016	-0.0003	-0.0003	**0.0008**	**0.002**
	(-0.008 0.0003)	(-0.001 to 0.001)	**(0.0004 to 0.001)**	**(0.001 to 0.002)**
GDP per capita (log) 2016	**0.39**	0.32	-0.11	**0.39**
	(0.22 to 0.56)	(-0.03 to 0.67)	(-0.31 to 0.09)	**(0.07 to 0.71)**
GINI index 2006-2016	-0.02	0.01	0.004	0.005
	(-0.06 to 0.01)	(-0.02 to 0.05)	(-0.03 to 0.04)	(-0.03 to 0.04)
Urbanization 2016	**0.02**	0.02	0.01	-0.01
	(0.01 to 0.03)	(-0.01 to 0.04)	(-0.001 to 0.02)	(-0.03 to 0.01)
	Prevalence of mental health and substance abuse disorders in 2016		**Log DALYs due to mental health and substance abuse disorders 2016**	
		N = 129		**N = 129**
Change in forestry area (% of land area) 2006-2016	0.06	0.003	-0.03	-0.04
	(-0.03 to 0.15)	(-0.10 to 0.11)	(-0.14 to 0.07)	(-0.13 to 0.05)
Peace index score 2016	-	0.0003	**-**	**0.002**
		(-0.0005 to 0.001)		**(0.001 to 0.002)**
GDP per capita (log) 2016	-	0.29	-	**0.40**
		(-0.07 to 0.66)		**(0.08 to 0.73)**
GINI index 2006-2016	-	0.001	-	0.002
		(-0.04 to 0.04)		(-0.03 to 0.04)
Urbanization 2016	**-**	0.02	-	0.008
	Change in Prevalence 2006-16		**Log Change in DALYs 2010-16**	
		N = 129		**N = 129**
Change in forestry area (% of land area) 2006-2016	0.002	0.002	-0.21	-0.13
	(-0.007 to 0.01)	(-0.01 to 0.01)	(-0.44 to 0.01)	(-0.33 to 0.07)
Peace index score 2016	-0.00003	**-0.0001**	**0.003**	**0.004**
	(-0.0001 to 0.00003)	**(-0.0002 to 0.00001)**	**(0.002 to 0.004)**	**(0.002 to 0.005)**
GDP per capita (log) 2016	0.004	0.04	**-0.89**	-0.004
	(-0.01 to 0.02)	(-0.09 to 0.006)	**(-1.31 to -0.47)**	(-0.700 to 0.69)
GINI index 2006-2016	-0.003	-0.004	**0.1**	0.05
	(-0.007 to 0.001)	(-0.008 to 0.001)	**(0.01 to 0.19)**	(-0.02 to 0.12)
Urbanization 2016	0.0004	0.002	-0.003	-0.006

DALYs, disability adjusted life years; GDP, gross domestic product.

mental health [34]. Microbiota in fact seems to play a role in this gut-brain axis and circadian rhythm where administration of probiotics can upregulate oxytocin, a hormone that improves mood and anxiety [11]. Moreover, a direct pathway between microbes and the vagus nerve has been identified where beneficial microbes reduce anxiety and vice versa [35,36]. As a consequence, ongoing studies are trialing the use of probiotics to treat mental health disorders [37]. Emerging research supports this theory demonstrating how the level of green space and biodiversity of surrounding vegetation in residential areas affects bacterial diversity found on the skin [38,39]. This backs up how microbial abundance influences mental health. The results for the change in forestry area between 2006 and 2016 were not significant in comparison to the forestry area in 2016 alone. Research shows that microbiota in the soil is already depleted and biodiversity increase through reforestation takes longer than 10 years to build back up again [40]; research indicates that this process can take a minimum of 30 years before the soil is replenished [41].

Conclusion

This is an ecological analysis of the association between forestry area and and mental health variables at a county level, worldwide. Percentage of forestry area in a country is negatively associated with the prevalence of mental health and substance abuse disorders in the same country. The association is maintained after adjusting for poverty, peace, country wealth and urbanization. The association seems to be particularly strong for lower- and upper-middle income countries. Causality cannot be inferred, but these findings suggest two possible pathways explaining the association: biodiversity and

geographical distance to forests. Further research is required to explore this association further and identify the underlying causal pathway.

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Authors' contributions

Study concept and design: V Gallo, A Bolton, D Montag
Analysis and interpretation of data: V Gallo, A Bolton
Drafting of the manuscript: A Bolton
Data collection: A Bolton
Critical revision of the manuscript for important intellectual content: V Gallo, D Montag
Conceptualisation: VG DM
Data Curation: AVB VG
Formal Analysis: AVB
Funding acquisition: N/A
Investiagtion: AVB VG
Methdodology: VG
Project administration: AVB
Resources: AVB DM VG
Software: VG
Supervision: VG DM
Validation: VG DM
Visualisation: AVB
Writing original draft: AVB
Writing review and editing: VG DM

Conflict of interest statement

We declare that we have no conflict of interests.

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