Nature Heals: Mangroves, Mental Health, and Cognitive Functions

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Abstract

Mangroves provide vital services including fisheries support, carbon sequestration, and natural protection against coastal erosion and flooding, but their health consequences are less well-understood. We study their impacts on mental health and cognitive functioning in Indonesia, which has the most extensive and biodiverse mangroves in the world. Decades of deforestation, fueled by climate pressures, oil palm expansion and aquaculture, have led to widespread mangrove loss in the country, disproportionately affecting vulnerable coastal communities. By merging high-resolution satellite data on coastal land use change with individual-level panel data from the Indonesian Family Life Survey (IFLS), we find that a one-standard-deviation increase in local mangrove cover reduces the likelihood of clinical depression by 4.7 percentage points, and buffers against declines in episodic memory for older adults. These effects operate through channels of enhanced economic security and reduced flood exposure. Notably, health impacts from mangrove restoration and loss are asymmetric: the mental health benefit from restoring one hectare of aquaculture to mangroves is more than double the mental health cost from converting one hectare of mangroves to aquaculture. We find that cash transfers and social capital are less influential in the mangroves-mental-health relationship. Our results establish an important link between ecosystem degradation and human capital decline, making a compelling case for integrating mangrove conservation and restoration in development strategies.

Key Words: Mangroves, mental health, depression, CESD-10, cognitive ability, ecosystem, aquaculture, restoration, conservation

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1. Introduction

Mangrove forests are amongst one of the most biodiverse and valuable coastal ecosystems on the planet, offering a wide range of services from supporting fisheries to carbon sequestration to buffering communities against storm surges and rising sea levels. Their ecological and economic importance has become increasingly evident as the impacts of climate change intensify, particularly in low-lying and densely populated coastal regions. But despite their provision of rich ecosystem benefits, the global stock of mangroves continues to decline due to climate change, conversion to aquaculture and other land uses, and environmental degradation. Nearly a third of global mangrove deforestation between 1996 and 2015 happened in Indonesia, a low-lying developing country prone to natural disasters (Bunting et al. 2022). This erosion of natural capital is especially concerning given the growing recognition of mangroves as a form of "blue infrastructure," essential for climate resilience and sustainable development (World Bank, 2024).[1]

The economic value of mangroves is increasingly recognized, but current research and policy frameworks have focused primarily on valuing a subset of ecosystem services that are mostly tangible, market-based or market adjacent, such as carbon sequestration (Siikamäki et al. 2012, Murdiyarso et al. 2015, Jakovac et al. 2020, Rahman et al. 2021), coastal flooding and disaster protection (Sheng et al. 2012, Hochard et al. 2019, del Valle et al. 2020, Menendez et al. 2020), and fishery and raw material provision (Barbier and Strand 1998, Barbier et al. 2011, Brander et al. 2012, Anneboina and Kumar 2017). Given the established linkages between these factors and outcomes including income shocks (Ridley et al. 2020, Banerjee et al. 2023), flooding and natural disasters (Escobar Carias et al. 2022), and ecological grief (Cunsolo and Ellis 2018), it follows that mangrove ecosystems could potentially entail significant yet unquantified public health benefits.

From a policy perspective, the missing quantification of social co-benefits also highlights a central challenge in global forest conservation: incentive misalignment between local versus global benefits. Key benefits of mangrove conservation, such as carbon sequestration, are global public goods. The opportunity costs of conservation, such as foregone profits from aquaculture or palm production, are borne locally (Glennerster and Jayachandran 2023). Policy tools exist to

[1] World Bank (2024) *The Changing Wealth of Nations 2024: Revisiting the Measurement of Comprehensive Wealth – Executive Summary*. Washington, D.C.: World Bank Group. Available at: http://documents.worldbank.org/curated/en/099100824155099751 (Accessed: 25 March 2025).

resolve such misalignment, including payment for ecosystem services (PES) in the form of carbon credits, voluntary programs like Reducing Emissions from Deforestation and Forest Degradation including sustainable forest management (REDD+), or market entry regulations like the European Union's Deforestation Regulation (EUDR). However, their effectiveness hinges upon local willingness for adoption of and compliance with such tools (Börner et al. 2017, Jayachandran et al. 2017, Jack and Jayachandran 2019, West et al. 2020, Balboni et al. 2023). Identifying and quantifying associated local co-benefits, especially non-market-based ones as we do in this study, may provide critical input for designing effective and sustainable conservation policies.

In light of these considerations, this study aims to quantify the impacts of mangrove forests on mental health and cognitive functions of nearby communities, two crucial yet previously understudied co-benefits of local ecosystems. Previous research has emphasized economic outcomes such household income, asset accumulation, and livelihood security. However, mental health and cognitive capacity are equally vital for long-term well-being, as they influence and are influenced by economic dimensions of life (Hussam et al. 2022). We focus on Indonesia, where decades of mangrove deforestation driven by climate change, oil palm expansion, and aquaculture have severely degraded coastal ecosystems and disproportionately affected vulnerable communities. Specifically, we address a series of connected questions. First, what are the effects of mangrove coverage on mental health and cognitive function, and do these impacts vary across the life-cycle and other demographic characteristics? Second, how do ecosystem stability and land use dynamics relate to these outcomes? Third, through which channels do these effects operate, and how do contextual factors shape the strength of the mangrove-well-being relationship?

To answer these questions, we construct a novel dataset linking high-resolution satellite data on coastal land use from Clark Labs with a rich set of individual-level panel data from the 2007 and 2014 waves of the Indonesian Family Life Survey (IFLS). The IFLS includes measures on depression symptoms, episodic memory, and fluid intelligence. We create localized measures of mangrove cover and its transition to and from aquaculture - the primary competing land use - within a 30-kilometer radius of each community. Our empirical strategy leverages the panel structure of the dataset and uses fixed effects models that identifies the impacts of mangrove cover using within-individual variations over time. We complement this with a first-difference model to isolate the distinct effects of specific land use changes, such as mangrove persistence, conversion, and restoration.

Our analysis yields three primary findings. First, we document a robust relationship between local mangroves and decreasing depression symptoms: a one-standard-deviation increase in mangrove cover is associated with a 0.13 standard deviation decrease in the CESD-10 score and a 4.7 percentage point reduction in the likelihood of clinical depression. Second, mangrove cover acts as a buffer against declines in episodic memory, with a one-standard-deviation increase in mangrove cover improving total memory recall by up to 0.19 standard deviation for the 60+ age group. Third, the social impacts of land use change are asymmetric: the mental health benefit from restoring one hectare of aquaculture to mangrove is more than double the harm from converting one hectare of mangrove to aquaculture. These effects operate through multiple channels: we find that the presence of mangroves reduces households' flood experiences, while the conversion of mangroves to aquaculture increases flood exposure. In addition to flood prevention, proximity to mangrove forests increases households' employment income and the amount of food consumption, echoing findings in Ickowitz (2023) and Yamamoto (2023).

Our findings also reveal the importance of ecological contexts and the limits of traditional policy tools. In areas with high potential for ecological restoration, the mental health benefits of mangroves are attenuated, suggesting that the prospect of future environmental renewal may moderate the psychological impacts of current degradation. Moreover, large-scale unconditional cash transfers and strong social capital, though widely expected to be associated with better mental health and cognitive outcomes, do not significantly mediate the effects of mangrove proximity.

Our study makes several contributions. First, we contribute to the broader literature linking ecosystem degradation, particularly deforestation, to human health and well-being (Berazneva and Byker 2017, Garg 2019, Chakrabarti 2021, Balboni et al. 2023, Berazneva and Byker 2024, Cordoba 2024, Kishida et al. 2024). Most of this work focuses on the health impacts of general deforestation or multiple environmental exposures, with only a smaller subset of studies directly examining the social consequences of mangrove loss (Basyuni et al. 2022, Ke et al. 2022, Yamamoto and Shigetomi 2022, Yamamoto 2023). We extend this literature by documenting the impacts of mangrove coverage on two fundamental dimensions of human capital: mental health and cognitive performance. Importantly, we explore key pathways that help explain these impacts. This mechanism-oriented approach enables us to connect our findings to specific streams of knowledge on environmental stress, poverty dynamics, and psychological resilience.

Relatedly, we contribute to the emerging literature on adaptation and resilience in the face of ecosystem degradation. By assessing whether declines in mental health and cognition are mitigated in areas with higher ecological recovery potential, stronger community cohesion, or better access to social protection (cash transfers), we offer new empirical insights into the role of institutions in buffering environmental shocks, a domain in which empirical evidence remains sparse (Garg et al. 2025).

Our study also speaks to the literature on the value of natural capital and its link to human welfare (Deutsch et al. 2003, Engelbrecht 2009, Polasky and Daily 2021, Damania et al. 2023). Much of this literature evokes the importance of incorporating ecosystem services into economic policy and development planning, yet empirical validation remains limited due to data constraints and the difficulty of measuring non-market outcomes. Our study helps bridge this gap by providing new micro-level evidence on the mental-health returns to ecosystem preservation. By doing so, we reveal that mangrove conservation yields not only ecological and economic benefits, but also major gains in human well-being.

Our work also contributes to the body of research linking environmental conditions and climate change to mental health and cognitive functioning (Zhang et al. 2017, Burke et al. 2018, Obradovich et al. 2018, Mullins and White 2019, Elsner and Wozny 2023, Hua et al. 2023). While studies have largely focused on acute stressors such as temperature extremes, air pollution, or severe weather events, the psychological and cognitive impacts of gradual ecosystem degradation remain underexplored. By focusing on mangrove coverage, we draw attention to a slower-moving yet deeply consequential dimension of environmental change with lasting effects on individual well-being. Understanding these links is essential for assessing the broader societal implications of environmental decline, and for designing forward-looking policies that anticipate and mitigate mental health risks from ongoing ecological transformation.

While our study centers on Indonesia's unique socio-environmental dynamics and the localized impacts of mangrove ecosystems, its findings carry broader global relevance as coastal regions worldwide face parallel pressures. In the Sundarbans of Bangladesh, mangroves provide a vital 50-60 km buffer against powerful winds and storm surges (World Bank 2024), and serve as a key source of livelihood for surrounding communities. These benefits are increasingly undermined by rampant deforestation, land reclamation, and the escalating impacts of climate change. Along the West African coast, the Guinean Mangroves, stretching from Senegal to Sierra Leone, are under severe strain from rice farming expansion and rapid coastal development. Their wide latitudinal range makes them especially vulnerable to climate-driven sea level rise and warming temperatures, threatening both biodiversity and the well-being of local populations. In the Caribbean, where mangroves are important for shoreline stability, reef and seagrass protection, and the sustainability of fisheries and tourism, they are threatened by unregulated development, pollution, and intensifying hurricanes. Brazil's mangroves are similarly imperiled with illegal land occupation, inadequate water and sewage infrastructure, and changes in coastal hydrodynamics that have accelerated biodiversity loss and weakened the ecosystems' resilience. Comparable threats persist in regions like the Florida Everglades (USA) and Northern Australia. Across these diverse contexts, the erosion of mangrove ecosystems visibly impairs ecological stability but, as our findings indicate, also pose invisible risks to mental and cognitive health functions in affected populations.

2. Background

2.1. Mangroves in Indonesia

Indonesia is home to the world's most extensive mangrove forests. Spanning about 3.4 million hectares, mangrove forests in Indonesia account for over 20% of the global mangrove area and include 40 of the 54 known true mangrove species (World Bank 2022). Beyond bolstering fisheries and supporting coastal livelihoods, mangrove ecosystems play a vital role in carbon sequestration and offer critical protection against coastal erosion and flooding events.[2] Over the past decades, Indonesia has experienced a significant loss of mangrove forests, primarily due to conversion for shrimp aquaculture and the expansion of oil palm plantations, resulting in the clearance of large acreages (Ilman et al. 2016, Richards and Friess 2016).[3] The ineffective integration of ecosystem-

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[2] Halting mangrove deforestation could reduce emissions by 10-31% of the estimated annual emissions from land-use sectors (Murdiyarso et al. 2015). Further, a recent World Bank technical report for mangrove conservation and restoration in Indonesia estimates that the combined quantified present value of mangrove benefits over a 30-year period ranges from less than USD 2 million to more than USD 50 million per district. Districts with extensive mangrove areas, such as those in Papua, Kalimantan, and Sumatra, typically see values exceeding USD 50 million. According to the Food and Agriculture Organization (FAO 2014), approximately 55% of the total fish biomass landed in Indonesia comprises species that depend on mangroves. For more details, please see Van Zanten et al. (2021) for the World Bank Technical Report "*The Economics of Large-Scale Mangrove Conservation and Restoration in Indonesia: Internal Document*".

[3] Data from the Ministry of Marine Affairs and Fisheries (2017) and the UNFCCC (2018) show regional disparities in the state of mangrove ecosystems in Indonesia. As of 2016, South Sulawesi emerges as the province most adversely affected, with 52% of its mangrove cover experiencing severe damage, thus indicating an urgent need for enhanced conservation initiatives. Significant damage to mangrove cover is also reported in Banten, Jawa Barat, Gorontalo, and DI Yogyakarta. For further details, please refer to the *2018 Second Biennial Update Report* under the United Nations Framework Convention on Climate Change, advised by the Minister of Environment and Forestry.

based management within the country's conservation policies also contributes to the ongoing decline (Yamamoto 2023). Further increases in deforestation are expected as the Indonesian government expands aquaculture to boost exports of fishery products (Mursyid et al. 2021).

Panel A of Figure 1 illustrates the net changes in global mangrove habitat (in gray) and in Indonesia (in bold) between 1996 and 2015, revealing consistent declines. From 1996 to 2007, Indonesia experienced a net loss of approximately 960 km^2, while global losses during the same period totaled 2,631 km^2, showcasing Indonesia's significant contribution to the global decline. By 2015, annual net losses had intensified, with Indonesia losing 1,708 km^2 and global losses reaching 5,260 km^2. Panel B presents the top 10 countries with the largest absolute net loss of mangrove habitat over this period, with Indonesia leading by a wide margin. While these absolute estimates should be interpreted alongside the countries' respective mangrove coverage, Indonesia's relatively high net loss reflects its critical importance in global conservation priorities. This also demonstrates the importance of evaluating the scale mangrove loss within Indonesia itself, and of understanding the associated damage in ecological, economic, and social spheres.[4]

We can obtain further information from Figure 2, which illustrates primary and secondary mangrove forest areas in selected provinces from 1990 to 2015, drawing on the land cover series for that period. The aggregated mangrove data underscores marked heterogeneity in both the extent and composition of mangrove loss. While Papua and West Papua have generally retained comparatively large areas of both primary, which are old-growth and undisturbed, and secondary mangroves, which have regenerated after disturbance, other provinces show much sharper losses. For example, in Gorontalo, primary mangrove area fell from 23 to 5 thousand hectares, a nearly 80% reduction, and South Sulawesi saw a 75% drop in primary mangroves. These shifting balances between primary and secondary mangrove cover suggest that differences exist not only in the overall magnitude of mangrove resources, but also in their ecological quality and maturity. Considering total mangrove area (primary plus secondary), North Kalimantan's decrease is particularly pronounced, declining from roughly 224 thousand hectares in 1990 to 128 thousand hectares in 2015 – over 40% lost – while East Kalimantan's total mangrove area diminished from about 234 to 177 thousand hectares, a loss of nearly 24%. These province-level aggregates mask

[4] Our source of data for Figure 1 is the Global Mangrove Watch portal, accessed in November 2024 (see Bunting et al. 2022). In 1996, Indonesia's mangrove habitat spanned 31,273.002 km^2, covering 43.35% of the country's 133,775.86 km coastline. No data is available for periods before 1996.

substantial sub-provincial heterogeneity due to different development pressures, local ecological conditions, and restoration efforts. It is this finer-grained variability that our empirical strategy aims to leverage in the analyses that follow.

With threats of sea level rise and tropical cyclones becoming increasingly salient for Indonesia due to climate change, mangrove ecosystems play a critical role in disaster risk mitigation as their intertwined roots effectively break up surge forces.[5] Mangrove forests can adapt to sea level rise by accumulating sediments to maintain suitable soil elevations. However, for the Indo-Pacific region, which holds most of the world's mangroves, Lovelock et al. (2015) finds that 69 % of their study sites experienced sea level rise rates that exceeded their soil surface elevation gain, threatening their ability to adapt. Degradation of mangrove ecosystems can potentially lead to more extensive damage from flooding, resulting in substantial economic and health costs.

While restoration projects can mitigate some environmental impacts, the potential for such initiatives varies significantly across Indonesia. Sasmito et al. (2023) points to East Kalimantan, North Kalimantan, South Sumatra, West Kalimantan, and Riau as provinces with the greatest potential for mangrove restoration, noting specific regencies that present significant opportunities. Effective mangrove conservation strategies could benefit an estimated 74 million coastal inhabitants in Indonesia. Appendix Figure A1 displays the mangrove coverage in year 2000 for Indonesian regencies identified as having significant restoration potential of more than 5 hectares, using data from Sasmito et al. (2023). The map shows the top 12 regencies with restoration opportunities exceeding 5,000 hectares with yellow circles. We take restoration potential into account in our study.

Empirical evidence on the social value of mangrove ecosystems is scarce. Despite the increasing recognition of environmental determinants of health, the connection between mangrove ecosystems and broader health markers is significantly underexplored. The literature on other ecosystems is quite extensive in terms of reviews focusing on economic values, terrestrial habitats, and resilience, but research on the health-related impacts of mangroves is fragmented and sparse

[5] By functioning as natural seawalls, mangroves indeed serve as essential coastal barriers that protect coastal communities from the impacts of rising sea levels, erosion, storms, and strong wave energies. The benefits of mangrove restoration for coastal defense are important as they cost two to five times less than constructing engineered defenses like submerged breakwaters (Narayan et al. 2016, Van Zanten et al. 2021).

(Awuku-Sowah et al. 2022).[6] This oversight limits the understanding necessary to inform policy and interventions aimed at leveraging mangrove conservation as a strategy to improve health.

2.2. Ecosystem degradation and health: potential linkages

In this study, we hypothesize that mangrove ecosystems in Indonesia have profound socio-economic effects that extend to mental health and cognitive abilities. Mangrove deforestation jeopardizes livelihoods and food security, particularly impacting vulnerable populations who suffer from reduced access and control over these critical resources. Ickowitz et al. (2023), for instance, emphasizes that mangroves are integral to improving the nutrition and food security of coastal communities in Indonesia, thereby stressing the importance of mangrove conservation for ecological and socio-economic reasons. Their findings reveal that households near high-density mangrove areas consumed 28% more fresh fish and aquatic animals than those farther away, and those near medium-density mangroves consumed 19% more. Conversely, aquaculture does not seem to provide similar benefits. Awuku-Sowah et al. (2022), analyzing the physiological benefits of mangroves, note the therapeutic potential of bioactive extracts from mangrove sediments and plants. They also document how mangroves sustain nutrition by supporting fisheries and food production, sometimes in conjunction with adjacent ecosystems.

Yamamoto (2023) identifies a direct economic impact of mangrove loss, finding that a 1% decrease in mangrove coverage correlates with a 5.3% to 9.8% reduction in annual income for fishery households. Faced with such income shocks, these households tend to increase labor input while reducing non-food expenses. This economic strain has cascading effects on various dimensions including educational and marital outcomes (Yamamoto and Shigetomi 2022).

When ecosystems are degraded or lost, the resulting economic instability and negative income shocks can increase stress and anxiety among communities. This stress limits access to nutritious food and educational resources, which are essential for overall health. The resulting "ecological grief" (Cunsolo and Ellis 2018), a mental health response to the loss of species, ecosystems, and landscapes, is particularly pronounced in communities deeply connected to their natural surroundings, and it can significantly exacerbate emotional burdens and health-related

[6] Khosravi Mashizi and Sharafatmandrad (2024) explain that ecosystems play a key role in promoting public health across five dimensions: physical, mental, spiritual, social, and environmental. Natural ecosystems like forests and rangelands are especially effective in supporting mental, spiritual, and environmental health while artificial ecosystems such as parks and gardens contribute more to physical and social health.

issues.[7] In regions like Papua, where local communities view mangroves and their associated fauna as ancestral beings, the impact of this loss is profound (Van Zanten et al. 2021). This suggests that the intrinsic value of mangroves extends beyond what may be monetized. Moreover, mangroves may contribute to improved mental health, particularly when their long-term benefits are secured and community involvement in development plans is promoted (Ke et al. 2022).

Ruslan et al. (2022) investigates how mangrove ecosystem services affect the well-being of coastal communities in the Klang Islands, Malaysia, discovering that these communities benefit significantly. In contrast, Kibria et al. (2019) report mixed effects in the Sundarbans mangrove forest of Bangladesh, where access to ecosystem services leads to cleaner water and increased social freedom and security, but paradoxically diminishes food sufficiency adversely affecting physical strength and mental health. These findings suggest that the ongoing mangrove degradation in Indonesia could potentially create social fragmentation as households compete for diminished benefits.[8]

Furthermore, as mangrove loss weakens the natural barrier against hazards like flooding and storm surges, communities become more exposed to physical risks. This heightened vulnerability jeopardizes overall health, especially mental and cognitive challenges among at-risk populations. Thus, mangrove benefits which include direct contributions (such as providing fish, natural habitats and timber) and indirect protections (such as shielding from storms and floods) can affect welfare measures of coastal communities. The second part of our empirical analysis emphasizes these potential channels through which mangrove deforestation influences mental health and cognitive functioning.

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[7] Cunsolo and Ellis (2018) emphasize that ecological grief encompasses the mourning of immediate physical losses, the erosion of environmental knowledge, and the dread of anticipated future damages. This is becoming more embedded in everyday experiences due to ongoing environmental changes, underscoring the need for further investigation into how ecological grief affects mental health and well-being. Crandon et al. (2022) explain that specific emotional responses to climate change, such as "eco-depression" (sadness about climate impacts), "solastalgia" (grief from environmental change at home), and "climate anxiety" are gaining attention, and can lead to significant mental health challenges and affect behaviors related to climate adaptation. Further, they note the bidirectional link between physical and mental health, where some conditions exacerbated for instance by air pollution can also increase the risk of mental health issues like anxiety and depression.

[8] These effects may be especially pronounced in Indonesia, where mental health care faces numerous challenges including stigma, inadequate funding and limited availability of professionals. Figure A2 illustrates the spatial distribution of mental disorder prevalence across Indonesian regencies, based on data from the 2013 Basic Health Research Survey (RISKESDAS) conducted by the Ministry of Health. The data reveal substantial regional variation, with prevalence rates reaching as high as 48.4% in Manggarai Timur.

3. Data

3.1. The Indonesian Family Life Survey (IFLS)

We use data from the fourth (IFLS4) and fifth (IFLS5) waves of the Indonesian Family Life Surveys, conducted in 2007 and from late 2014 to early 2015, respectively.[9] The IFLS is a longitudinal socioeconomic and health survey that began in 1993 and is representative of 83% of the Indonesian population across 13 province.[10] IFLS4 successfully interviewed 13,535 households and 44,103 individuals, and IFLS5 interviewed 16,204 households and 50,148 individuals. Our final analytical sample consists of 18,548 adults whom we observe in both waves.

The survey's primary strength for longitudinal analysis lies in its rigorous tracking protocol and resulting high re-contact rates. The re-contact rate for original 1993 "dynasty" households was 93.6% in IFLS4 and remained high at 92.0% in IFLS5. Overall, 87.8% of the original 1993 dynasty households were successfully followed across all five waves over 21 years. This commitment to tracking is essential, as the population is highly mobile; between IFLS4 and IFLS5 alone, 35.4% of all interviewed households had moved from their previous location.[11]

The precision of our spatial analysis relies on the restricted-access geocoded data provided by the IFLS for respondent communities.[12] Residents of the original 312 IFLS communities (enumeration areas, or EAs) are consistently tracked across all survey waves. For households that move out of these original enumeration areas ("movers"), the IFLS tracks their new locations and assigns new community identifiers. GPS coordinates are available for most communities in IFLS5 where interviewed households reside, whereas coordinates are only available for the original 312 communities in earlier waves. As a result, we are able to derive community locations for 83.6% of

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[9] IFLS 4 was a collaborative effort of RAND, the Center for Population and Policy Studies (CPPS) of the University of Gadjah Mada and Survey Meter. For more details, see Strauss, J., F. Witoelar, B. Sikoki and AM Wattie. -*The Fourth Wave of the Indonesia Family Life Survey (IFLS4): Overview and Field Report*. March 2009. WR-675/1-NIA/NICHD.
IFLS 5 was a collaborative effort of RAND and Survey Meter. For more details, please see Strauss, J., F. Witoelar, and B. Sikoki. "*The Fifth Wave of the Indonesia Family Life Survey (IFLS5): Overview and Field Report*". March 2016. WR-1143/1-NIA/NICHD

[10] The first wave (IFLS1) surveyed individuals from 7,224 households. Four years later, IFLS2 attempted to re-interview these same respondents. In response to the economic and political crisis in 1998, a supplemental survey (IFLS2+) was conducted with 25% of the original sample.

[11] Our sample consists of 22.3% of the respondents who moved to a different community between 2007 and 2014.

[12] Community coordinates are restricted data and required a separate request for access. For more details, see the data updates and data notes provided for the IFLS datasets here: https://www.rand.org/well-being/social-and-behavioral-policy/data/FLS/IFLS/datanotes.html.

the households in IFLS4 and 96.5% in IFLS5.[13] Comprehensive community-level characteristics, collected through the full Community-Facility Survey (CFS) are available for the original IFLS communities, and a reduced set of community data is collected via an abridged "Mini-CFS" questionnaire for spin-off communities.

3.1.1. Mental health

Our primary measure of mental health is based on the 10-item Centre for Epidemiological Studies Depression Scale (CESD-10), which was administered to all respondents aged 15 and older in both the 2007 and 2014 waves of the IFLS. The CESD-10 is a widely used self-reported assessment that screens for depressive symptoms (Radloff 1977). A shortened version of the original 20-item survey, CESD-10 is widely used in clinical settings to screen for depression and maintains validity and reliability across age, gender, and culture (Irwin et al. 1999, Saracino et al. 2018).

The CESD-10 questionnaire consists of ten questions. Eight questions are negatively framed, including statements such as "*I felt depressed*", "*I was bothered by things that usually don't bother me*", and "*I felt everything I did was an effort*". The remaining two items convey positive sentiments, namely "*I was happy*" and "*I felt hopeful about the future*". Respondents are then instructed to rate, using a 4-category ordinal scale, the frequency of these emotional symptoms over the past week. We reconstruct the CESD-10 score following the medical literature by recalibrating responses using a four-category ordinal scale ranging from 0-3, and summing up scores from all questions. The CESD-10 score thus ranges from 0-30, with higher scores indicating more severe depressive symptoms. We also explore alternative specifications by taking the logarithm of the CESD-10 score, and by inverse-hyperbolic-sine (inhs) transforms of the raw score to mitigate the effects of data skewness and to account for zero values in the depression score (Kumar 2021). We also used two binary variables: the first flags individuals with a CESD-10 score equal to or above the clinical threshold of 10, commonly used to screen depressive symptoms; the second flags individuals whose CESD-10 score exceeds the sample median score of 4.

3.1.2. Cognitive ability

We construct measures for two key dimensions of cognitive ability: episodic memory and general intelligence. Episodic memory is measured using immediate and delayed word-recall tasks,

[13] For IFLS4, we are able to track locations of all original communities plus communities that appear in IFLS5, for which most community locations are available via a common community ID (*commid*). We are unable to exactly locate communities that appear (first) in IFLS4 but not in IFLS5.

administered to all individuals aged 15 and older in both waves.[14] Following the protocol from the U.S. Health and Retirement Study (HRS), respondents are initially presented with a list of 10 simple, commonly used words. They are then asked to recall as many words as possible, first immediately after hearing them and again after a delay of 12-15 minutes during which they engage with unrelated sections of the questionnaire concerning acute morbidity (Strauss et al. 2009a, Strauss et al. 2009b). Four different word lists are randomized among individuals to minimize memory spillover within households and prevent learning from one another's responses. From these tasks, we construct three outcome variables: the number of words recalled in the immediate recall task, the delayed recall task, and the total recall score (the sum of both). These skills are critical but often underestimated determinants of vital economic outcomes that significantly affect well-being (McArdle et al. 2009).

Fluid intelligence and numeracy are measured using tasks from the IFLS EK module, which is based on Raven's Progressive Matrices and a standardized numeracy test. The module comprises two parts of cognitive tests with eight cognitive questions and five math questions. The first part is based on Raven's Colored Progressive Matrices (CPM), assessing fluid intelligence by asking respondents to identify the missing elements in a pattern. The second part measures numeracy skills through arithmetic questions (Strauss et al. 2016). The tests were administered to individuals up to 35 years old in 2007.[15] In 2014, the Raven's test was administered to all individuals aged 15 or older, and the numeracy test was given only to respondents aged 15-59. Our final sample on cognitive ability only includes individuals who completed these tests in both waves, effectively allowing us to track changes in fluid intelligence and numeracy skills over time for the younger population.[16] We use standardized z-score measures provided by the survey for the Raven test, the numeracy test, and a combined z-score measuring overall intelligence.

[14] Important changes were made to the cognitive capacity sections of IFLS5 (Strauss et al. 2016), aiming to better align with the methodologies employed by the Health and Retirement Study (HRS). New tasks include, amongst others, serial subtraction of 7s from 100, naming animals within 60 seconds as a test of verbal fluency, and counting backwards from 20, targeted at respondents aged 50 and above. Additionally, adjustments were made to the immediate and delayed word recall tasks to ensure a consistent four-minute interval, mirroring HRS protocols. An adaptive number series test was refined to address the comparatively lower numeracy levels in Indonesia.

[15] Two levels of tests were administered: an easier version, EK1, for respondents aged 7-14, and a more challenging version of the math questions in the EK2, originally intended for respondents aged 15-24. We note that some respondents in 2007 were aged up to 35-years-old because respondents who completed the EK2 module in the 2000 IFLS wave were re-administered the same module in 2007, regardless of whether they had aged beyond 24.

[16] The maximum age in the 2014 wave that the cognitive module is consistently tracked is 42, corresponding to them aged 35 in the 2007 wave.

3.2. Mangrove and aquaculture data

Our analysis uses high-resolution spatial data on coastal land use from Clark University's Center for Geospatial Analytics (Clark Labs).[17,18] The dataset contains two data products at 15-meter resolutions based on Landsat satellite imagery: (1) a land cover product that identifies five distinct coastal land cover types of mangrove, wetland, pond aquaculture, water, and other land cover in 1999, 2014, 2018, 2020, and 2022; and (2) a land use change product, which identifies persistence of mangrove and aquaculture ponds, and transition to and from mangrove and aquaculture into other land use types between years 1999 and 2022. We construct our main exposure variables as the percentage of land cover (mangrove and aquaculture) and land use change (mangrove persistence, mangrove to aquaculture, aquaculture to mangrove, etc.) within 5, 10, 20, and 30 km of each community (the "cluster" location in the IFLS) location.[19]

To link the spatial data to our survey waves, we match the 1999 land cover snapshot to the IFLS4 (2007) wave and the 2014 snapshot to the IFLS5 (2014) wave. While the Clark Labs dataset offers the advantage of identifying coastal aquaculture operations and granular land use transitions, this approach creates a temporal mismatch for the 2007 wave. This is justifiable in our view as mangrove cover is a slow-moving stock variable, and as such the 1999 measure likely serves as a strong proxy for baseline ecological conditions in the years leading up to the 2007 survey.

As additional robustness checks for data quality and the matching process, we compile an alternative mangrove cover dataset from the Global Mangrove Watch (GMW) which identifies global mangrove extents and changes for years 1996, 2007-2009, and 2015-2020 at a 25m resolution.[20] After matching GMW mangrove cover with community locations, we find that the between-wave correlation for mangrove coverage in the GMW data is 0.998 for the 2007–2014 period, confirming that mangrove extent is stable over a comparable seven-year interval.

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[17] The data is open-access on Clark Lab's website, https://www.clarku.edu/centers/geospatial-analytics/aquaculture-data-download/, accessed July 30th, 2025.

[18] Coastal zones are defined as 10 km on either side of the coastline, and up to 60 km inland from the coast when elevation is less than 5 meters.

[19] We adjust for coastal locations by masking permanent water bodies (ocean and lakes) when calculating percentages of land cover and land use change within each buffer ring.

[20] The Global Mangrove Watch (GMW) is a collaborative effort involving Aberystwyth University in the UK, solo Earth Observation (soloEO) in Japan, Wetlands International, the World Conservation Monitoring Centre (UNEP-WCMC), and the Japan Aerospace Exploration Agency (JAXA). It focuses on generating updated mangrove maps, conducting regular monitoring, understanding the drivers of mangrove changes, validating updates using field and other remote sensing data, and contributing to the Ramsar Global Wetlands Observing System (GWOS).
Other cited reference: Thomas N, Lucas R, Bunting P, Hardy A, Rosenqvist A, Simard M. (2017). *Distribution and drivers of global mangrove forest change, 1996-2010*. PLOS ONE 12: e0179302. doi: 10.1371/journal.pone.0179302

Furthermore, the mangrove cover measures from the Clark and GMW datasets are highly correlated with coefficients of 0.857 for the 2007 wave and 0.866 for the 2014 wave. We are thus confident that the temporal mismatch in using Clark Labs' land use data is inconsequential.

3.3 Summary statistics

Table 1 provides the summary statistics for key variables across four panels. In Panel A, mental health is measured using the CESD-10 scale, with an average score of 4.8 and a standard deviation of 4.3. Logarithmic and inverse hyperbolic sine transformations of the CESD-10 yield similar central tendencies, while binary indicators show that 40.9% of respondents score above the median CESD-10 score of 4, and 13.4% meet or exceed the clinical cutoff of 10 for depressive symptoms. Panel B summarizes cognitive outcomes: the average immediate recall is 4.9 words, delayed recall is 3.9 words, resulting in a total episodic memory score of about 8.8 words, with a standard deviation of 3.7. The average z-scores for the raven test, numeracy test, and overall intelligence is 0.3, 0.2, and 0.3, respectively.

In Panel C, the average mangrove coverage within a 30 km radius is 0.2% (standard deviation of 0.9). 0.2% of mangrove cover persists over time, with 0.04% converted to aquaculture ponds and 0.04% converted from aquaculture ponds. Panel D shows considerable variation across individual and household control variables, including age, marital status, rural residence, religion, household size, and educational attainment. This diversity underscores the importance of accounting for a broad range of socioeconomic characteristics in our empirical design.

4. Empirical strategy

To assess the impact of mangrove ecosystems on mental health and cognitive ability, our empirical approach leverages the panel structure of the IFLS data from 2007 and 2014. We estimate two main specifications. Our primary specification assesses the relationship between the extent of local mangrove cover and individual outcomes using the following fixed effects model:

$$y_{ihct} = \beta\, MangroveCover_{ct} + \gamma' X_{ihct} + u_i + v_t + \epsilon_{ihct} \tag{1}$$

where y_{ihct} represents the outcome (either for mental health or cognitive ability) for individual i living in household h in community c surveyed in IFLS year t. Our model includes a rich set of individual- and household-level control variables, X_{ihct}, including age, marital status, a rural residency indicator, religion, education, and gender of the household head, as shown in Table 1. $MangroveCover_{ct}$ is the primary independent variable of interest, measuring the percentage of mangrove cover within a 30-kilometer radius of community c in year t. We chose a 30 km buffer to trace the ecological footprint of mangroves and the broader environmental impacts associated with changes in mangrove cover. This distance reflects local evidence that alterations in mangrove cover can potentially have spillover effects beyond the immediate proximity. We conduct robustness checks for the choice of buffer distance in Appendix Figure A3.

Equation (1) includes both an individual fixed effect, u_i, and a wave fixed effect, v_t. The individual fixed effect allows us to account for all time-invariant, unobserved characteristics at the individual level such as genetic predispositions, inherent cognitive ability, baseline health status, cultural attributes, and persistent socioeconomic factors, that might otherwise confound the relationship between mangrove coverage and the outcomes of interest. The survey-wave fixed effects control for common shocks and trends that affect all individuals at a particular time, including environmental conditions, economic cycles, and policy changes, amongst others. The coefficient of interest, β, is identified from variations in mangrove cover within a community between the 2007 and 2014 survey waves. Our key identifying assumption is that, conditional on fixed effects and the set of time-varying controls, changes in a community's mangrove coverage are not systematically correlated with other unobserved, time-varying factors that also influence individual health and cognitive outcomes. As robustness checks, we vary the level of fixed effects, with results presented in Table A1. All regressions are weighted by IFLS survey weights, and standard errors are clustered at the community level, coinciding with the levels of both the treatment variation and the sampling scheme (Abadie et al. 2023).

Complementing our main strategy, we also estimate models exploring the effects of land use change dynamics, specifically focusing on aquaculture operations, a major source of mangrove loss in Indonesia. Specifically, we are interested in the effects of persistent mangrove ecosystems, as well as transitions between mangrove and aquaculture landscapes, on health. To do so, we utilize long-run (1999-2022) land use transition data from Clark Labs which provides persistence and transitions to and from coastal land use types, including mangrove and aquaculture ponds. Since the land use transition data is in first-differenced form, we pair this with a first-difference estimation strategy, specified as

$$\Delta y_{ihc} = \beta_1 MangrovePersistence_c + \beta_2 PondPersistence_c + \beta_3 Mangrove\ to\ Pond_c + \beta_4 Pond\ to\ Mangrove_c + \gamma' \Delta X_{ihc} + \Delta \varepsilon_{ihc} \tag{2}$$

where Δy_{ihc} is the difference in the outcome variable of interest for individual i living in household h, in community c between waves 2007 and 2014, and ΔX_{ihc} is the first-differenced individual- and household-level control variables. We include four land-use-change variables: persistence of mangrove and aquaculture ponds, as well as transitions from mangrove to aquaculture ponds and vice versa. The identification assumptions in Equation (2) are analogous to those in Equation (1).

5. Results

5.1. The effects of mangrove coverage on mental health and cognitive ability

We begin by presenting the estimated effects of mangrove coverage on mental health and cognitive ability from our main fixed effects specification (Equation 1) in Table 2. In Panel A, we focus on mental health outcomes constructed using the CESD-10 measure. Across columns (1)-(5), we find that higher mangrove coverage is consistently associated with better mental health outcomes. For example, in column (1), the estimate indicates that a one-standard-deviation (1 SD) increase in mangrove coverage is associated with a 0.13 standard deviation (SD) decrease in the CESD-10 score.[21] These negative associations persist when we use logarithmic (column 2) and inverse hyperbolic sine transformations (column 3) of the CESD-10 score. Furthermore, when using the binary indicator for a CESD-10 score exceeding the clinical cutoff of 10 (column 5), we find that a 1 SD increase in mangrove coverage is associated with a 4.7 percentage point (pp) reduction in the likelihood of experiencing clinical depressive symptoms.

In contrast to the strong association with mental health, Panel B of Table 2 shows few significant effects of mangrove coverage on average cognitive performance for the general population. The estimated coefficients for measures of episodic memory - immediate, delayed, and total recall (columns 1-3) - are small and not statistically distinguishable from zero. Similarly, we observe no significant average effects on fluid intelligence or numeracy skills, as measured by the Raven's, numeracy, and overall intelligence z-scores (columns 4-6). It is plausible, however, that these benefits are concentrated among specific demographic groups. We explore this possibility in the next section by examining heterogeneous effects across the life-cycle.

[21] The coefficient on *Mangrove Cover* in column (1) is -0.663. We multiply this coefficient by the standard deviation of mangrove cover (0.866) to obtain a 0.574. Since the standard deviation of CESD-10 scores is 4.315, this is a 0.574/4.315= 0.133 standard deviation decline in the CESD-10 score.

5.2. Older, more educated groups benefit more from mangrove presence

We investigate whether benefits are uniformly distributed across demographic groups, and start with examining differential impacts by age cohorts, particularly since memory and cognition losses are likely to be more prevalent among the elderly. To do so, we estimate models that interact mangrove cover with respondents' age groups. Results are plotted in Figure 3.

We find clear age gradients for both mental health and, most notably, for episodic memory. The top panels of Figure 3 show the age-specific effects of mangrove coverage on mental health outcomes. While the estimated effects are statistically significant for every other age group except for ages 15-19, the effects are much larger amongst middle-aged and older individuals. For instance, the coefficient on the CESD-10 score is negative across all age groups but becomes larger in magnitude and more statistically precise for cohorts aged 40 and above. While on average, a 1 SD increase in mangrove coverage decreases CESD-10 score by 0.13 standard deviation, it decreases CESD-10 score by 0.26 standard deviation for both the 50-60 and the 60+ age group.[22] For the likelihood of exceeding the clinical threshold of 10, compared to the average decrease of 4.7 pps for a 1 SD increase in mangrove coverage, the likelihood decreases by 8.4 and 7.9 pps for ages 50-60 and 60+. This indicates that older individuals, who may have accumulated longer exposures to their local environment, rely more on it for their well-being, or are at greater risk of mental and cognitive decline, derive greater psychological benefits from intact mangrove ecosystems.

More strikingly, the middle panel of Figure 3 reveals a significant relationship between mangrove coverage and cognition that was masked in the average effects. While the coefficients on episodic memory are statistically insignificant for younger individuals, they become positive and statistically significant for older cohorts. For total recall, the effect is statistically significant for the 60+ age group, and large and marginally significant for the 50-59 age group. A 1 SD increase in mangrove coverage improves total memory by 0.11 and 0.19 SDs for the 50-59 and 60+ age groups, respectively. We observe a similar pattern for both immediate and delayed recall. These results provide evidence for a key, previously undocumented benefit of natural capital: mangroves serve as protective buffers against age-related memory loss.

[22] We used age-specific standard deviations for CESD-10 scores (SD = 4.340 for age 50-60, and SD=4.225 for age 50-60) in the above calculations. Both the mean and the standard deviation of CESD-10 scores are stable across different age groups.

We also find that mangrove coverage is positively associated with improvements for the Raven's matrix completion test and the combined intelligence z-score for the middle-aged cohort (age 30-40). The estimated coefficients for the numeracy tests are positive for the middle-aged cohort but are statistically insignificant at the 10% level. Since both the Raven and the numeracy tests are restricted to younger individuals, we cannot predict the impacts of mangrove cover on cognitive functions in the elderly population.[23]

Besides differential impacts by age, we also explore potential heterogeneity by gender, education, and household food security status. Results are presented in Table 3. In Panel A, we find minimal gender gaps in the mental health benefits of mangrove cover. Point estimates on the CESD-10 score are close and statistically indistinguishable between male and female individuals. Panel B examines heterogeneity across education levels. We find that mangrove coverage provides larger benefits for more-educated individuals compared to their less-educated peers. Mangrove coverage has no significant impact on depression symptoms for individuals with no formal education, and becomes larger in magnitude for individuals with more educational attainment. For individuals with college or higher education, a 1 SD increase in mangrove coverage decreases CESD-10 score by 0.20 SD (pooled average effect = 0.13 SD) and the likelihood of above clinical cutoff by 5.6 pps (pooled average effect = 4.7 pps). Finally, Panel C examines the differential impacts of mangrove coverage by food security status. We do not observe meaningful differences in mangrove impacts in this sphere.

5.3. Migration

A central challenge in identifying the effect of environmental quality on welfare is the selective migration. If individuals who are healthier or more resilient choose to remain in places with better environmental amenities and move out of places with worse amenities, then the relationship between mangrove cover and individual well-being could be biased. While our fixed effects strategy partially addresses this by differencing out time-invariant individual characteristics, we explicitly address this here by examining how the effects of mangrove cover differ between non-movers and movers by stratifying the sample by migration status between the two waves. This analysis serves two purposes: first, it is a direct test of whether our findings are robust to potentially endogenous sorting; second, it provides insights into the mechanisms by which ecosystems affect well-being by comparing two distinct sources of variation in our model. For non-movers, the effect

[23] We caution reading too much into the large effects for the age 40-42 cohort as the sample size is small.

is identified from temporal changes in mangroves *within* a community, while for movers, identification leverages differences in mangroves *between* the origin and destination communities.

Table 4 presents these results. We find that, compared to the full sample, mangrove cover has significantly larger mental health benefits for non-movers. A 1 SD increase in mangrove coverage decreases CESD-10 score by 0.26 SDs, and the likelihood of reaching the clinical cutoff by 8.1 pps (as seen in Column 2).[24] For movers, we find smaller effects.

The fact that mangrove coverage provides more mental health benefits to non-movers has a number of implications. First, the mental health benefits of mangrove ecosystems could be a function of cumulative exposure and long-term integration. The benefits may not be instantaneous but may accumulate over time as individuals build a sense of place and stable, nature-linked livelihoods. Second, while the effect for movers is still statistically significant, its smaller magnitude could reflect selective migration driven by unobserved heterogeneities, such as the fact that movers may be less sensitive to local environmental amenities. These results underscore that the benefits of mangrove ecosystems are greater for established communities, suggesting that *in-situ* conservation and restoration initiatives may be effective tools for protecting well-being.

5.4. Robustness checks for the main results

To ensure the robustness of our results, we replicate our main regression model with a series of alternative specifications by adding additional control variables and varying the level of fixed effects. Results are presented in Table A1. Column (1) reports the baseline model, which includes individual and survey year fixed effects. In column (2), we include additional control variables related to media consumption and household amenities. Specifically, we add indicators for whether an individual can read a local newspaper in the local or a foreign language, as well as variables for household access to electricity, safe water, private toilet facilities, garbage disposal, and television. Column (3) replaces the individual fixed effect with the household fixed effect. In light of evidence that childhood conditions can significantly influence future welfare outcomes (Ahmed et al. 2023, Hughes et al. 2017, Kivimaki et al. 2018), column (4) adds additional controls for early-life circumstances including childhood health status, resource constraints during childhood, early family stress, childhood educational stimulation, and economic disadvantages during childhood.[25]

[24] 0.093 (the marginal effect) multiplied by 0.866 (the SD of mangrove cover) = 0.081 or 8.1 pps.

[25] We control for childhood health status by including an indicator for whether respondents frequently missed school or were required to remain in bed or at home due to illness, proxying for potential limitations on educational and social opportunities. To account for overcrowding and limited living space during childhood, we include a variable equal to

Column (5) retains individual and wave fixed effects while adding province fixed effects, which help control for persistent regional differences such as cultural norms, institutional variations, and persisting regional economic disparities. Column (6) replaces individual fixed effects with community (village) fixed effects. Column (7) replaces individual fixed effect with subdistrict fixed effects. Across all specifications, the estimated coefficients on the mangrove coverage indicator remains broadly consistent in magnitude and significance when it comes to impacts on mental health.

A key parameter in our specification is the choice of the buffer distance to define a community's "treatment" level of mangrove cover. While we have posited that the benefits of mangroves may have spillover effects extending longer distances beyond their immediate ecological footprint, the precise scale is an empirical question. To guide our choice, we estimate our main specification across a series of buffer distances, from 5 *km* to 30 *km*. Figure A3 presents the results showing that for our primary mental health outcome, the CESD-10 score, the beneficial effect of mangrove cover is robust across all distances but the magnitude of the coefficient is largest at the 30 *km* radius. We find few results for memory and intelligence outcomes. We therefore select 30 *km* buffers for our main analysis as it best capture the full spatial scale of effects in our sample.

5.5. Land use transition, mental health, and cognitive ability

So far, we have focused on estimating the effect of mangrove coverage by leveraging its change over time. While this approach controls for time-invariant heterogeneity, it yields a single net effect of mangrove stock, potentially masking variations in land use dynamics. One of the primary drivers of mangrove loss in Indonesia is the expansion of coastal aquaculture, and the economic health costs of this specific transition may differ from the benefits of a stable, persistent mangrove ecosystem, or potential restoration of degraded mangrove ecosystems. To evaluate these channels in detail, we employ a complementary first-difference (FD) model as described in Equation (2), exploring the effects of two aspects of mangrove presence: a land transition effect as we observe

one if the respondent's childhood household had two or fewer bedrooms. To proxy for early family stress, we introduce two indicators: one for whether at least one parent exhibited heavy drinking or mental health issues, and another for whether the respondent's biological parents were no longer married by age 12. As a measure of limited educational stimulation in the household, we include a variable equal to one if the respondent reported reading none or very few books at age 12. Lastly, to control for childhood economic disadvantages, we introduce a variable indicating whether the main household breadwinner was engaged in unpaid family work or casual agricultural labor.

mangroves converted to aquaculture and vice versa; and an endowment effect that estimates the effects of persistent mangrove cover over time.[26]

Results are presented in Table 5, where Panel A presents the effects on mental health. We find detrimental effects on mental health when mangrove is converted to aquaculture, with an effect size that is approximately three times larger than our estimated baseline effect (2.12 versus 0.66 for the CESD-10 score, and 0.17 versus 0.06 for the likelihood of exceeding the clinical cutoff). Conversely, we find large beneficial effects when aquaculture is converted to mangroves, around 6-7 times larger than the baseline effect. Notably, these effects are asymmetric: the marginal mental health benefit from restoring one unit of land is more than double the marginal cost from converting one unit of mangroves to aquaculture. To contextualize these magnitudes, a mid-sized local mangrove restoration project of 50 hectares (ha) that converts from aquaculture results in a 0.26 point decrease in CESD-10 score and a 1.8 pp decrease in the likelihood of reaching the clinical depression cutoff for the surrounding communities.[27] Converting 50 hectares of mangrove to aquaculture, on the other hand, will result in a 0.12 point increase in CESD-10 score and a 1.0 pp increase in the likelihood of reaching the clinical cutoff.

In addition to effects from land conversions, our results show that persistent land use matters for mental health, albeit the effect sizes are relatively smaller compared to effects from land use changes. As shown in Panel A of Table 5, 1% more persistent mangrove cover decreases CESD-10 score by 0.27 points and the likelihood of reaching the clinical cutoff by 2.3 pps. Interestingly, we also find that 1% more persistent aquaculture ponds increase CESD-10 score by 0.11 points and the likelihood of reaching the clinical cutoff by 0.8 pps. Most of the estimated endowment effects are statistically significant, but are of an order of magnitude smaller compared to the impacts of land use transitions.

The findings for cognitive ability, presented in Panel B of Table 5, show that land use changes have the most pronounced effects on episodic memory. Restoring aquaculture ponds to mangroves is associated with a large and statistically significant improvement in memory. A 50-hectare mangrove restoration project on average increases 0.03, 0.10, and 0.13 words for immediate, delayed, and total words recalled, respectively. In contrast to the mental health results,

[26] Results from the full set of land use transitions are presented in Table A2 for completeness. We focus on conversion to aquaculture in particular below as these are the largest changes.
[27] 50 ha is at the 66th percentile of all mangrove restoration projects in terms of size surveyed by Goto et al. (2025).

however, conversion of mangroves to aquaculture has few effects on this outcome. We also find significant effects for the persistence of the ecosystem endowment on episodic memory. A 1 pp increase in persistent mangrove cover is associated with a 0.16-word increase in the total recall score. Conversely, a one pp increase in persistent aquaculture cover is associated with a 0.12-word decrease in total recall.

The results for fluid intelligence are more muted. We find no statistically significant effects for land use transitions on the Raven, numeracy, or overall intelligence scores. However, we do find land endowment to have small impacts on fluid intelligence outcomes, with more persistent mangrove cover linked to higher Raven and numeracy scores, and persistent aquaculture ponds linked to lower Raven scores.

Taken together, results from the first-difference models show that the composition of land use change is an important determinant of mental health beyond the net effect of mangrove cover alone, with two noteworthy insights beyond those offered in the baseline models. First, the effects of mangrove gains and losses are asymmetric: the marginal benefits associated with restoring mangroves from aquaculture are substantially larger than the marginal damages of converting to aquaculture, indicating potentially large health benefits of mangrove restoration efforts. Second, our results also point to the existence of endowment effects in that stable mangrove ecosystems also provide mental health and cognitive benefits to nearby communities.[28] This corroborates our earlier finding that non-movers enjoy relatively larger mental health benefits from mangrove cover.

6. Mechanisms

Our main findings show that the presence of local mangrove ecosystems is associated with improved mental health and, for older populations, better cognitive function. Having established this relationship, we now explore potential mechanisms through which these benefits may arise. We test three candidate hypotheses. First, we examine whether mangroves provide direct protection from environmental hazards, thereby reducing residents' exposure to economically costly and mentally stressful shocks. Second, we investigate whether mangrove presence bolsters economic and nutritional security by supporting local livelihoods, employment, and food consumption. We also explore a third, more subjective channel related to ecological grief, where

[28] Results from the full set of transitions presented in Table A2 are broadly consistent. We focus on those in Table 5 since multicollinearity is likely to be a factor given the multiple land use categories we evaluate in Table A2.

communities experience psychological distress from the tangible loss of ecosystems and the anxiety associated with anticipated future environmental decline.

6.1. Exposure to environmental hazards

Mangroves play a key role in shielding coastal communities from natural hazards, particularly coastal flooding. Their dense root systems and thick foliage dissipate wave energy, reduce storm surges, and mitigate the impact of high winds, thereby protecting both infrastructure and human well-being (Das and Vincent 2009, Sheng et al. 2012, Hochard et al. 2019, Del Valle et al. 2020, Menendez et al. 2020, Zhu et al. 2023).[29] However, when mangrove forests are degraded or lost, these natural protections weaken, increasing community exposure to floods, windstorms, and other environmental threats. Thus, flood exposure potentially serves as a key mechanism through which mangrove loss affects welfare. Frequent or severe flooding can lead to significant socioeconomic disruptions, including property damage, displacement, and loss of livelihoods, all of which contribute to more stress, anxiety, and cognitive strain.

To examine flood protection as a potential channel, we use panel data from the IFLS based on respondents' personal experience of natural disasters and experience of disasters in their communities in the past five years. We focus on floods and windstorms given mangroves' critical role in mitigating these hazards. Table 6 presents the impact of mangrove on three groups of disaster exposure measures: personal experience, community exposure, and disaster preparedness. In columns (1)-(3), the dependent variables indicate whether during the past 5 years, an individual has personally experienced flood, flood and windstorm, and any type of natural disasters, respectively. In columns (4) and (5), we examine whether the community has ever been flooded, and the number of flooding events in the past 5 years. In columns (6) and (7), we evaluate whether the community has received flooding preparation and training.[30]

In Panel A of Table 6, we report the estimated effects of mangrove cover from the fixed effect model in Equation (1). We find no effect of mangrove cover on flood experience or preparedness. Interestingly, we find that more aquaculture ponds increase the likelihood of a household experiencing floods and windstorms (column 2). In Panel B, we report the estimated

[29] Menendez et al. (2020) find that mangroves provide over $65 billion annually in global flood protection, with their loss exposing 15 million more people to flooding each year.

[30] To code the disaster preparedness variable, we rely on the community-level questionnaire, which asks two key questions: "*Has there been training on disaster preparedness in this village*?" and "*Has there been a briefing on disaster preparedness for the residents*?" These items serve as proxies for community flood training, infrastructural readiness, overall emergency response capacity, and public awareness in disaster management.

effects of land use change from the first-difference model in Equation (2). Here, we find that mangrove persistence significantly decreases the instances of households experiencing flood events. A 10% increase in mangrove stock (0.024% land cover) decreases the likelihood of a household experiencing flood events in the past 5 years by 0.17 pps.[31] The estimated effects are larger at the community level, with a 10% increase in mangrove stock decreasing the likelihood of flooding by 0.32 pps. We also find that communities with higher mangrove endowments are more likely to be trained on disaster preparedness. Further, converting mangrove to aquaculture significantly increases the likelihood of a household experiencing flood events, with marginal effects of mangrove conversion approximately three times larger than the marginal effects of mangrove endowment. We find few effects of aquaculture persistence or mangrove restoration from aquaculture on flood experience and community preparedness.

Taken together, our results suggest that local ecosystem dynamics are a key determinant of flood exposure and a potential channel for the observed effects of mangroves on mental health. The first-difference specification shows that the stability of mangrove ecosystems is critical for flood protection, and active conversion of existing mangrove stocks increases a community's vulnerability to floods. Interestingly, we do not find a statistically significant effect of mangrove restoration on flood protection within our timeframe. This may be because young, restored mangrove forests have not yet developed mature root systems to provide the same level of protection as established mangroves. These findings identify increased flood exposure as a mechanism through which mangrove degradation may impact health. As future sea-level rise is projected to more than double the exposure of coastal populations to flooding, the costs associated with mangrove loss are likely to be amplified in the coming decades (Blankespoor et al. 2017).[32]

6.2. Income, employment, and nutritional outcomes

A second potential channel may work through disruptions to income and livelihoods that are supported by mangrove ecosystems. Our analysis in this section builds upon findings from Yamamoto (2023) which indicate that in Indonesia, an increase in mangrove loss reduces annual income for fishery-dependent households. Affected households typically respond by increasing

[31] The marginal effect (in column 1 of Panel B) is -0.073. 0.024 * (-0.073) = -0.0017, or -0.17 percentage points. Similar calculation is performed below.

[32] Blankespoor et al. (2017) find that, under current climate conditions and existing mangrove coverage, approximately 3.5 million people and US$400 million in GDP are at risk from coastal inundation across 42 developing countries. The greatest exposure is concentrated in East Asia, particularly in Indonesia, the Philippines, and Myanmar.

labor effort and decreasing non-food expenditures, yet they remain engaged in fishing despite falling returns. We posit that these economic shocks likely have spillover implications beyond the directly affected households, which we should be able to estimate given the size of our mangrove buffers.

Table 7 presents results on the impact of mangrove and aquaculture coverage on income, employment, and food consumption. All regressions include household and wave fixed effects, and control for the set of characteristics used in our main analysis. Panel A reports results on income and employment. On the intensive margin, we find that a 1 SD increase in mangrove coverage increases income (column 1) by 18.3%.[33] The estimated effects of mangroves on worked for pay in column 2 and employed last year in column 3, are positive but noisy. We also do not find that mangroves impact hours worked (column 4). For aquaculture ponds, we find that aquaculture ponds increase the likelihood of being employed (column 3).

Panel B of Table 7 reports results on household consumption and nutritional intake. We find positive coefficient estimates for all outcomes, including the likelihood of purchasing fish (column 1), purchasing protein-rich food (column 2), healthy food expenditure (column 3), total food expenditure (column 4), and non-food expenditure (column 5), although only the effects of healthy and total food expenditures are significant. For aquaculture, we find positive coefficient estimates for food expenditures, but only expenditure for non-food items is significant.[34]

Collectively, these results provide evidence that mangroves are measurable sources of income and they boost nutritional status. This corroborates findings in Ickowitz et al. (2023) and Yamamoto (2023). Considering that economic precarity and nutritional deficiencies are well-established risk factors for impaired cognitive performance and heightened mental distress (Spencer et al. 2017, Ridley et al. 2020, Banerjee et al. 2023, de Almeida et al. 2024), these results highlight a probable link between environmental degradation and mental insecurity.

6.3. Perceived upward mobility and future economic outlook

Finally, we examine whether the presence of mangroves is associated with more positive perceptions of social and economic prospects for the future. Building on the concept of ecological grief, where environmental degradation diminishes optimism about the future, we consider the

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[33] Income and expenditures are in real values pegged to 2010 Rupiahs. The estimated coefficient is 0.192; log-linear model specifies percentage interpretation as (e^beta - 1)*100 = 21.2%; the standard error of mangrove cover = 0.866, which implies that a one SD change in mangrove leads to 21.2% * 0.866 = 18.3% increase in income.

[34] Given this, it is probable that it's detrimental impact on mental health arises primarily from increased flood risk.

possibility that greater mangrove coverage fosters a sense of security, opportunity, and upward mobility. Such confidence could be one pathway through which mangroves support better mental health and cognitive functioning. In the IFLS data, respondents are asked to evaluate their perceived position on the social ladder at three time points – five years ago, today, and five years in the future, along with assessments of their current standard of living and their ability to sustain it over the next five years.[35] We construct measures of perceived upward social mobility and economic outlook, two key aspects of quality of life, to assess impacts on individuals residing in areas affected by mangrove deforestation.

Results are presented in Table A3. Panel A reports results for perceived upward social mobility. We find evidence that having more mangrove cover decreases the likelihood of individuals perceiving themselves as having low social status in current and future periods (column 1), past and future periods (column 2), or consistently across the past, present, and future (column 3), although only the estimate in column 1 is estimated with precision. A 1 SD increase in mangrove cover is associated with a 2.1 pp decrease in the likelihood of reporting low perceived social status. This is suggestive evidence that mangroves alleviate ecological grief as proxied by improved perception of social standing. It is also possible that mangroves presence raises local economic prospects, thus improving perceived social mobility. These findings highlight the non-pecuniary benefits that mangroves engender in terms of life satisfaction and subjective well-being.

We attempt to shed more light on these aspects by examining how mangroves influence individuals' economic expectations and living conditions. In Panel B of Table A3, we explore respondents' assessments of their current standard of living, as well as their future outlook. In column (1), the variable is coded as one if the respondent indicates an inability to keep up with future living standards, whereas column (2) measures inadequacies in the standard of living for both adults and children (for respondents with children under age 15).[36] Column (3) presents a

[35] The survey asked participants to evaluate their societal position by presenting an illustration of a ladder with six steps. They are then prompted as follows: "*Please imagine a six-step ladder where on the bottom (the first step) stand the poorest people, and on the highest step (the sixth step), stand the richest people. On which step are you today*?" They are then asked, "*On which step were you five years ago*?" and "*On which step do you expect to find yourself five years from now*?" Based on these responses, we code a variable that equals one if the respondent reports low social status (i.e., being at the bottom of the social ladder on the 1st or 2nd step), and we categorize the remaining responses as middle (steps 3 and 4) or highest (steps 5 and 6). They are also asked whether their current living conditions, food consumption, access to health care, and educational opportunities for themselves and their children are adequate for their needs.

[36] Respondents were asked "*Knowing about how prices change in recent years, do you think you can keep the standard of living you have today in the next 5 years?*" We recoded the responses so that the higher values indicate a less

composite measure "*Bleak Economic Outlook and Low Social Mobility,*" which equals one if the respondent reports a bleak economic outlook and exhibits persistent low perceived social mobility. In general, we find few impacts across these measures.

Our findings weakly resonate with Cunsolo and Ellis (2018), who argue that ecological grief encompasses not only the sorrow of tangible environmental losses but also the deep distress associated with anticipated future declines. Their concept of anticipatory grief, a persistent, forward-looking anxiety, demonstrates how communities intimately connected to their environment endure diminished hope and agency, alongside a spectrum of negative emotions. Moreover, as Ma et al. (2022) highlights, knowledge of changing environmental conditions and/or indirect exposures to climate change can provoke adverse emotional responses.

7. Contextual factors in the mangrove-welfare relationship

The associations between mangroves and welfare markers documented above may not be uniform across all ecological and socioeconomic contexts. Local environmental conditions, economic support, and community characteristics can shape individuals' experience and benefits from mangrove ecosystems. Drawing from the literature, we focus on restoration potential, social assistance, and social capital – each representing a potential mechanism for strengthening community resilience to environmental stressors. Understanding their relative contributions is key to informing interventions aimed at maximizing the benefits of mangrove ecosystems.

7.1. Ecological recovery potential

Our main effects may vary depending on ongoing restoration efforts and the broader feasibility of ecological recovery. While the benefits of restoration are well established, growing research emphasizes its role not only as an ecological process but also as a crucial factor in human well-being (Suding et al. 2015). Active restoration initiatives and higher ecological recovery potential can help reduce climate risks, improve environmental quality, and contribute to food security, all of which have implications for health. Participation in restoration activities has also been linked to lower stress levels, greater life satisfaction, and stronger community cohesion, reinforcing the psychological and emotional benefits of environmental engagement (Marsh et al. 2023).

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favorable economic outlook. In particular, responses of "*unlikely*" or "*very unlikely*" reflect a pessimistic view regarding the ability to maintain current living standards. This variable is then used as a proxy for respondents' expectations about their future current standard of living and their perceptions of economic security. Respondents with children below the age of 15 were also asked about whether they perceived their children's standard of living as adequate ("*Concerning your children's standard of living, which of the following is true?*"*).* We code a variable that equals one if the respondent says "*it is less than adequate for their needs*."

However, data on the locations and effectiveness of restoration initiatives are limited. Instead, we use an indirect measure: restoration potential, defined as the feasibility of recovering mangrove ecosystems in a given area. The underlying idea is that in regions where recovery is more feasible, residents may experience less psychological distress, as this potential entails future resilience and influences perceptions of security, economic opportunity, and migration patterns.[37] Conversely, communities in areas with limited recovery prospects may face increased stress, uncertainty, and feelings of entrapment in a declining environment, all of which can exacerbate cognitive burdens and mental distress.

We use supplementary data from Sasmito et al. (2023) which estimates restoration opportunity areas under various scenarios in Indonesia. This dataset provides regional and provincial-level information on deforested areas with restoration potential, categorized into low, medium, and high opportunity scenarios.[38] We digitize this data to construct an indicator variable that equals one if an individual resides in a province where the share of total restoration opportunity area, as a percentage of the mangrove area in 2000, is above the sample median. We then interact this variable with our mangrove coverage variable.

The results are shown in Table 8. Panel A presents results on mental health outcomes. We find that the coefficient on the interaction term between mangrove cover and restoration opportunity ratio is positive and statistically significant in all cases, indicating that the beneficial effects of existing mangrove cover on mental health are significantly attenuated in areas with high restoration potential. This pattern holds across various functional forms. Joint significance tests confirm this finding: the estimated net effect of mangrove cover in high-restoration-potential areas is not statistically different from zero. In areas with low restoration potential, the estimated effects are larger than the baseline average effect in our main results (-2.481 in column 1 vs. -0.663 in

[37] The Indonesian government recently established the Peatlands and Mangrove Restoration Agency to supervise large-scale rehabilitation efforts for the restoration of degraded and deforested mangrove areas. However, despite policy commitments, Sasmito et al. (2023) finds that only 30% of the designated restoration areas are viable due to socio-political challenges, ecological limitations, and competing land-use demands. Roughly 193,367 hectares could feasibly support mangrove rehabilitation, a conservative estimate that contrasts with the official target of 600,000 hectares. This discrepancy underscores the importance of also assessing actual restoration potential rather than relying solely on current and planned targets.

[38] We note again the different temporal coverage for the data used to construct the restoration opportunity classifications in this study. These classifications reflect multiple factors influencing restoration feasibility, such as prior land use, land tenure, management status, and environmental conditions. For instance, areas within protected mangrove forests have the highest restoration potential, as they are legally designated for conservation and must be restored. Degraded locations converted to urban settlements or affected by erosion or frequent climate events have lower feasibility. Restoration success is also affected by several bio-geomorphic conditions.

column 1 of Table 2). This suggests that where mangrove expansion is unlikely, the existing stock plays a disproportionately important role in supporting psychological well-being. For cognitive outcomes (Panel B), the pattern is similar for memory measures, although estimates are less precise. We find no meaningful differences for fluid intelligence.

By incorporating restoration potential into our analysis, we provide further understanding of how ecological recovery feasibility influences the relationship between ecosystem degradation and welfare. Further research with more fine-grained data on restoration efforts would enable a clearer understanding of how recovery potential shapes the benefits of mangrove ecosystems.

7.2. Ecological degradation in the presence of a social safety net

Next, we turn to the effects of social safety nets, specifically in the form of unconditional cash transfers (UCT). A substantial body of research demonstrates that cash transfer programs can improve mental health and stimulate child cognitive development by alleviating poverty-related stress (Macours et al. 2012, Haushofer and Shapiro 2016, Ridley et al. 2020, Baird 2021). This raises a relevant question for our context: do income-based interventions interact with natural capital, such as mangrove ecosystems, to shape mental health and cognitive outcomes?

We use variation in Indonesia's large-scale Unconditional Cash Transfer programs – Bantuan Langsung Tunai (BLT) 2005, BLT 2008, and Bantuan Langsung Sementara Masyarakat (BLSM) 2013 – to assess whether these transfers mediate benefits from mangrove coverage.[39] This analysis serves two purposes. First, it tests whether the associations identified in our results vary with economic assistance. Second, it serves as a placebo check on whether poverty reduction is the primary channel through which mangrove coverage affects human capital outcomes. The UCT programs aimed to support the poorest 33% of households by offsetting the economic shock of rising prices (Pritadrajati 2023).[40] If the interaction between mangrove coverage and UCT receipt is measured without error, it would suggest that economic constraints are a key pathway; if not, it would imply that other mechanisms – such as psychological benefits from the physical environment or ecosystem service provision – are also important.

[39] As detailed in Pritadrajati (2023), these UCTs were implemented as responses to economic shocks. BLT 2005 was introduced following a rise in global oil prices and provided assistance to 15.5 million households. BLT 2008 targeted 19.0 million households in response to the global financial crisis, rising food prices, and fuel subsidy reductions. BLSM 2013, introduced amid domestic oil shortages and trade imbalances, supported 15.5 million households.

[40] While the BLT program was designed as emergency income support, it was not intended to influence household behavior or permanently reduce poverty. As a result, it neither addressed behavioral factors nor targeted the structural correlates of poverty (World Bank 2012).

Using data from the two IFLS survey waves, we construct a time-varying indicator that identifies whether a household received at least one UCT within the past 5 years of the survey wave (BLT 2005 for the 2007 wave, BLT 2008/BLSM 2013 for the 2014 wave). We then regress mental health and cognitive outcomes on mangrove coverage, the UCT indicator, and their interaction. Results are presented in Table A4. For mental health outcomes (Panel A), our main effects of mangrove coverage on CESD-10 scores remain largely unchanged. The interaction terms between UCT receipt and mangrove coverage are negative, suggesting potential complementarity in reducing depressive symptoms, although most estimates are not significant. For cognitive outcomes (Panel B), most estimates are again imprecise, with the exception of delayed recall, where we find a positive and marginally significant interaction impact. Overall, these results suggest that while economic assistance may in some cases reinforce the welfare benefits of mangrove coverage, these complementarities are limited in our sample. UCTs are unlikely to be the main driver of the positive effects associated with mangroves, pointing to the importance of other mechanisms such as psychosocial benefits that result from natural environments.

7.3. Community engagement and social capital

The ability of individuals and communities to withstand environmental changes is often influenced by the strength of their social networks. Social capital, encompassing community engagement and communal bonds, is increasingly recognized as an important factor in mitigating the scarring effects of deforestation. This subsection explores whether social capital, measured through perceptions of safety and community participation, conditions the relationship between mangrove coverage and mental well-being. The central premise is that strong social cohesion and active community involvement may provide alternative coping mechanisms, facilitate access to social and economic resources, overcome information constraints, and ultimately enhance resilience.

To test this hypothesis, we use data from the IFLS on multiple dimensions of social capital. Following Riumallo-Herl et al. (2014), Cao and Rammohan (2016), and Bai and Li (2021), we construct a composite variable that integrates perceptions of safety in the community with participation in communal activities. Individuals are classified as having high social capital if they report feeling safe in their village during both the day and night and they actively engage in at least one community program.[41]

[41] The perception of safety variable is derived from two survey questions: "*How safe do you consider this village*?" and "*In most of the village, is it safe for you to walk alone at night*?" Community participation is coded as one if the

Results are shown in Table A5. Starting with the depression outcome (Panel A), we find that mangrove cover remains significantly associated with better mental health as indicated by lower CESD-10 scores. High social capital is strongly linked to improved mental health, confirming its protective role. We do not find strong interaction effects between mangrove cover and social capital though, suggesting that while social capital supports mental health, it does not systematically mediate the strength of the mangrove-mental health association. For memory outcomes in Panel B, high social capital significantly improves total recall, but again there is no evidence of social capital moderating the mangrove-memory relationship. We do not find statistically significant effects of either mangrove coverage or social capital on fluid intelligence.

8. Conclusion

This paper provides new evidence on the mental health benefits of mangrove forests, showing that their value extends beyond commonly measured ecosystem services such as carbon sequestration, fisheries support, and flood protection, to include important effects on pyschosocial measures and cognitive functioning. Using high-resolution spatial data combined with detailed individual-level longitudinal information from two waves of the IFLS in Indonesia, we find that local mangrove ecosystems are significantly associated with improved mental well-being. In particular, we document a robust association between mangrove coverage and reduced depressive symptoms.

Our findings also uncover additional relationships. We identify a previously undocumented benefit: mangroves buffer against age-related declines in episodic memory, thus protecting older populations. Our analysis of land use changes also shows that the impacts of ecosystems depend on the direction of change, rather than on net values of changes alone. We find that mental health gains from restoring aquaculture ponds to mangroves are larger than the losses from converting mangroves to aquaculture. We also document an endowment effect: the long-term, stable presence of mangrove ecosystems yields a distinct, though smaller, improvement in mental health compared to more immediate impacts of land use transitions. These results highlight that nature of land use change is a critical determinant of the economic and health spillovers of ecosystems.

These effects appear to operate through multiple channels, including reduced exposure to flooding, higher household income, and improved dietary consumption. The analysis of contextual factors further shows that the strength of these relationships depends in part on local ecological

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respondent takes part in at least one of five community activities: community meetings, cooperatives, voluntary labor, village/neighborhood improvement programs, and religious activities.

conditions. Effects of social safety nets and social capital are limited, suggesting that while these factors bring their own benefits, they do not speak to the mangrove – well-being relationship.

As climate change and ecological degradation continue to accelerate worldwide, it is urgent to recognize the human capital consequences of natural capital loss. Our results suggest that mangrove conservation and restoration are not only ecological and economic imperatives, but also foundational to protecting mental well-being and cognitive functioning in vulnerable populations. Integrating ecosystem preservation into development policy, alongside targeted social and institutional supports, will be important to ensuring more resilient and sustainable futures in the face of escalating environmental challenges.

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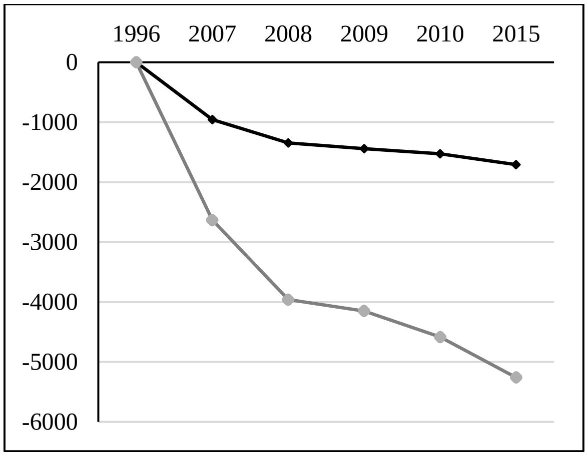
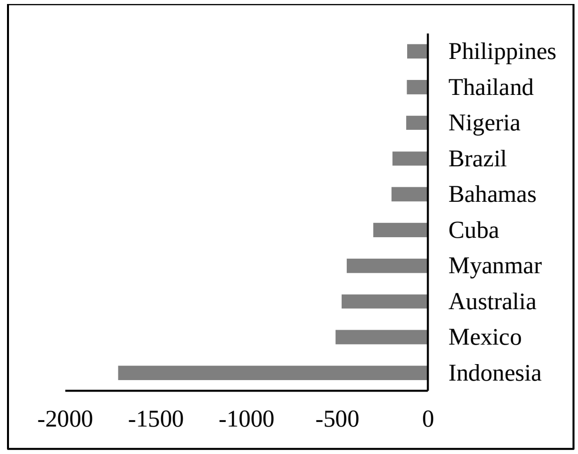
Figure 1: Net changes in mangrove habitat area from 1996 to 2015

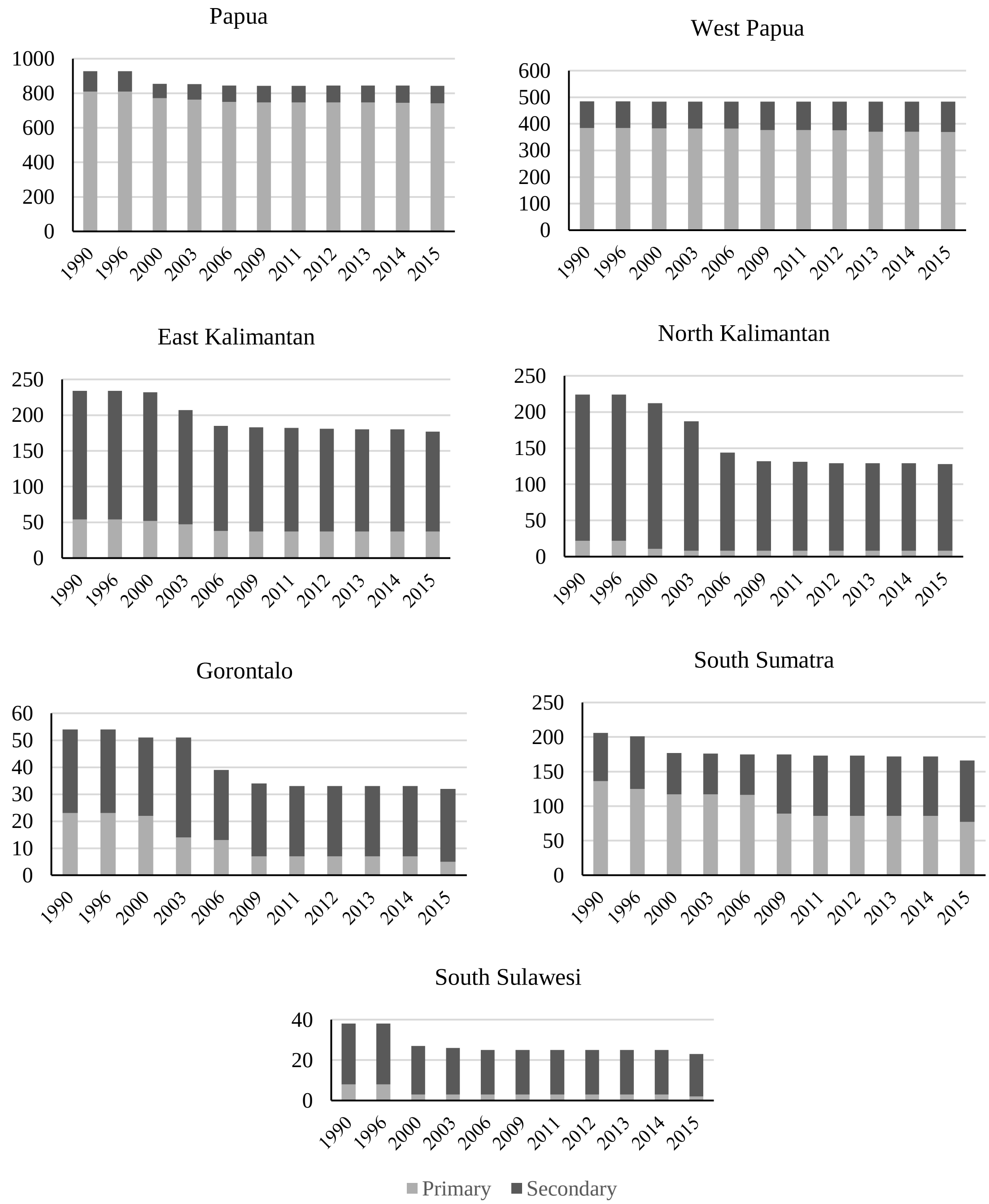
Panel A **Panel B**





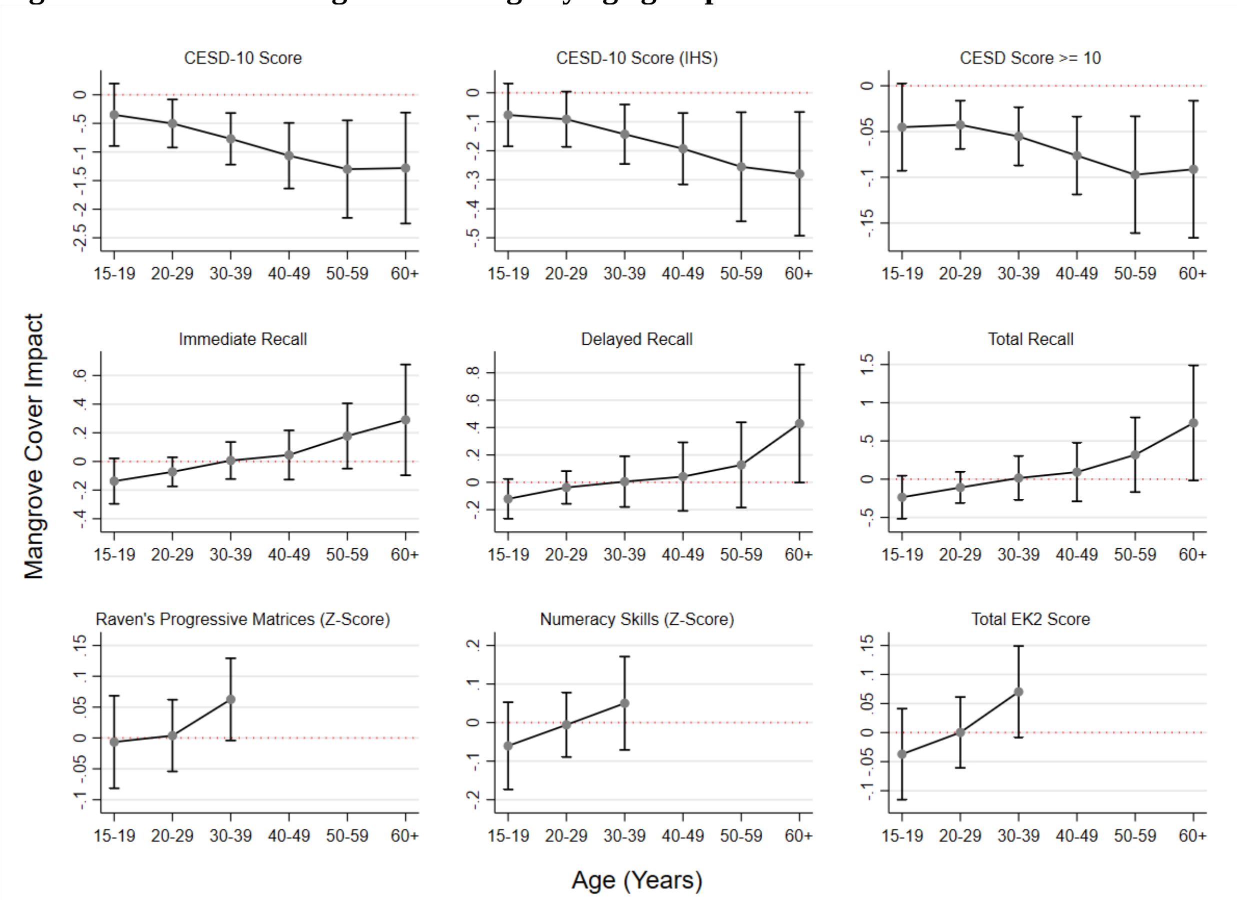
Notes: Panel A shows the global (in gray) and Indonesian (in bold) net change in areal extent of mangrove habitat (in km^2). Panel B shows the top 10 countries with the largest net change in areal extent of mangrove habitat between 1996 and 2015. Source: Global Mangrove Watch. For more details, see Bunting et al. (2022).

Figure 2: Primary and secondary mangrove forest areas in selected Indonesian provinces (thousands of hectares), 1990-2015



Notes: These figures are obtained from the Indonesian National Forest Monitoring System (SIMONTANA), administered by the Ministry of Environment and Forestry. We use the land cover series available on the data portal (https://nfms.menlhk.go.id/statistic), accessed in December 2024.

Figure 3: Effects of mangrove coverage by age groups



Notes: This figure shows age-specific estimates of the effects of mangrove coverage on mental health and cognitive outcomes. Each sub-panel corresponds to a separate regression on the effects of mangrove coverage on different dependent variables. All regressions are estimated with survey weights and have identical controls and fixed effects as the main specification. Robust standard errors are clustered at the community level. Error bars denote 90% confidence intervals. See Table 2 for details on the dependent variables and control variables.

Table 1: Summary statistics of selected variables

	Mean (1)	SD (2)	Min (3)	Max (4)
Panel A: Mental health outcomes (CESD-10)				
Total CESD-10 score	4.790	4.315	0.000	28.000
Log of CESD-10 score	1.476	0.787	0.000	3.367
Inverse hyperbolic sine of CESD-10	1.884	0.977	0.000	4.026
Binary: CESD-10 > median score	0.409	0.492	0.000	1.000
Binary: CESD-10 >= 10 (clinical cutoff)	0.134	0.341	0.000	1.000
Panel B: Cognitive outcomes				
Immediate word recall	4.907	1.872	0.000	10.000
Delayed word recall	3.879	2.044	0.000	10.000
Total episodic memory (immediate + delayed)	8.793	3.666	0.000	20.000
Raven's progression matrices test (z-score)	0.300	0.830	-2.359	1.452
Numeracy skills test (z-score)	0.199	0.995	-1.216	2.527
Overall intelligence (Raven + Numeracy, z-score)	0.299	0.855	-2.205	2.077
Panel C: Mangrove variables				
% Mangrove coverage (within 30km of community location)	0.240	0.866	0.000	10.880
% Aquaculture pond coverage (within 30km of community location)	0.764	1.911	0.000	16.536
% Persistent mangrove coverage across 1999-2022 (within 30 km of community location)	0.173	0.717	0.000	8.524
% Persistent aquaculture pond coverage across 1999-2022 (within 30 km of community location)	0.588	1.680	0.000	15.002
% Mangrove converted to aquaculture pond between 1999-2022 (within 30 km of community location)	0.037	0.182	0.000	4.923
% Aquaculture pond converted to mangroves between 1999-2022 (within 30 km of community location)	0.039	0.106	0.000	0.935
Panel D: Individual and household controls				
Age	39.427	14.219	14.000	101.000
Married	0.772	0.419	0.000	1.000
Rural	0.470	0.499	0.000	1.000
Muslim	0.906	0.292	0.000	1.000
Household size	4.282	1.840	1.000	15.000
No formal education	0.056	0.230	0.000	1.000
Primary education	0.375	0.484	0.000	1.000
Junior high education	0.185	0.388	0.000	1.000
Senior high education	0.276	0.447	0.000	1.000
College/university education	0.108	0.31	0.000	1.000
Household head is male	0.838	0.368	0.000	1.000

Table 2: The effects of mangrove coverage on mental health and cognitive ability

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Mental health			
	CESD-10	CESD-10 (log)	CESD-10 (inhs)	> median CESD-10	>=10 cutoff	
% Mangrove cover	-0.663***	-0.104**	-0.126**	-0.035	-0.055***	
(within 30km of community location)	(0.236)	(0.042)	(0.051)	(0.023)	(0.016)	
Mean of dependent variable	4.79	1.476	1.884	0.409	0.134	
Observations	36,948	36,948	36,948	36,948	36,948	
R-squared	0.637	0.623	0.619	0.604	0.583	
			Panel B: Cognitive ability			
		episodic memory			**fluid intelligence**	
	immediate recall	delayed recall	total recall	general reasoning (Raven's z-score)	numeracy skills (z-score)	overall intelligence
% Mangrove cover	-0.026	-0.021	-0.047	0.002	-0.021	-0.010
(within 30km of community location)	(0.058)	(0.082)	(0.130)	(0.031)	(0.046)	(0.035)
Mean of dependent variable	4.907	3.879	8.793	0.3	0.199	0.299
Observations	36,084	36,084	36,084	13,982	13,982	13,982
R-squared	0.748	0.721	0.759	0.691	0.674	0.721
Individual FE	✓	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓	✓
Individual and household controls	✓	✓	✓	✓	✓	✓

Notes: This table presents the estimated coefficients on mangrove coverage as specified in Equation 1. In Panel A, the outcomes relate to mental health, whereas Panel B reports measures of cognitive ability. In Panel A, Column (1) uses the CESD-10 score as the dependent variable, Column (2) uses the natural logarithm of the CESD-10 score, and Column (3) uses the inverse hyperbolic sine transformation of the CESD-10 score. In column (4), the binary indicator is equal to one if the CESD-10 score is above the median, and in column (5) it equals to one if the score is equal to or exceeds a cutoff of 10. In Panel B, Columns (1)-(3) focus on episodic memory, measured by the number of words immediately recalled, after a delay, and in total, respectively. Column (4) – (6) focus on cognitive ability for respondents under 40 years old: Column (4) reports the z-score for Raven's progressive matrices test; Column (5) reports the z-score for a standardized numeracy test; and Column (6) reports a combined z-score measure of Raven and math tests. All regressions are estimated via OLS, weighted according to the survey design, and include both individual and survey-year fixed effects. The model controls for individual- and household-level characteristics, including age, marital status, religion, education (with appropriate dummies), a rural indicator, household size, and the gender of the household head. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table 3: Heterogeneous effects of mangrove coverage

	(1)	(2)	(3)	(4)
		Panel A: By gender		
	CESD-10	**CESD score >= 10**	**total recall**	**overall intelligence**
% Mangrove cover x female	-0.708**	-0.060***	-0.009	-0.027
	(0.280)	(0.022)	(0.164)	(0.043)
% Mangrove cover x male	-0.619**	-0.050***	-0.083	0.004
	(0.253)	(0.017)	(0.139)	(0.041)
Observations	36,948	36,948	36,084	13,982
R-squared	0.637	0.583	0.759	0.721
		Panel B: By highest education level		
	CESD-10	**CESD score >= 10**	**total recall**	**overall intelligence**
% Mangrove cover x no formal education	-0.188	-0.022	-0.290	-0.111
	(0.445)	(0.028)	(0.337)	(0.148)
% Mangrove cover x primary school	-0.642	-0.051*	0.011	-0.145
	(0.390)	(0.027)	(0.220)	(0.099)
% Mangrove cover x junior high school	-0.798**	-0.063**	0.017	-0.002
	(0.369)	(0.031)	(0.178)	(0.061)
% Mangrove cover x senior high school	-0.563***	-0.052***	-0.113	-0.010
	(0.187)	(0.015)	(0.129)	(0.028)
% Mangrove cover x college or above	-0.961**	-0.065**	0.030	0.084
	(0.398)	(0.028)	(0.155)	(0.055)
Observations	36,948	36,948	36,084	13,982
R-squared	0.637	0.583	0.759	0.722
		Panel C: By food insecurity status		
	CESD-10	**CESD score >= 10**	**total recall**	**overall intelligence**
% Mangrove cover x not food insecure	-0.665***	-0.054***	-0.072	-0.009
	(0.234)	(0.016)	(0.118)	(0.037)
% Mangrove cover x food insecure	-0.622**	-0.063***	0.184	-0.016
	(0.275)	(0.019)	(0.159)	(0.042)
Observations	36,934	36,934	36,070	13,978
R-squared	0.637	0.583	0.760	0.721
Individual FE	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓
Individual and household controls	✓	✓	✓	✓

Notes: This table presents the estimated coefficients on mangrove coverage interacted with different population groups. In Panel A, mangrove coverage (percentage within 30 km of the community) is interacted with the respondents' gender; In Panel B, mangrove coverage is interacted with the respondents' highest education level; In Panel C, mangrove coverage is interacted with a dummy variable indicating whether the respondents' household is food insecure. Column (1) uses the CESD-10 score as the dependent variable, Column (2) uses the inverse hyperbolic sine transformation of the CESD-10 score. Column (3) focuses on total number of words recalled (immediate plus delayed). Column (4) uses the z-score combining Raven and math tests. All regressions are estimated via OLS, weighted according to the survey design, and include both individual and survey-year fixed effects. The models control for individual- and household-level characteristics, including age, marital status, religion, education (with appropriate dummies), a rural indicator, household size, and the gender of the household head. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table 4: Impacts of mangrove cover by migration status

		Migration status			
	full sample	HH stayed in community	HH stayed in subdistrict	HH moved out of community	HH moved out of subdistrict
	(1)	(2)	(3)	(4)	(5)
Panel A: CESD-10					
% Mangrove cover	-0.663***	-1.308***	-1.094**	-0.454*	-0.504**
(within 30km of community location)	(0.236)	(0.425)	(0.435)	(0.243)	(0.216)
Observations	36,948	28,468	32,602	8,238	4,104
Panel B: CESD score >= 10					
% Mangrove cover	-0.126**	-0.093***	-0.080***	-0.042**	-0.048***
(within 30km of community location)	-0.051	(0.029)	(0.029)	(0.017)	(0.017)
Observations	36,948	28,468	32,602	8,238	4,104
Panel C: Total recall					
% Mangrove cover	-0.047	0.021	-0.106	-0.096	-0.010
(within 30km of community location)	(0.130)	(0.321)	(0.284)	(0.110)	(0.093)
Observations	36,084	27,722	31,778	8,120	4,064
Panel D: Overall intelligence					
% Mangrove cover	-0.010	-0.141*	-0.138*	-0.006	0.006
(within 30km of community location)	(0.035)	(0.083)	(0.072)	(0.036)	(0.038)
Observations	13,982	9,500	11,202	4,314	2,612

Notes: This table reports the estimated effects of mangrove cover on mental health and cognitive ability when we consider different sub-samples. The dependent variables are defined as in Table 2 for the main results. All models include the same set of control variables and individual and wave fixed effects. All regressions are estimated via OLS, weighted according to the survey design. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table 5: The effects of land use change on mental health and cognitive ability

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Mental health					
	CESD-10	CESD-10 (log)	CESD-10 (inhs)	> median CESD-10	>=10 cutoff	
% Mangrove persistence	-0.269***	-0.026	-0.029	-0.017	-0.023***	
(1999-2022, within 30 km buffer)	(0.099)	(0.022)	(0.028)	(0.011)	(0.006)	
% Aquaculture persistence	0.107**	0.012	0.014	0.016***	0.008***	
(1999-2022, within 30 km buffer)	(0.047)	(0.011)	(0.015)	(0.005)	(0.003)	
% Mangrove converted to aquaculture	2.12***	0.264**	0.308**	0.144***	0.174***	
(1999-2022, within 30 km buffer)	(0.515)	(0.120)	(0.155)	(0.053)	(0.030)	
% Aquaculture converted to mangrove	-4.72***	-0.740***	-0.891***	-0.509***	-0.332***	
(1999-2022, within 30 km buffer)	(0.745)	(0.183)	(0.235)	(0.076)	(0.043)	
	Panel B: Cognitive ability					
	episodic memory			**fluid intelligence**		
	immediate recall	delayed recall	total recall	general reasoning (Raven's z-score)	numeracy skills (z-score)	overall intelligence
% Mangrove persistence	0.060*	0.104***	0.161**	0.035*	0.067**	0.057**
(1999-2022, within 30 km buffer)	(0.034)	(0.040)	(0.067)	(0.020)	(0.034)	(0.025)
% Aquaculture persistence	-0.021	-0.096***	-0.116***	-0.019*	-0.013	-0.016
(1999-2022, within 30 km buffer)	(0.018)	(0.024)	(0.036)	(0.011)	(0.017)	(0.013)
% Mangrove converted to aquaculture	0.085	-0.082	-0.016	-0.001	0.116	0.069
(1999-2022, within 30 km buffer)	(0.210)	(0.194)	(0.366)	(0.114)	(0.129)	(0.115)
% Aquaculture converted to mangrove	0.578**	1.77***	2.37***	0.153	-0.184	-0.012
(1999-2022, within 30 km buffer)	(0.292)	(0.404)	(0.629)	(0.185)	(0.367)	(0.257)

Notes: This table presents the estimated coefficients as specified in Equation 2. In Panel A, the outcomes relate to mental health, whereas Panel B reports measures of cognitive ability. In Panel A, Column (1) uses the CESD-10 score as the dependent variable, Column (2) uses the natural logarithm of the CESD-10 score, and Column (3) uses the inverse hyperbolic sine transformation of the CESD-10 score. In column (4), the binary indicator is equal to one if the CESD-10 score is above the median, and in column (5) it equals to one if the score is equal to or exceeds a cutoff of 10. In Panel B, Columns (1)-(3) focus on episodic memory, measured by the number of words immediately recalled, after a delay, and in total, respectively. Column (4) – (6) focus on cognitive ability for respondents under 40 years old: Column (4) reports the z-score for Raven's progressive matrices test; Column (5) reports the z-score for a standardized numeracy test; and Column (6) reports a combined z-score measure of Raven and math tests. All regressions are estimated by first differencing all except for the land use change variables, weighted according to the survey design. The models control for individual- and household-level characteristics, including age, marital status, religion, education (with appropriate dummies), a rural indicator, household size, and the gender of the household head. Standard errors are clustered at the household level. ***p<0.01, **p<0.05, *p<0.1.

Table 6: Mangroves and exposure to floods and other disasters

	Dependent variables:						
	household exposure (past 5 years)			community exposure (past 5 years)		community preparedness	
	flood	flood and windstorm	flood, windstorm and other disasters	community flooded	number of floods in community	community preparedness	community training
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Land use cover							
% Mangrove cover	0.005	0.002	0.006	-0.023	-0.310	0.474	0.497
(within 30km of community location)	(0.024)	(0.025)	(0.025)	(0.218)	(1.439)	(0.355)	(0.505)
% Aquaculture ponds	0.013	0.017*	0.018*	0.024	-0.655	0.179	0.371
(within 30km of community location)	(0.008)	(0.009)	(0.009)	(0.178)	(0.777)	(0.195)	(0.262)
Observations	36,924	36,924	36,924	26,418	26,418	26,418	26,418
R-squared	0.617	0.606	0.630	0.725	0.606	0.601	0.596
Panel B: Land use change							
% Mangrove persistence	-0.073***	-0.085***	-0.077***	-0.137**	-1.89***	0.001	0.168***
(1999-2022, within 30 km buffer)	(0.027)	(0.024)	(0.026)	(0.059)	(0.696)	(0.047)	(0.063)
% Aquaculture persistence	-0.002	-0.004	-0.002	0.009	-0.033	0.016	0.048
(1999-2022, within 30 km buffer)	(0.011)	(0.011)	(0.011)	(0.024)	(0.086)	(0.035)	(0.039)
% Mangrove converted to aquaculture	0.199**	0.259***	0.217**	0.309	6.64	-0.146	-0.216
(1999-2022, within 30 km buffer)	(0.082)	(0.086)	(0.087)	(0.339)	(5.34)	(0.384)	(0.580)
% Aquaculture converted to mangrove	-0.013	0.035	-0.014	-0.321	0.517	0.366	-0.095
(1999-2022, within 30 km buffer)	(0.171)	(0.169)	(0.178)	(0.391)	(1.55)	(0.576)	(0.601)
Observations	18,462	18,462	18,462	13,209	13,209	13,209	13,209
R-squared	0.01142	0.01024	0.01123	0.04481	0.02830	0.01604	0.03671

Notes: This table reports the impacts of mangrove coverage on the likelihood of respondents reporting exposure to floods, windstorms, and other disasters. Panel A is estimated using two-way fixed effects and mangrove and aquaculture cover variables; Panel B is estimated using first-differencing and include land use change variables. Columns (1) – (3) focus on whether individual households experienced flood and related disasters; Columns (4)-(5) focus on flood experience in the past 5 years for the community that individuals lived in. Column (6)-(7) focus on disaster training and preparedness at the community level. The same set of Individual and household controls as in our main analysis are included. Panel A includes individual and wave fixed effects. All regressions are estimated via OLS, weighted according to the survey design. Standard errors are clustered at the household level. ***p<0.01, **p<0.05, *p<0.1.

Table 7: Mangrove Loss, income and employment

	(1)	(2)	(3)	(4)	(5)
	Panel A: Income and employment				
	income (last year)	worked for pay	employed last year	hours worked	
% Mangrove cover	0.192***	0.025	0.018	-1.055	
(within 30km of community location)	(0.064)	(0.018)	(0.014)	(1.126)	
% Aquaculture pond	-0.001	0.010	0.023***	-0.224	
(within 30km of community location)	(0.031)	(0.009)	(0.008)	(0.452)	
Observations	18,508	34,848	34,838	24,579	
R-squared	0.531	0.370	0.374	0.418	
	Panel B: Consumption and nutrition				
	Whether household purchases		**(log) expenditure on**		
	fish	protein-rich food	healthy food	total food	non-food
% Mangrove cover	0.014	0.014	0.128*	0.086***	0.034
(within 30km of community location)	(0.020)	(0.015)	(0.071)	(0.033)	(0.039)
% Aquaculture pond	0.017	0.012	0.033	0.019	0.047**
(within 30km of community location)	(0.012)	(0.009)	(0.068)	(0.022)	(0.020)
Observations	34,816	34,816	34,816	34,816	34,816
R-squared	0.641	0.639	0.672	0.738	0.777
Household FE	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓
Individual and household controls	✓	✓	✓	✓	✓

Notes: This table presents estimated coefficients on mangrove coverage using income- and employment-related dependent variables. Panel A reports impacts on income and employment: Column (1) reports results where the dependent variable is the log of total annual individual income (in 2010 Rupiah). In Column (2), the dependent variable is a binary indicator equal to one if the individual reports currently working for pay. Column (3) uses a binary indicator for whether the respondent was employed in the previous year, while Column (4) examines the number of hours worked in a typical week. Panel B reports purchase behavior and nutritional intake: In columns (1) and (2), the dependent variables indicate whether the household purchased fish and protein-rich foods (including fish, beef, and chicken), respectively. Columns (3) to (5) examine total household expenditure on healthy food, overall food, and non-food consumption (all in logarithmic form and in 2010 Rupiah). All regressions are estimated via OLS, weighted according to the survey design, and include both household and survey-year fixed effects. We use the same set of individual- and household-level characteristics. Standard errors are clustered at the household level. ***p<0.01, **p<0.05, *p<0.1.

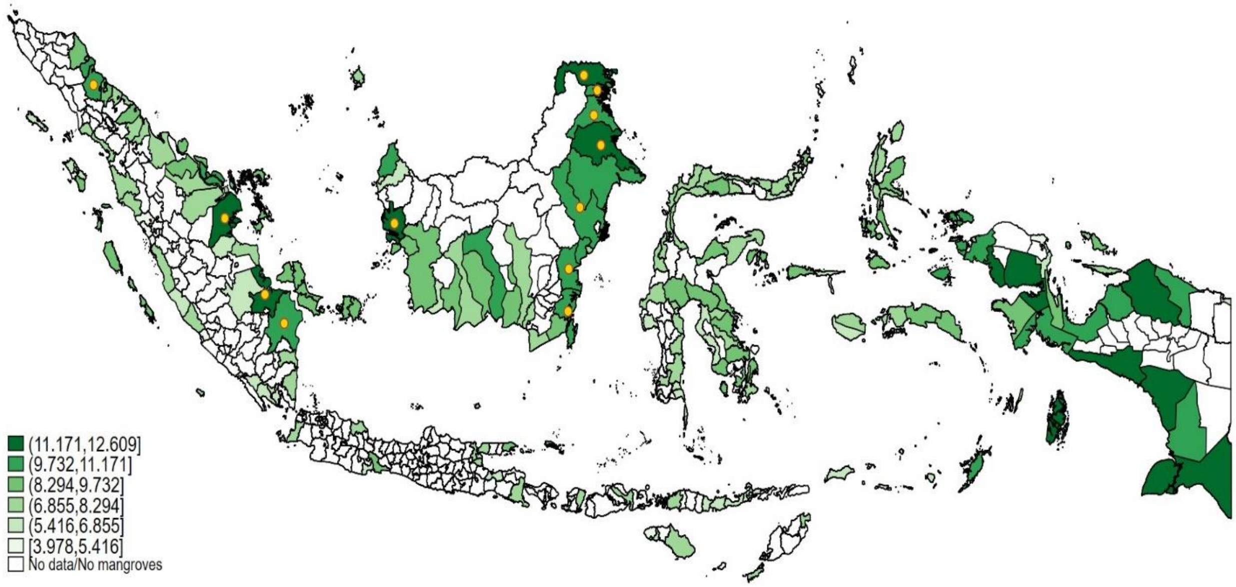
Table 8: The effects of mangrove coverage with heterogeneous restoration potential

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Mental health			
	CESD-10	**CESD-10 (log)**	**CESD-10 (inhs)**	**> median CESD-10**	**>=10 cutoff**	
% Mangrove cover	-2.481***	-0.415***	-0.505***	-0.204***	-0.180***	
(within 30km of community location)	(0.472)	(0.080)	(0.099)	(0.052)	(0.035)	
Restoration opportunity ratio	-0.150	-0.016	-0.016	0.012	-0.043	
(=1 if >median, 0 otherwise)	(0.568)	(0.098)	(0.121)	(0.065)	(0.047)	
Mangrove cover x rest.opport.ratio	2.269***	0.388***	0.474***	0.210***	0.159***	
	(0.510)	(0.087)	(0.107)	(0.056)	(0.038)	
Observations	30,446	30,446	30,446	30,446	30,446	
R-squared	0.634	0.617	0.613	0.603	0.585	
Joint test	-0.212	-0.0270	-0.0317	0.00669	-0.0215	
F-statistic	1.208	0.573	0.513	0.113	2.645	
p-value	0.272	0.449	0.474	0.737	0.104	
			Panel B: Cognitive ability			
		episodic memory			**fluid intelligence**	
	immediate recall	delayed recall	total recall	general reasoning (Raven's z-score)	numeracy skills (z-score)	overall intelligence
% Mangrove cover	0.227	0.308	0.535	-0.121	-0.168	-0.160
(within 30km of community location)	(0.143)	(0.275)	(0.378)	(0.092)	(0.205)	(0.135)
Restoration opportunity ratio	0.071	0.225	0.297	0.068	-0.246*	-0.070
(=1 if >median, 0 otherwise)	(0.154)	(0.185)	(0.310)	(0.107)	(0.143)	(0.119)
Mangrove cover x rest.opport.ratio	-0.311**	-0.404	-0.715*	0.137	0.173	0.172
	(0.150)	(0.280)	(0.389)	(0.097)	(0.210)	(0.139)
Observations	29,734	29,734	29,734	11,578	11,578	11,578
R-squared	0.745	0.715	0.755	0.688	0.662	0.714
Joint test	-0.0843	-0.0956	-0.180	0.0159	0.00505	0.0118
F-statistic	2.941	2.633	3.226	0.221	0.0112	0.100
p-value	[0.087]	[0.105]	[0.073]	[0.638]	[0.916]	[0.752]

Notes: This table reports the estimated effects of mangrove coverage on mental health and cognitive ability when we consider the restoration potential ratio. We use data from Sasmito et al. (2023) to build the restoration potential indicators. The dependent variables are defined as in Table 2 for the main results. All models include the same set of control variables and individual and wave fixed effects, and all regressions are estimated via OLS, weighted according to the survey design. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

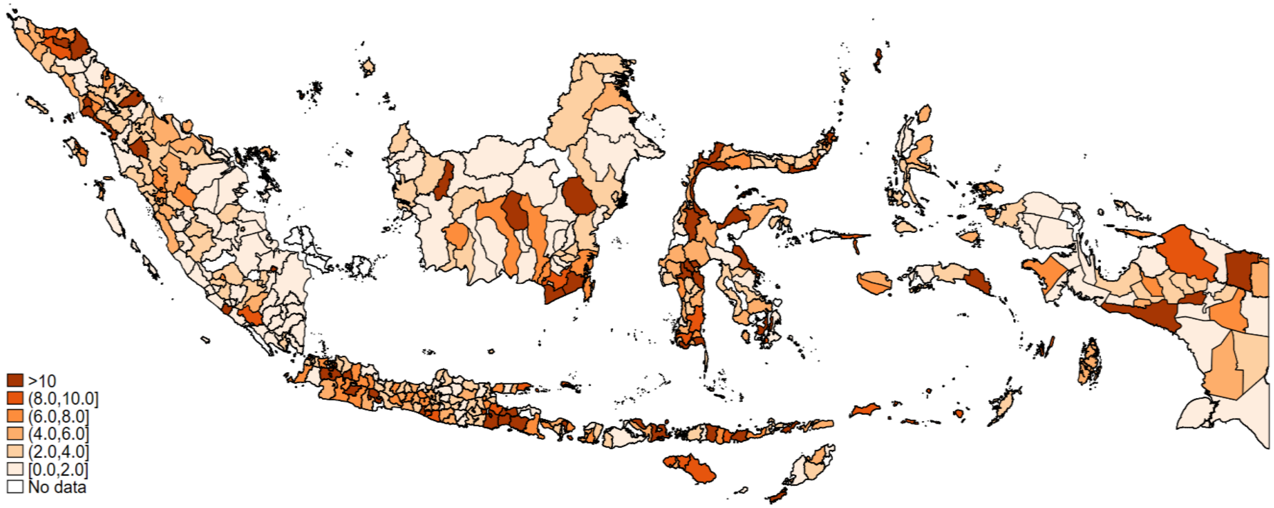
Appendix

Figure A1: Mangrove coverage across regencies in Indonesia in 2000



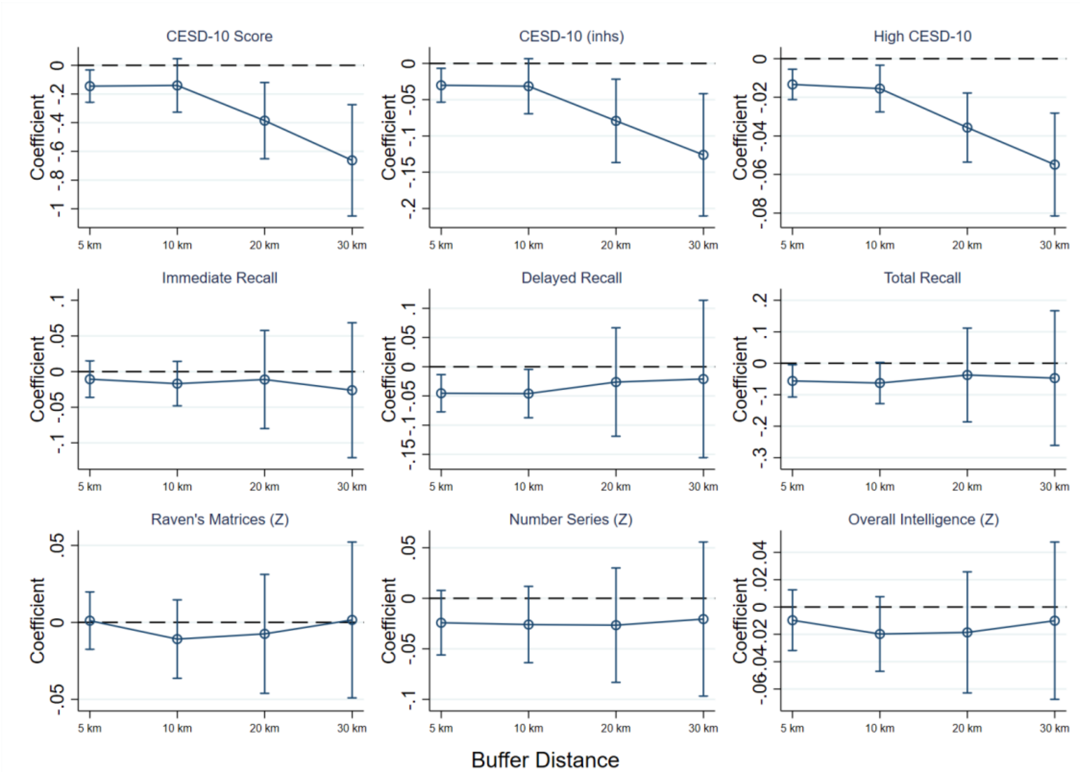
Notes: This map presents the natural logarithm of mangrove coverage in hectares for Indonesian regencies with a restoration potential exceeding 5 hectares as of the year 2000. Yellow circles identify the top 12 regencies with restoration opportunities exceeding 5,000 hectares. Note that data for 84 other regencies, which collectively had a potential restoration area of less 5 hectares, are not available. The data source is Sasmito et al. (2023).

Figure A2: The prevalence of mental disorders in Indonesia



Notes: This figure depicts the prevalence of emotional mental disorders across Indonesia in 2013. Assessment is based on responses to the Self-Reporting Questionnaire-20 (SRQ-20), a tool comprising 20 questions designed to identify depression, anxiety, and other non-psychotic mental health conditions. Responses are evaluated on a binary scale of "yes" or "no", and a threshold of six affirmative answers qualifies a respondent as having an emotional mental disorder. Data source: Authors' calculations from the data available in the various manually digitized province-level individual reports from the Indonesian Basic Health Research Survey of 2013, conducted by the Ministry of Health. More information can be obtained here: https://layanandata.kemkes.go.id/.

Figure A3: The effects of mangrove coverage by distance bands



Notes: This figure shows estimates of the effects of mangrove coverage on mental health and cognitive outcomes by distance bands. Each sub-panel corresponds to a series of regressions varying the buffer distance bands for mangrove coverage exposure, from 5km to 30km. All regressions are estimated with survey weights and have identical controls and fixed effects as the main specification. Robust standard errors are clustered at the community level. Error bars denote 90% confidence intervals. See Table 2 for details on the dependent variables and control variables.

Table A1: Mangrove coverage, mental health and cognitive ability - additional controls and alternative sets of fixed effects

	baseline (Ind + wave FE)	additional controls	household + wave FE	household + wave FE + childhood controls	individual + province + wave FE	community + wave FE	sub-district + wave FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: CESD-10							
% Mangrove cover	-0.663***	-0.648***	-0.782***	-0.843***	-0.783***	-1.305***	-1.259***
(Mangrove coverage within 30 km buffer)	(0.236)	(0.233)	(0.251)	(0.257)	(0.273)	(0.493)	(0.367)
Panel B: CESD score >= 10							
% Mangrove cover	-0.061***	-0.054***	-0.062***	-0.068***	-0.096***	-0.089***	-0.017**
(Mangrove coverage within 30 km buffer)	(0.017)	(0.016)	(0.019)	(0.018)	(0.032)	(0.024)	(0.007)
Panel C: Total recall							
% Mangrove cover	-0.047	-0.052	-0.044	-0.021	-0.010	-0.137	-0.144
(Mangrove coverage within 30 km buffer)	(0.130)	(0.130)	(0.147)	(0.156)	(0.152)	(0.314)	(0.249)
Panel D: Overall Intelligence							
% Mangrove cover	-0.010	-0.010	-0.019	-0.012	-0.031	-0.207**	-0.172***
(Mangrove coverage within 30 km buffer)	(0.035)	(0.035)	(0.043)	(0.043)	(0.042)	(0.089)	(0.063)

Notes: This table reports the estimated effects of mangrove cover on mental health and cognitive ability with additional control variables and various fixed effects specifications. The dependent variables are defined as in Table 2 for the main results. All models are estimated via OLS, weighted according to the survey design. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table A2: The effects of mangroves on mental health and cognitive ability – all land-use groups

	(1)	(2)	(3)	(4)
	Outcome variable:			
	CESD-10	CESD score >= 10	total recall	overall intelligence
% Mangrove persistence	-0.153**	-0.015***	0.171***	0.078***
(1999-2022, within 30 km buffer)	(0.074)	(0.005)	(0.061)	(0.014)
% Aquaculture persistence	-0.005	0.001	-0.148***	-0.015
(1999-2022, within 30 km buffer)	(0.055)	(0.003)	(0.048)	(0.015)
% Mangrove converted to aquaculture	1.30***	0.131***	-0.350	0.148*
(1999-2022, within 30 km buffer)	(0.376)	(0.023)	(0.333)	(0.075)
% Mangrove converted to other land uses	-1.22***	-0.092**	-0.045	-0.303**
(1999-2022, within 30 km buffer)	(0.468)	(0.040)	(0.469)	(0.121)
% Aquaculture converted to mangrove	-3.57***	-0.212***	3.35***	0.140
(1999-2022, within 30 km buffer)	(0.988)	(0.060)	(0.842)	(0.313)
% Aquaculture converted to other land uses	-0.269	-0.039**	-0.475**	0.015
(1999-2022, within 30 km buffer)	(0.246)	(0.019)	(0.205)	(0.058)
% Other land uses converted to aquaculture	1.48***	0.072***	0.491	-0.170*
(1999-2022, within 30 km buffer)	(0.392)	(0.026)	(0.354)	(0.092)
Observations	18,474	18,474	18,042	7,029
R^2	0.0105	0.007	0.005	0.01

Notes: This table presents the estimated coefficients on mangrove coverage as specified in Equation 2 with full sets of land use transition measures. Column (1) uses the CESD-10 score as the dependent variable, Column (2) uses a dummy variable of whether CESD-10 score is equal or higher than 10. Column (3) focuses on episodic memory, measured by the total (immediate plus delayed) number of words recalled. Column (4) reports a combined z-score measure of Raven and math tests for respondents under 40 years old. All regressions are estimated by first differencing all except for the land use change variables and weighted according to the survey design. The models control for individual- and household-level characteristics, including age, marital status, religion, education (with appropriate dummies), a rural indicator, household size, and the gender of the household head. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table A3: Mangrove coverage, perceived upward social mobility, and future economic outlook

	(1)	(2)	(3)
	Panel A: Low perceived upward social mobility (based on subjective social status)		
	current and future	past and future	past, current, future
% Mangrove cover	-0.024*	-0.017	-0.017
(within 30km of community location)	(0.012)	(0.011)	(0.011)
Observations	32,734	32,734	32,734
R-squared	0.581	0.579	0.582
	Panel B: Standard of living and future economic outlook		
	bleak economic outlook	inadequate std of living (adults and children)	bleak economic outlook and low social mobility
% Mangrove cover	-0.022	0.011	-0.012
(within 30km of community location)	(0.020)	(0.012)	(0.009)
Observations	35,868	15,416	32,174
R-squared	0.614	0.596	0.571
Individual FE	✓	✓	✓
Wave FE	✓	✓	✓
Individual and household controls	✓	✓	✓

Notes: This table presents the estimated coefficients on mangrove coverage. In Panel A, we focus on low perceived upward social mobility based on subjective economic status. In column (1), the binary variable is coded as one if the respondent reports low social status (i.e., being at the bottom of the social ladder) in both the current and future periods. In column (2), the binary indicator equals to one if the respondent reports low social status in both the past and future periods. In column (3), the dummy variable equals one if the respondent consistently reports low social status across the past, current, and future periods. In Panel B, we focus on standard of living and future economic outlook. In column (1), the variable is coded as one if the respondent indicates an inability to keep up with future living standards in the coming years. In column (2), this binary variable is coded for individuals who have children under the age of 15 and who report that their own and their children's living standards are inadequate. In column (3), "Bleak Economic Outlook and Low Social Mobility" is a composite measure coded as one if the respondent both reports a bleak economic outlook and exhibits persistent low perceived social mobility. All regressions are estimated via OLS, weighted according to the survey design, and include both individual and survey-year fixed effects. The models control for the same set of individual and household characteristics as in the main analysis. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table A4: Mangrove coverage, mental health, cognition, and unconditional cash transfers

	Dependent variables:					
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Mental health					
	CESD-10	CESD-10 (log)	CESD-10 (inhs)	> median CESD-10	>=10 cutoff	
% Mangrove cover	-0.650***	-0.103**	-0.125**	-0.034	-0.054***	
(within 30km of community location)	(0.235)	(0.041)	(0.051)	(0.023)	(0.016)	
Received unconditional cash transfer (BCT/BLSM)	0.270*	0.055**	0.068**	0.026	0.019	
(1 = Received BCT/BLSM in the past 5 years)	(0.145)	(0.025)	(0.031)	(0.016)	(0.012)	
% Mangrove cover x received cash transfer	-0.222	-0.024	-0.027	-0.029**	-0.017	
	(0.172)	(0.024)	(0.029)	(0.014)	(0.017)	
Observations	36,948	36,948	36,948	36,948	36,948	
R-squared	0.637	0.624	0.619	0.604	0.583	
	Panel B: Cognitive ability					
	episodic memory			**fluid intelligence**		
	immediate recall	delayed recall	total recall	general reasoning (Raven's z-score)	numeracy skills (z-score)	overall intelligence
% Mangrove cover	-0.026	-0.027	-0.052	-0.000	-0.017	-0.010
(within 30km of community location)	(0.057)	(0.082)	(0.129)	(0.032)	(0.046)	(0.036)
Received unconditional cash transfer (BCT/BLSM)	-0.010	-0.098*	-0.108	0.011	-0.003	0.003
(1 = Received BCT/BLSM in the past 5 years)	(0.052)	(0.056)	(0.096)	(0.034)	(0.048)	(0.038)
% Mangrove cover x received cash transfer	-0.001	0.098*	0.097	0.027	-0.043	-0.001
	(0.059)	(0.051)	(0.089)	(0.043)	(0.066)	(0.050)
Observations	36,084	36,084	36,084	13,982	13,982	13,982
R-squared	0.748	0.721	0.759	0.691	0.674	0.721

Notes: This table reports the estimated effects of mangrove cover on mental health and cognitive ability when we consider the impacts of unconditional cash transfers. The dependent variables are defined as in Table 2 for the main results. All models include the same set of control variables and individual and wave fixed effects. All regressions are estimated via OLS, weighted according to the survey design. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.

Table A5: Mangrove coverage, mental health, cognition, and social capital

	Dependent variables:			
	(1)	(2)	(3)	(4)
	Panel A: CESD-10			
% Mangrove cover	-0.663***		-0.658***	-0.657***
(within 30km of community location)	(0.236)		(0.235)	(0.236)
1 = High social capital (Trust public safety and participate in comm. meetings)		-0.254**	-0.252**	-0.251**
		(0.103)	(0.103)	(0.108)
Mangrove cover x high social Capital				-0.001
				(0.081)
	Panel B: Total recall			
% Mangrove cover	-0.047		-0.047	-0.032
(within 30km of community location)	(0.130)		(0.130)	(0.132)
1 = High social capital (Trust public safety and participate in comm. meetings)		0.128*	0.128*	0.133*
		(0.068)	(0.068)	(0.071)
Mangrove cover x high social Capital				-0.026
				(0.117)
	Panel C: Overall intelligence			
% Mangrove cover	-0.010		-0.010	0.009
(within 30km of community location)	(0.035)		(0.035)	(0.041)
1 = High social capital (Trust public safety and participate in comm. meetings)		0.032	0.033	0.040
		(0.025)	(0.025)	(0.026)
Mangrove cover x high social Capital				-0.036
				(0.027)
Individual FE	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓
Individual and household controls	✓	✓	✓	✓

Notes: This table reports the estimated effects of mangrove cover on mental health and cognitive ability when we consider the impacts of social capital. The dependent variables are defined as in Table 2 for the main results. All models include the same set of control variables and individual and wave fixed effects. All regressions are estimated via OLS, weighted according to the survey design. Standard errors are clustered at the community level. ***p<0.01, **p<0.05, *p<0.1.