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Mangroves, Mental Health, and Cognition

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Abstract

Mangroves provide vital ecosystem 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 4.5 percentage points, highlighting that benefits are concentrated in areas where mangrove stocks persist or where aquaculture ponds are restored to mangroves. These effects operate partly through reduced flood exposure, higher household income, and improved food consumption. We also find that restoration potential matters more than blue carbon potential, cash transfers, or social capital in shaping the mangrove-mental health relationship. Our results show that mangrove conservation and restoration can generate important local human capital and welfare benefits beyond their more widely acknowledged ecological and climate mitigation roles.

JEL classification

Q57, Q50, O1, O13

Keywords

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] In this paper, we go beyond the ecological and climate resilience function of mangroves to evaluate and demonstrate their crucial role in also preserving health and cognition.

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, Liu et al. 2026, Menendez et al. 2020, del Valle 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 substantial yet unquantified health and cognition benefits, which is the focus of this paper.

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

[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).

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 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). These instruments are central to the economics of biodiversity conservation, which emphasizes incentive design, policy effectiveness, and the need to account for human responses to conservation policy (Gerling and Shah 2026). 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 that have community buy-in.

This study quantifies 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 as 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-health 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 identify the impacts of mangrove cover using within-individual variations over time. We complement this framework with a first-difference model to isolate the distinct effects of specific land use changes, such as mangrove persistence, conversion, and restoration. Robustness checks using alternate empirical designs offer additional confirmation of our findings.

Our analysis yields important findings. First, we document that local mangroves reduce depression symptoms. A one-standard-deviation increase in mangrove cover lowers the CESD-10 score by 0.12 standard deviation and the likelihood of clinical depression by 4.5 percentage point (pp). Second, mangrove cover acts as a buffer against declines in episodic memory for the elderly. Third, the social impacts of land use change are asymmetric as the mental health benefit from restoring one hectare of aquaculture to mangrove is more than double the estimated cost of 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 et al. (2023) and Yamamoto (2023).

We also show that the welfare value of mangroves depends on local ecological conditions and the feasibility of restoration. Using Goto et al.'s (2025) global data on mangrove ecological zones and restoration project costs, we construct region-specific Biophysical Restorability Indices based on predicted restoration costs, as well as region-specific Blue Carbon indices that measure carbon sequestration density. The results indicate that restoration potential moderates the mental health impacts of land use change. The harms from mangrove-to-aquaculture conversion are smaller in areas where restoration is easier; additionally, the benefits of restoring aquaculture ponds to mangroves are larger where restoration is easier; and persistent mangrove stocks are most valuable where restoration is difficult. By contrast, Blue Carbon potential does not systematically moderate mental health outcomes, underlining that climate-mitigation benefits and local mental health value accrue in spatially-distinct patterns. We do not find statistically significant moderation effects for large-scale unconditional cash transfers and social capital in our context.

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. In doing so, we also respond to recent calls for more rigorous evidence on the human welfare value of biodiversity and the consequences of biodiversity decline (Baylis et al. 2026). 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.

We further align our work with emerging studies on the economic and health returns of restoring natural capital. For example, Heal et al. (2026) demonstrate that restoring nature generates substantial economic returns for rural communities, while Rizzi and Lewis (2025) quantify the economic costs of wetland loss, revealing the market consequences of ecosystem degradation. Additionally, our findings complement those of Taylor and Druckenmiller (2022), who emphasize the economic costs of wetland loss due to diminished flood protection. Their work shows how environmental degradation can have widespread impacts on local communities, much like the effects of mangrove loss in Indonesia. Our study also connects to the emerging biodiversity risk literature which has gained increasing attention in recent years, especially in financial economics (Beverdam et al. 2025, Giglio et al. 2025, Giglio et al. 2026, Flammer et al. 2025). This literature focuses primarily on the financial effects of biodiversity loss, such as its influence on asset values and financial strategies. We expand on this by highlighting the non-market social consequences of ecosystem degradation, offering new perspectives into the wider societal impacts of biodiversity risk.

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 give 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. Consistent with the Asia-Pacific Climate Report's framing of nature as a "core economic asset" (Asian Development Bank 2025), we show that mangroves generate local welfare and human capital benefits that extend beyond globally valued carbon services. In doing so, our study helps bridge a key empirical gap in the natural capital literature by demonstrating that ecosystem preservation yields not only ecological and economic returns, but also measurable gains in human wellbeing.

Lastly, our work contributes to the body of research linking environmental conditions and climate change to mental health and cognition (Zhang et al. 2017, Burke et al. 2018, Obradovich et al. 2018, Mullins and White 2019, Elsner and Wozny 2023, Hua et al. 2023). Several studies have largely focused on acute stressors such as temperature extremes, air pollution, or severe weather events, but 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 welfare. Understanding these links is essential for assessing the 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 socio-environmental dynamics and the localized impacts of mangrove ecosystems, its findings carry 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. 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 by 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 also persist in regions like the Florida Everglades (USA) and Northern Australia. Across these diverse contexts, the erosion of mangrove ecosystems visibly impairs environmental stability but, as our findings indicate, could also pose risks to mental and cognitive health functions.

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 sizeable 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-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,

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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.

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 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 shows marked heterogeneity in both the extent and composition of mangrove loss. While Papua and West Papua have generally retained comparatively large areas of primary (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 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 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

[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.

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 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 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 remains fragmented and sparse (Awuku-Sowah et al. 2022).[6] This oversight limits the understanding necessary to inform policy 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 can have socioeconomic effects that extend to mental health and cognitive abilities. Mangrove deforestation jeopardizes

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[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 protection like submerged breakwaters (Narayan et al. 2016, Van Zanten et al. 2021).

[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.

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 socioeconomic 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. It also documents 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 leads to 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. 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 can exacerbate emotional burdens and health-related 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

[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.

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, to find beneficial effects. In contrast, Kibria et al. (2019) reports 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.

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 compromises 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 protection (such as shielding from storms and floods) can influence the welfare of coastal communities. The second part of our empirical analysis emphasizes these potential channels.

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 Survey, conducted in 2007 and from late 2014 to early 2015, respectively, as these are the only two geo-coded rounds.[8] The IFLS is a longitudinal socioeconomic and health survey that began in 1993 and is representative of 83% of the Indonesian population across 13 provinces.[9] IFLS4 successfully interviewed 13,535 households and 44,103 individuals, and IFLS5 interviewed 16,204 households and 50,148 individuals. Our initial analytical sample consists of 18,548 adults whom we observe in both waves, for a total of 37,096 observations. For reasons explained below,

[8] 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

[9] 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.

we further limit our sample to individuals living within 40 kms of the coast, which leaves us with a total of 25,270 observations (12,635 individuals).

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 the 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.[10]

The precision of our spatial analysis relies on the restricted-access geocoded data provided by the IFLS for respondent communities.[11] 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 the households in IFLS4 and 96.5% in IFLS5.[12] 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).

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

[11] 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.

[12] For IFLS4, we can 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.

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 (IHS) 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, administered to all individuals aged 15 and older in both waves.[13] 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 abilities are

[13] 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.

critical but often underestimated determinants of vital economic outcomes that affect wellbeing (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.[14] 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.[15] 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.

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).[16,17] The dataset contains two data products at 15-meter resolution 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

[14] 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.

[15] 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.

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

[17] Coastal zones are defined by Clark Labs 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.

of each community (the "cluster" location in the IFLS) location.[18] 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.

An alternative widely used data source is the Global Mangrove Watch (GMW), which identifies global mangrove extents at a 25-meter resolution for multiple years, including a 2007 layer that is temporally closer to our first survey wave.[19, 20] However, our research questions require identifying the primary competing land use and the specific dynamics of ecosystem change. The Clark Labs data provides two key advantages in this regard - it allows us to identify the presence of aquaculture, a main driver of coastal change, and it provides granular land use transitions beyond simple changes in forest cover.

The advantage of using the Clark Labs data comes at the cost of a potential temporal mismatch for the 2007 wave. We argue this is a justifiable tradeoff as mangrove cover is a slow-moving stock variable, and the 1999 measure likely serves as a relatively good proxy for baseline ecological conditions. To verify this, we compare the mangrove cover measures from both the Clark and GMW datasets. The two are highly correlated, with correlation coefficients of 0.857 for the 2007 wave and 0.866 for the 2014 wave.

We restrict our analysis to IFLS communities located within 40 km of the coast. This restriction reflects the spatial nature of the treatment, since mangrove ecosystems are coastal resources and the most direct ecological and livelihood channels are likely to operate among coastal communities. In our data, local mangrove exposure exhibits essentially no meaningful variation beyond this distance threshold, so including further inland communities would only add observations with essentially zero signal. The 40 km threshold therefore focuses the analysis on locations where local mangrove exposure is both empirically variable and conceptually relevant.

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[18] 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.

[19] 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 provides global mangrove extent maps for 1996, 2007-2010, and 2015-2020. 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).

[20] Another alternative approach to identify spatial-temporal patterns of mangrove cover is to overlay a snapshot of mangrove map onto spatial-temporal general-purpose forest coverage maps. For example, Yamamoto (2023) used the USGS mangrove cover map in 2000 overlayed on spatial-temporal forest cover maps provided by the University of Maryland.

We verify that our main findings are not driven by this sample definition by re-estimating the baseline models using alternative distance-to-coast cutoffs, including the full IFLS sample and samples restricted to communities within 30 km and 50 km of the ocean. We also assess sensitivity to alternative exposure definitions by measuring mangrove cover within different community buffer radii.

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 4.6 and a standard deviation of 4.2. Logarithmic and inverse hyperbolic sine transformations of the CESD-10 yield similar central tendencies, while binary indicators show that 39.5% of respondents score above the median CESD-10 score of 4, and 12.5% meet or exceed the clinical cutoff of 10 for depressive symptoms.

Panel B summarizes cognitive outcomes. The average immediate recall is 4.7 words, delayed recall is 3.7 words, resulting in a total episodic memory score of about 8.4 words, with a standard deviation of 3.8. The average z-scores for the Raven test, numeracy test, and overall intelligence is 0.4, 0.2, and 0.4, respectively. We also find that cognitive and mental health outcomes are in general uncorrelated with each other as their pairwise correlation ranges between 0.03-0.07.

In Panel C, the average mangrove coverage within a 30 km radius is 0.3% (standard deviation of 0.8). On average, 0.2% of mangrove cover persists over time, with 0.04% converted to aquaculture ponds and 0.06% 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.

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 individual fixed effects model:

$$y_{ihct} = \beta MangroveCover_{ct} + \gamma' X_{ihct} + u_i + v_t + \epsilon_{ihct} \qquad (1)$$

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 as impacts are evident up to this point.

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 predisposition, 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 for the same person between the 2007 and 2014 survey waves. 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).

Our key identifying assumption is that conditional on the fixed effects and the set of time-varying controls, changes in a person's mangrove exposure are not systematically correlated with other unobserved factors that also influence health and cognitive outcomes. A violation of this assumption would be if mangrove change in Indonesia is largely conversion-driven: a decline in local mangrove cover may accompany the expansion of aquaculture ponds or oil palm plantations and may therefore proxy for a broader trajectory of local economic development that affects mental health through non-mangrove channels. Section 5.4 addresses this concern with three sets of checks. We show that the estimates are robust to additional individual, household, and childhood controls, alternative geographic fixed effects, region-by-wave trends, and direct controls for aquaculture and palm expansions (Appendix Figure A2); that randomly assigned mangrove trajectories do not benefit inland individuals who are not exposed to them (Appendix Figure A3); and that the results survive an instrumental variable strategy that isolates variation in mangrove cover arising from geomorphological suitability for mangrove growth rather than from local economic conditions (Appendix Table A1).

Complementing our main regression, 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 implement a first difference estimation strategy specified as

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

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.[21] 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 cognition

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 consistently improves mental health outcomes. For example, in column (1), the estimate indicates that a one-standard-deviation (1 SD) increase in mangrove coverage reduces the CESD-10 score by 0.12 standard deviation (SD).[22] These negative effects 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

[21] Note that the first-difference estimator is equivalent to two-way fixed-effects (TWFE) when the panel has two periods (t=2). So, Equation (1) can also be estimated using the first-difference estimator.

[22] The coefficient on *Mangrove Cover* in column (1) is -0.629. We multiply this coefficient by the standard deviation of mangrove cover (0.836) to obtain a 0.526. Since the standard deviation of CESD-10 scores is 4.229, this is a 0.526/4.229= 0.124 standard deviation decline in the CESD-10 score.

reduces the likelihood of experiencing clinical depressive symptoms by 4.5 percentage points (pp).[23,24]

In contrast to the strong effects on mental health, Panel B of Table 2 shows few precisely estimated effects of mangrove coverage on average cognitive performance (columns 1-3). Similarly, we observe few significant effects on fluid intelligence or numeracy skills, as measured by the Raven, numeracy, and overall intelligence z-scores (columns 4-6). It is plausible, however, that these averages hide heterogeneous effects which we explore next.

5.2. Older, more educated people benefit more from mangroves

Figure 3 examines whether the relationship between mangrove cover, mental health, and cognition differs by age. The top panels report the age-specific estimates for depressive symptoms. Mangrove cover lowers CESD-10 score across all age groups. The estimates are small and imprecise for respondents aged 15-19, but they become larger in magnitude among middle-aged and older adults. A similar age gradient appears for the indicator for scoring above the clinical threshold. These results indicate that the mental health benefits of mangrove cover are concentrated among older individuals, who may be more vulnerable to environmental stressors or more dependent on local ecological conditions.

The middle set of panels reports the results for episodic memory. The estimates for younger respondents are close to zero, whereas the coefficients become positive for older age groups, especially for delayed and total recall. These estimates are marginally significant and are less precise than the mental health results. We interpret these results as suggestive evidence that mangrove cover may have stronger effects on memory outcomes among older adults than conclusive proof that mangroves slow age-related cognitive decline. This age gradient is also consistent with a life cycle interpretation of cognitive health, whereby later life cognition may

[23] These results are robust to the inclusion of height and BMI as additional controls. We include these separately from our baseline specification because different health markers may themselves be affected by environmental conditions, through nutritional and economic channels, raising concerns about over-controlling. Focusing on all mental health results, the coefficients remain statistically significant at the same level.

[24] We also try to control for retirement status and pension receipt to address the concern that mangrove coverage may affect mental health among older adults indirectly through labor market channels. These variables are available only for a subsample of respondents aged 50 and above. When we include a dummy for being retired or partly retired, the signs of our estimates are maintained, though we lose statistical power due to considerably smaller sample size.

reflect the accumulated effects of nutrition, physical health, chronic stress, and environmental conditions (Asian Development Bank 2024).

The last set of panels in Figure 3 reports additional cognitive outcomes available for younger respondents. The point estimates are positive, though insignificant, for Raven's progressive matrices and the combined EK2 score for the 30-39 age group. The numeracy estimates are also positive for this group, though not significant. Since the Raven's and numeracy tests are only available for younger individuals, we cannot assess whether similar relationships hold among older adults.

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 men and women. 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 does not affect depression symptoms for individuals with no formal education, and the effect becomes larger in magnitude for individuals with more educational attainment. Consistent with evidence that educational background shapes how residents value mangrove ecosystem services (Iqbal 2020, Jadin and Rousseau 2022), this pattern likely reflects complementarities between education and environmental quality. Educated individuals may be better able to recognize the benefits provided by mangrove ecosystems, including coastal protection, livelihood opportunities, and access to environmental information or institutions. Finally, Panel C examines the differential impacts of mangrove coverage by food security status, with few meaningful differences.

5.3. 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 health could be biased. While our fixed effects strategy partially addresses this by differencing out time-invariant individual characteristics, we explicitly account for this here by examining how effects differ between non-movers and movers.

This analysis serves two purposes. First, it is a direct test of whether our findings are robust to potentially endogenous sorting; second, it compares two distinct sources of variation in our model. For non-movers, the effect 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 larger mental health benefits for non-movers, as seen in columns (2) and (3). For movers, we find statistically insignificant smaller effects in columns (4) and (5). This may reflect not only differential exposure to mangrove ecosystems at the destination, but also the adjustment costs associated with migration. Non-movers who can maintain occupations and livelihood strategies may benefit more, while the estimated effect for movers may combine the effects of varied environmental exposure with the costs of adapting to a new location. Future work could examine this mechanism more directly by comparing movers with and without occupational changes, as well as by assessing the degree of livelihood continuity between origin and destination.

The fact that mangrove coverage provides more mental health benefits to non-movers implies that the benefits may not be instantaneous but may accumulate over time as individuals build a sense of place and stable, nature-linked livelihoods. Since the benefits of mangrove ecosystems are greater for established communities, *in-situ* conservation and restoration initiatives may be more effective tools for protecting health and cognition.

5.4. Robustness checks for the main results

Identification of our mangrove effects relies on comparing the same individuals in coastal communities (within 40 kms of the coast) before and after changes in local mangrove cover, so that all time-invariant individual and community characteristics, as well as common shocks between the two survey waves, are differenced out. What this design cannot account for is contemporaneous, community- and/or individual-specific changes that coincide with mangrove variation. Because mangrove loss in Indonesia primarily reflects conversion to aquaculture or plantation agriculture, an issue is that a change in mangrove cover proxies for a broader trajectory of local economic development that affects mental health independently. The remainder of this section reports a sequence of checks, each designed to rule out a particular set of concerns. We net out regional development trends and the competing land uses in aquaculture and palm (Section 5.4.1); we show that mangrove change carries no explanatory power for inland individuals who cannot plausibly be exposed to it (Section 5.4.2); and we isolate the component of mangrove cover driven by exogenous geomorphological suitability, which is unaffected by local economic conditions (Section 5.4.3).

5.4.1. Additional controls, additional fixed effects, and region-specific trends

We start by replicating our main regression model under a series of alternative specifications that include additional control variables, vary the level of fixed effects, and account for correlated land use changes. These checks are summarized in Figure A2, which plots the estimated coefficient on mangrove cover, together with its 90% confidence interval, across each specification.

We first examine the robustness of our results by varying the level of geographic fixed effects. Alongside the individual and survey-year fixed effects, we successively add province, regency (*kabupaten*), subdistrict (*kecamatan*), and community (village) fixed effects, which help control for persistent regional differences such as cultural norms, institutional variations, and regional economic disparities. The coefficient estimates become larger in magnitude as finer levels of geographic controls are added. We then conduct a check that addresses the concern that changes in mangrove cover may be correlated with time-varying regional shocks. To do so, we augment the baseline fixed effects model with province-by-wave and regency (*kabupaten*)-by-wave fixed effects. These specifications test whether the estimated effect survives after netting out regional development trends or shocks that evolve between survey waves. The results remain robust.

Next, we probe sensitivity to omitted individual- and household-level factors. We add control variables related to media consumption and household amenities, namely indicators for whether an individual can read a 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. We then replace the individual fixed effect with a household fixed effect, which absorbs time-invariant characteristics shared by co-resident household members. Considering evidence that childhood conditions can significantly influence future welfare outcomes (Ahmed et al. 2023, Hughes et al. 2017, Kivimäki et al. 2018), we further augment this household fixed effects specification with controls for early-life circumstances, including childhood health status, resource constraints during childhood, early family stress, childhood educational stimulation, and economic disadvantage during childhood.[25] Across these specifications, the coefficient on mangrove cover remains negative, precisely measured, and close to the baseline estimate.

Finally, we examine whether the estimate reflects other land use changes that may occur alongside mangrove loss. This is important because mangrove conversion may coincide with the expansion of aquaculture ponds or oil palm plantations, both of which could affect local livelihoods, environmental quality, and mental health through channels other than mangrove cover itself. We therefore add controls for pond expansion, and then for both palm and pond expansion. Estimates from these regressions are presented in the last two rows of Figure A2. The coefficient on mangrove cover remains negative and significant, and close to the baseline estimate. The result is also similar when these land use controls are combined with *kabupaten*-by-wave fixed effects.

5.4.2. Spatial placebo tests

The tests presented in the last subsection absorb regional, time-variant shocks within the coastal population that is actually exposed to mangroves. We now evaluate the mirror image and ask whether regional level co-movement may generate our results among people with no mangroves exposure. If the estimated effects are driven by regional-level time-varying unobservables, e.g. economic shocks, institutional or policy changes, or regional environmental changes, then a mangrove trajectory borrowed from elsewhere in the same province will spuriously reproduce our results even for those who are not truly exposed to mangroves.

The placebo recipients we utilize are those individuals in communities that lie inland (non-coastal) in both survey waves and therefore have no local mangrove cover. For each recipient community, we randomly draw one coastal community from the same province and assign the recipient that donor's mangrove trajectory, meaning the donor's mangrove cover in 2007 and in 2014. The recipient community is thereby given a fictitious change in mangrove cover equal to the donor's actual change, which is applied to all individuals in that community. We then re-estimate our baseline specification in first-difference form on this placebo treatment, using the same

[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 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.

controls, weights, and clustering scheme, and deliberately without regional fixed effects, so that any province-level co-movement is free to appear in the estimate. We repeat the random assignment 1,000 times. Because donor and recipient share a province, the assigned trajectory carries whatever province-wide shocks are correlated with real mangrove change.

Figure A3 reports the results. Panel (a) restricts both the recipients and the coastal comparison to village stayers. The placebo distribution has a mean close to zero (-0.120), while the true coastal estimate is -1.288. Panel (b) repeats the exercise on the full inland sample against the full-sample coastal estimate, with a placebo mean of -0.084, while the true coefficient is -0.629. These tests suggest that province-matched fictitious mangrove cover does not reproduce the mental health effect among people who cannot be exposed to mangroves, indicating that the result depends on actual local mangrove variation rather than on province-wide co-movements.

5.4.3. Instrumental variable strategy

As a complementary check, we isolate variation in mangrove cover that is driven by physical suitability for mangrove growth which is likely uncorrelated with local economic conditions. We instrument mangrove cover with an indicator for whether a community's nearest coastal landform is a river delta. Deltas are sheltered, sediment-rich environments formed by river deposits, making them naturally favorable to mangroves, so deltaic communities tend to have systematically higher mangrove cover. The instrument is a fixed feature of coastal geography, and thus identification comes from between-community differences in deltaic status, and the estimate is best read as a local average effect among communities whose mangrove cover is shaped by this geomorphology.

Table A1 reports the results for depression. The first stage is strong, with a cluster-robust F-statistic of 98.5 in the full sample and 68.0 among village stayers. The two-stage least squares estimates preserve the sign and significance of the main result. We treat these estimates as corroborating rather than preferred estimates for two reasons. First, deltaic settings may affect mental health through channels other than mangroves, such as delta-based livelihoods and employment. Second, the exclusion restriction is not directly testable in our setting: essentially all deltaic communities have some mangrove cover, so there is no set of deltaic communities without mangroves against which to check for a direct effect on mental health. We nonetheless follow recent work that uses geography as an instrument (Faber and Gaubert 2019, Baran et al. 2025) in conducting this test.

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 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 (2.17 versus 0.63 for the CESD-10 score, and 0.18 versus 0.05 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. Importantly, 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.[27] To contextualize these magnitudes, a mid-sized local mangrove restoration project of 50 hectares (ha) that converts from aquaculture results in a 0.09 point decrease in CESD-10 score and a 0.6 pp decrease in the likelihood of being clinically depressed for the surrounding communities.[28] Converting 50 hectares of mangrove to aquaculture, on the other hand, will result in a 0.04 point increase in CESD-10 score and a 0.3 pp increase in the likelihood of being clinically depressed.

[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] We assess whether the asymmetry could be due to nonlinearities in the relationship between mangrove exposure and mental health. We residualize both the mental health outcome and mangrove exposure with respect to the included fixed effects, and then examine their relationship non-parametrically. The plot does not reveal a clear nonlinear relationship, suggesting that strong omitted nonlinearities are unlikely to explain the estimated asymmetry.

[28] 50 hectares is at the 66th percentile of all mangrove restoration projects in terms of size surveyed by Goto et al. (2025). We do not accurately net out water bodies in our estimations. However, given the first-difference specification, this is a relatively innocuous issue since the bulk of our sample is stayers (74.7%) for whom this aspect would be differenced out.

An explanation for this asymmetry is that aquaculture-to-mangrove restoration combines two channels. It removes some of the environmental and social stressors associated with pond aquaculture while also restoring the ecosystem services provided by mangroves. Coastal aquaculture can generate income and employment, but it is also associated with mangrove loss, waste discharge, disease risks, migration, loss of livelihoods, and food insecurity (Primavera 2006). Restoring aquaculture ponds to mangroves may therefore produce a "double dividend" by reducing the pressures associated with degraded or intensive pond systems while rebuilding coastal protection, fisheries habitat, and other ecosystem services. The Asymmetric Response Concept (Vos et al. 2023) provides a useful ecological rationale for this idea, as ecosystem degradation and recovery need not be mirror-image processes when responses to increasing stressor intensity and subsequent stressor release are governed by different mechanisms. While the human health consequences of restoration may depend on the specific ecological trajectory through which recovery occurs, well-designed restorations are more likely to promote human health outcomes, consistent with Speldewinde et al. (2015).

Evidence from abandoned fishpond restoration shows that targeted pond reversion can enhance carbon storage and coastal protection potential (Duncan et al. 2016), while meta-analytic evidence indicates that mangrove restoration generates ecological benefits and positive benefit-cost ratios (Su et al. 2021). At the same time, the estimated asymmetry may partly reflect differences in the contexts in which these transitions occur, since aquaculture-to-mangrove restoration may be more likely in degraded or abandoned pond areas, or coincide with restoration programs and related public or community investments. Such investments may themselves affect mental health by providing short-term support, signaling government commitment, or reducing economic and environmental risk among nearby communities.[29] These estimates are therefore best interpreted as the net effects of distinct land use transitions, rather than as mirror-image changes along a single linear pathway.

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

[29] Ideally, this mechanism would be tested directly using data on government restoration, program intensity, or restoration funding, and by examining whether effects differ between areas receiving different types of investments. Such an analysis would help distinguish the ecosystem-service channel from a public investment or expectations channels. However, because detailed data on restoration investments are not available in our setting, we leave this test for future research.

land use changes. As shown in Panel A of Table 5, 1% more persistent mangrove cover decreases CESD-10 score by 0.32 points and the likelihood of reaching the clinical cutoff by 2.6 percentage points (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 0.9 pps.

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 leads to a large and 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, however, conversion of mangroves to aquaculture has few effects on this outcome. We also find precise effects for the persistence of the ecosystem endowment on episodic memory. A 1 pp increase in persistent mangrove cover increases the total recall score by 0.18 words (in column (3) of Panel B). Conversely, a one pp increase in persistent aquaculture cover decreases total recall by 0.12 words.

The results for fluid intelligence are more muted. We find few 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.

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 larger than the marginal damages of converting to aquaculture, indicating potentially large health benefits of mangrove restoration efforts. Second, our results point to the existence of endowment effects in that stable mangrove ecosystems also provide mental health and cognitive benefits to nearby communities.[30] This corroborates our earlier finding that non-movers enjoy relatively larger mental health benefits from mangrove cover.

[30] 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.

6. Mechanisms

Our main findings show that the presence of local mangrove ecosystems improves human capital. 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 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 wellbeing (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).[31] 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 may 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 mangroves 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 disaster, respectively. In columns (4) and (5), we examine whether the community has ever been flooded,

[31] 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.

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.[32]

In Panel A of Table 6, we report the estimated effects of mangrove cover from the fixed effect model in Equation (1). While we find few effects 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 (columns 2 and 3). In Panel B, we report the estimated effects of land use change from the first-difference model in Equation (2). Here, we find that mangrove persistence decreases the instances of households experiencing flood events. In column (1), 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 0.18 pps.[33] The estimated effects are larger at the community level in column (4), with a 10% increase in mangrove stock decreasing the likelihood of flooding by 0.35 pps. We also find that communities with higher mangrove endowments are more likely to be trained in disaster preparedness in column (7).[34]

Further, converting mangroves to aquaculture increases the likelihood of a household experiencing flood events, with the 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. The latter may be because young, restored mangrove forests have not yet developed mature root systems to provide the same level of protection as established mangroves.

Our results indicate 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. These findings identify increased flood exposure as a mechanism through which mangrove

[32] 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.

[33] The marginal effect (in column 1 of Panel B) is -0.074. 0.024 * (-0.074) = -0.0018, or -0.18 percentage points. Similar calculations are performed below.

[34] The positive association between mangrove endowments and disaster-preparedness training likely reflects the layered nature of flood-risk management rather than a contradiction in the protective function of mangroves. Mangroves can reduce flood exposure and storm impacts, but they cannot fully eliminate residual risk, particularly during extreme events. Communities with greater mangrove endowments may also be more likely to be recognized as coastal or high-risk areas and therefore targeted for preparedness programs.

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).[35]

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 labor and decreasing non-food expenditures.

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. We find that a 1 SD increase in mangrove coverage increases income (column 1) by 16.3%.[36] 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).

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 for healthy and total food expenditures are marginally significant.

Collectively, these results indicate that mangroves are measurable sources of income and boost nutritional status, aligning with the 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.

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[35] 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.

[36] Income and expenditures are in real values pegged to 2010 Rupiahs. The estimated coefficient is 0.181; log-linear model specifies percentage interpretation as $(e^{\beta} - 1)*100 = 19.8\%$; the standard deviation of mangrove cover = 0.836, which implies that a one SD change in mangrove leads to approximately 16.3% increase in income.

6.3. Perceived upward mobility and future economic outlook

Finally, we examine whether the presence of mangroves is related to positive perceptions of social and economic prospects for the future. Building on the concept of ecological grief (Cunsolo and Ellis 2018), where environmental degradation diminishes optimism about the future, we consider the possibility that greater mangrove coverage fosters a sense of security, opportunity, and upward mobility. Such confidence could be a 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.[37] We construct measures of perceived upward social mobility and economic outlook to assess impacts.

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. This is suggestive evidence that mangroves alleviate ecological grief as proxied by improved perception of social standing. It is also possible that mangrove 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

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[37] 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.

both adults and children (for respondents with children under age 15).[38] Column (3) presents a composite measure "*bleak economic outlook and low social mobility,*" which equals one if the respondent reports a negative economic outlook and exhibits persistent low perceived social mobility. Two of these measures have a negative sign (although measured imprecisely) suggesting that mangrove cover improves perceptions of subjective well-being.

Our findings 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. Ma et al. (2022) also highlights that 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 relationship 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 protection, 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. Reversibility and mangrove restoration potential

A key policy tool to reverse the adverse impact of deforestation is the restoration of native ecosystems.[39] While the ecological benefits of restoration are well established, growing research

[38] 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 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 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.*"

[39] Restoration effectiveness hinges on biophysical feasibility. In Indonesia, the government established the Peatlands and Mangrove Restoration Agency with an official target of 600,000 hectares, but Sasmito et al. (2023) estimate that

emphasizes its role not only as an environmental process but also as a crucial factor in human wellbeing (Suding et al. 2015). Active restoration initiatives can help reduce climate risks, improve environmental quality, and contribute to food security, all of which have direct 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).

Beyond the direct benefits of active restoration, the broader feasibility of ecological recovery may shape how communities experience environmental change. If an ecosystem possesses high innate restorability, its degradation may be perceived as a temporary, recoverable loss rather than a permanent one. The theory of option value under irreversibility (Arrow and Fisher 1974, Pindyck 1991, Amacher et al. 2009) provides a natural framework that may be applied in this context: when degradation can be reversed, communities retain the option to restore, attenuating the psychological cost of current loss. Conversely, the marginal value of existing natural capital should be highest where restoration is infeasible and loss is permanent.

To test these mechanisms, we examine whether the mental health impacts of land-use change vary systematically with the feasibility of ecological recovery. The natural economic measure of restorability is the marginal cost of restoration - a lower marginal cost implies that the mangrove ecosystem is easier to restore, and vice versa. We use data from Goto et al. (2025), which provides a global geospatial dataset of over 4,000 mangrove ecological zones, alongside a database of approximately 200 historical restoration projects and their associated costs.[40] While Goto et al. (2025) computes a direct marginal restoration cost metric (in US dollars/hectare), this metric is estimated as a function of both local biophysical and economic conditions, rendering it a potentially contaminated measure for our purposes.[41] To circumvent this, we re-estimate the cost model using their project-level data, but only use plausibly exogenous factors (including the

only 193,367 hectares, roughly 30%, can feasibly support mangrove rehabilitation due to ecological limitations and competing land-use demands.

[40] An ecological zone corresponds to a typological unit in Worthington et al. (2020). A macroscale geomorphic unit defined by the coastal landform (delta, estuary, lagoon, or open coast) encompassing one or more contiguous mangrove patches. Globally, approximately 4,000 such units are identified, with a median restorable area of roughly 18 hectares (though deltaic units can span several thousand hectares).

[41] Specifically, Goto et al. (2025) uses local GDP per capita as an explicit predictor of restoration costs alongside with biophysical predictors.

geomorphological class of the estuary as well as erosion and weather-related mangrove losses) to generate predicted marginal restoration costs.[42] Normalizing this metric yields our measure of biophysical restorability index, or BRI, scaled from 0 (hardest to restore) to 100 (easiest to restore), capturing the exogenous determinants of marginal restoration costs.[43] Separately, we construct a Blue Carbon index to measure the carbon sequestration potential of each ecological zone. Following Goto et al. (2025), we compute carbon dioxide per hectare as *3.67 × (aboveground biomass + soil organic carbon)*. We also apply the same min-max normalization to a 0-100 scale, with biomass and soil organic carbon provided by Goto et al. (2025) at the estuary level.

We interact these indices with our land-use variables to test for heterogeneous effects. Table 8 reports the results for restoration potential. In Panel A, we interact BRI with the aggregate measures of mangrove and aquaculture pond coverage. We do not find statistically significant effects for BRI interactions across most columns. Panel B decomposes these aggregate effects into land use transition variables, which show that the aggregate land cover measure masks opposing forces across distinct land-use transitions.

We highlight three results. First, the mental health damages of converting mangroves to aquaculture are attenuated in areas with high restoration potential (column 2). Where ecological conditions favor restoration, the loss of natural capital operates as a reversible shock rather than a permanent loss, dampening the corresponding distress. We also find statistically significant attenuation effects for the intelligence outcome in the same direction in column (4). Second, the protective mental health benefits of restoring aquaculture ponds back to mangroves are larger in high-BRI areas (column 1), indicating that restoration delivers the highest psychological returns when biophysical conditions facilitate successful ecological recovery. Third, the protective value of persistent mangrove stocks is highest where restoration is difficult (column 2). This is the pattern predicted above - where restoration is biophysically feasible, communities retain the option to reverse ecological damage, attenuating the psychological cost of current degradation. Where

[42] The predictive model confirms that the dominant biophysical cost driver is erosion ($\beta = 2.18$, $p < 0.001$). Heavily eroded coastlines are far more expensive, and thus harder, to restore. Geomorphology also matters - deltas (the reference category) are the least costly to restore, while open coasts carry the highest predicted costs ($\beta = 1.94$, $p < 0.001$), consistent with their exposure to wave energy and sediment instability.

[43] BRI varies at the estuary level. We assign each IFLS community its BRI value using nearest-neighbor spatial matching to the three closest estuaries and apply inverse distance weights.

restoration is infeasible and loss is permanent, current mangrove stocks become irreplaceable, raising their perceived value and the psychological cost of their loss.

We also test whether carbon sequestration potential moderates the mental health and cognitive impacts of land-use change by interacting the Blue Carbon Index with our land-use variables. Carbon sequestration potential is biophysically orthogonal to restorability in mangrove ecosystems.[44] Results are presented in Table A4. The blue carbon interactions yield few effects across both mental health outcomes (CESD-10 score and clinical depression). For episodic memory, however, a familiar pattern emerges as the conversion of mangroves to aquaculture leads to statistically significant improvements in recall in high-carbon areas (Panel B, column 3), which results in a net smaller negative impact of mangrove conversion to aquaculture on average. Moreover, persistent mangrove stocks with higher carbon potential have lower memory benefits. This suggests that carbon-dense mangrove zones, characterized by thick below ground organic stocks and dense canopy, may not provide the same local livelihood or amenity benefits as other mangrove types, such that their conversion to productive aquaculture can yield relative cognitive gains even as mental health effects remain neutral.

These results yield three implications for the spatial allocation of conservation and restoration resources. First, biophysical restorability is an important determinant of local human capital returns to both conservation and restoration. The mental health benefits of protecting mangroves and the psychological dividends of restoring them are each amplified by ecological feasibility, creating a self-reinforcing cycle in areas with high restorative potential. Second, where restoration is infeasible, current mangrove stocks carry an irreplaceability premium, consistent with the option value of maintaining natural capital when degradation is irreversible. Conservation investments in these areas may yield disproportionately high returns per unit of ecosystem protected. Third, the orthogonality between blue carbon density and biophysical restorability implies that the spatial allocation that maximizes global climate mitigation benefits differs from the allocation that maximizes local welfare gains. Financing mechanisms that prioritize carbon sequestration, such as REDD+ or blue carbon credits, do not incidentally optimize for community

[44] The Pearson correlation between BRI and Blue Carbon Index across 4,044 global estuaries is -0.03. Adding carbon density to the BRI cost model produces a statistically insignificant coefficient and no change in R^2, confirming that blue carbon stocks and physical restorability characterize independent dimensions of the ecosystem. Appendix Figure A4 maps the spatial distribution of the Biophysical Restorability Index, Goto et al's (2025) marginal restoration cost measure, and the Blue Carbon Index used in this analysis.

mental health or cognitive outcomes and may thus have less local buy-in. Site selection for mangrove restoration that incorporates local wellbeing metrics alongside global carbon accounting would better serve the populations most affected by environmental change.

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

Having established that environmental degradation harms mental health and cognitive function, we test whether formal economic assistance or informal community cohesion may also buffer these psychological shocks. A substantial body of research demonstrates that safety nets can improve mental health by alleviating poverty-related stress (Macours et al. 2012, Baird et al. 2013, Haushofer and Shapiro 2016, Ridley et al. 2020, Duquennois and Jagnani 2026). Here we evaluate two social and financial dimensions, namely large-scale unconditional cash transfer programs, and community social capital, to assess whether they moderate the relationship between mangrove ecosystems and mental health.

We first evaluate the role of economic safety nets using Indonesia's large-scale unconditional cash transfer programs: Bantuan Langsung Tunai (BLT) and Bantuan Langsung Sementara Masyarakat (BLSM). These programs aimed to support the poorest 33 percent of households by offsetting the economic shocks of rising prices (Pritadrajati 2023).[45] The results, presented in Table A5, show that the interaction between UCT receipt and mangrove cover is insignificant across most mental health and cognitive outcomes. Cash transfers do not replace the psychological benefits derived from these standing forests.

We next test whether strong community cohesion moderates the relationship between environmental change and mental health. Following Riumallo-Herl et al. (2014), Cao and Rammohan (2016), and Bai and Li (2021), we construct a composite index of social capital that identifies individuals who report feeling safe in their neighborhoods and actively participate in at least one community program.[46] Table A6 shows that high social capital strongly predicts better baseline mental health and protects cognitive function. However, the protective effects of social

[45] 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).

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

capital operate independently from the main effect of mangroves, as the interaction between social capital and mangrove cover is mostly measured with error.

Findings in this subsection show that cash transfers, social capital, and mangrove ecosystems operate through distinct pathways. While economic assistance and social cohesion provide meaningful baseline benefits for mental health, they do not systematically interact with the psychological effects of mangrove presence. The absence of complementarity or substitutability between these factors underscores the distinct role of natural capital.

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 psychosocial 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 precisely measured beneficial effects of local mangrove ecosystems on mental wellbeing. In particular, we document a robust relationship between mangrove coverage and reduced depressive symptoms.

Our analysis of land use changes shows that the impacts of ecosystems depend on the level of the stock as well as 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, whereby 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 the nature of land use change is a critical input in the ecosystems-mental health nexus.

Effects appear to operate through multiple channels including reduced exposure to flooding, higher household income, and improved dietary consumption. The analysis of contextual factors shows that the strength of these relationships depends in part on local ecological conditions. Effects of social safety nets and social capital are limited, suggesting that while these factors bring their own benefits, they speak relatively little to the mangroves-mental health 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 wellbeing and cognitive functioning. Integrating ecosystem preservation into development policy, alongside targeted social and institutional supports, will be important in ensuring more resilient and sustainable futures for vulnerable populations in the face of escalating environmental insults.

A related avenue for future research is to examine whether exposure to mangrove ecosystems earlier in life has persistent effects on later life mental health and cognitive outcomes. While our measure of persistent mangrove cover reflects one dimension of longer-term environmental exposure and includes individuals as young as 15 years of age, data limitations do not allow us to separately identify the role of childhood or place-of-birth exposure. Future work could link individuals' birthplaces or childhood locations to historical mangrove data to assess whether the benefits of mangrove ecosystems accumulate over the life course, consistent with early-life exposure having important consequences for later life health.

The welfare estimates in this paper also raise a question about the institutional conditions under which mangrove loss occurs. More research could link the spatial measures developed here to data on concessions, land titles, aquaculture permits, enforcement actions, and community claims. This would make it possible to test whether institutional failures raise both degradation and human capital losses. It would also help distinguish ecological risk from governance risk in settings where conversion reflects insecure tenure, elite capture or land grabbing, rather than local comparative advantage alone. The results can also speak more directly to policy design. If human capital benefits are largest where exposure and vulnerability are high, restoration and adaptation programs should not rank sites only by carbon storage, flood protection or restoration costs. They should also account for expected gains in mental health and cognition. Recent evidence that tenure arrangements and supporting institutions can affect mangrove protection (Tanner and Ratzke 2022) makes this link between welfare measurement and policy design especially relevant. Another priority is to clarify how environmental degradation shapes long run development through both exposure and anticipation.

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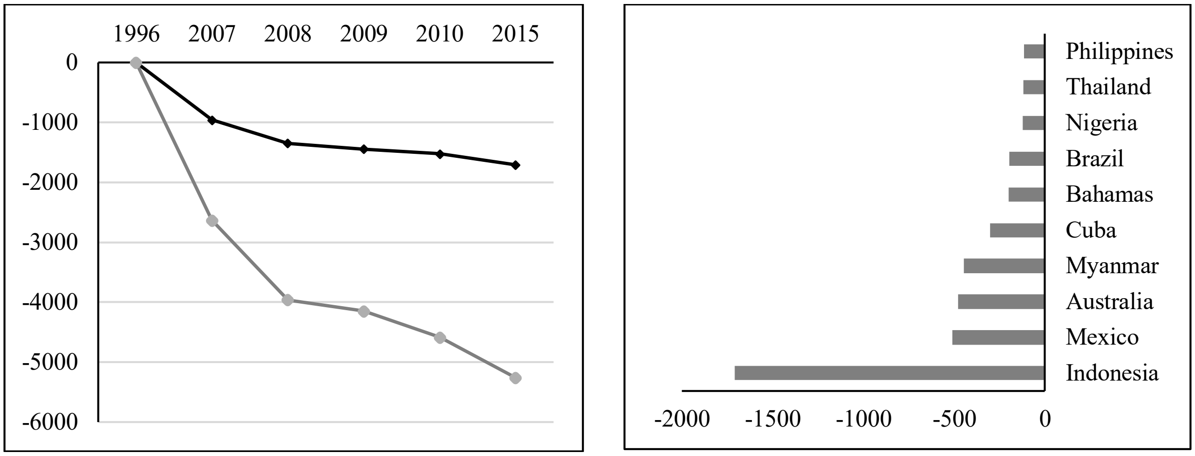
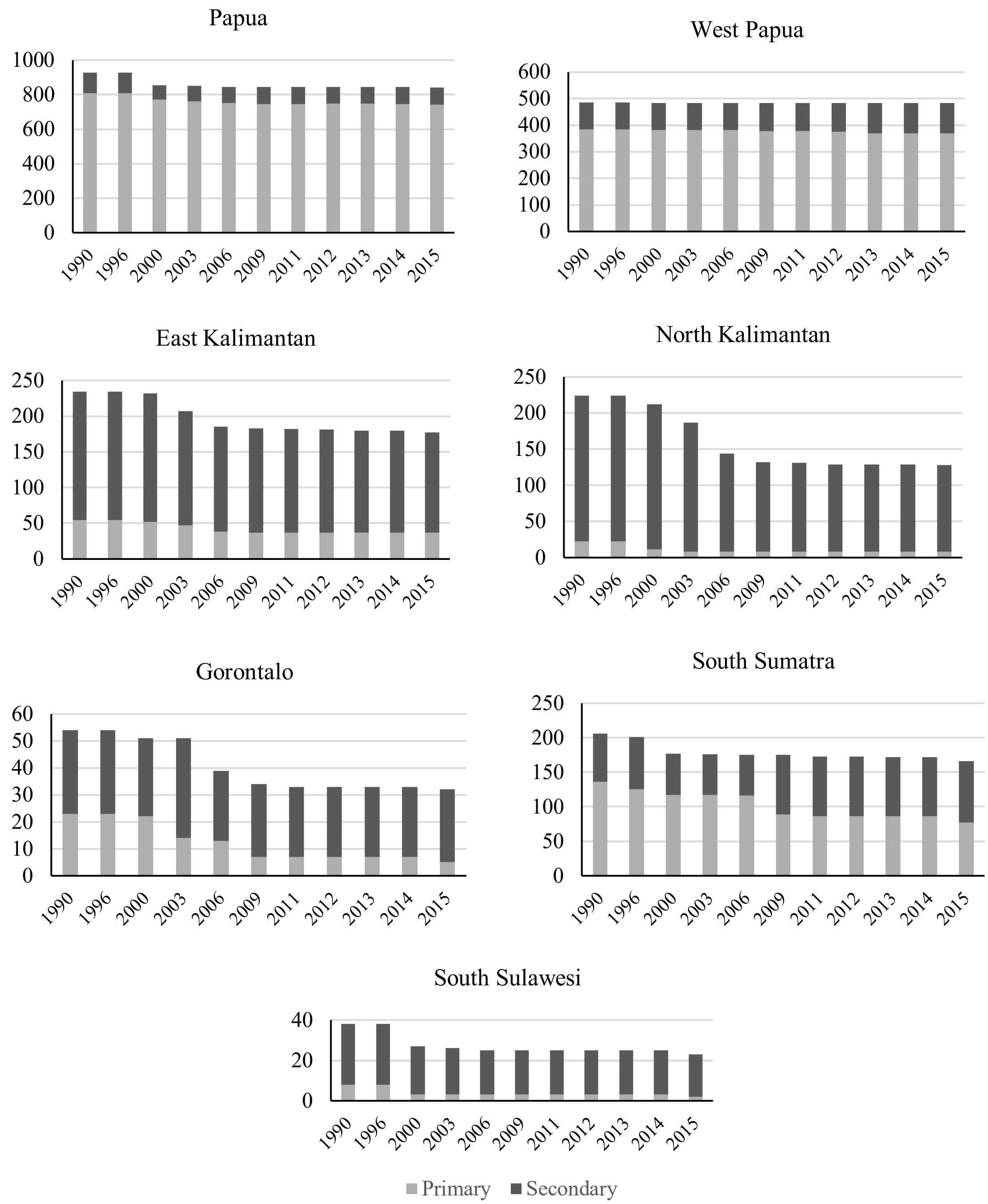
Figure 1: Net changes in mangrove habitat area from 1996 to 2015

Panel A **Panel B**



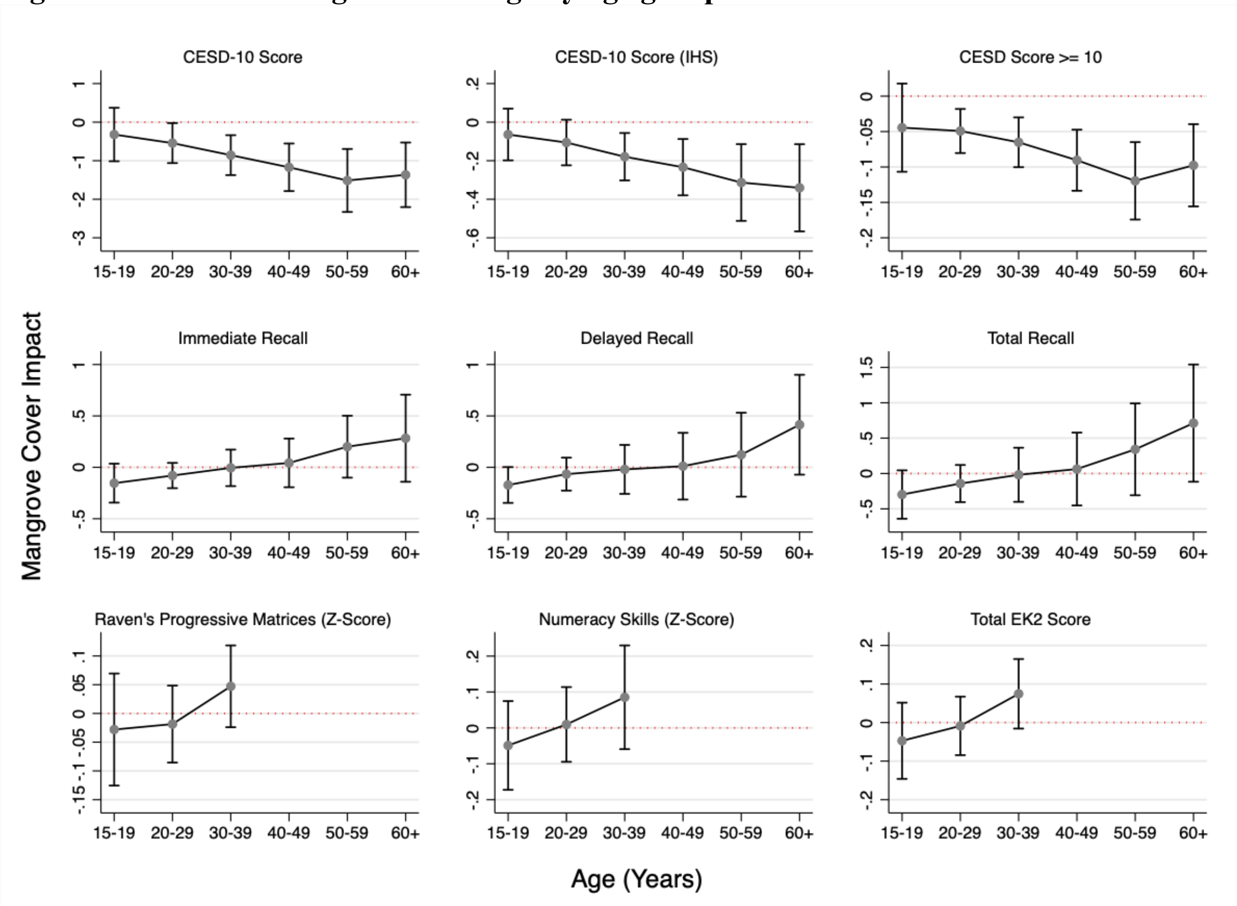
Notes: Panel A shows the global (in gray) and Indonesian (in bold) net change from 1996 to 2015 in areal extent of mangrove habitat (in km^2). The net loss for Indonesia is 1,707 km^2 in Panel A. Panel B shows the top 10 countries with the largest net change in areal extent of mangrove habitat between 1996 and 2015 (in km^2). The area of mangrove habitat in Indonesia was 29,565.37 km^2 in 2015 (100 Hectares = 1 km^2). Source: Authors' calculations from 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)	Std. Dev. (2)	Min (3)	Max (4)
Panel A: Mental health outcomes (CESD-10)				
Total CESD-10 score	4.640	4.229	0.000	28.000
Log of CESD-10 score	1.448	0.788	0.000	3.367
Inverse hyperbolic sine of CESD-10	1.850	0.980	0.000	4.026
Binary: CESD-10 > median score	0.395	0.489	0.000	1.000
Binary: CESD-10 >= 10 (clinical cutoff)	0.125	0.331	0.000	1.000
Panel B: Cognitive outcomes				
Immediate word recall	4.729	1.929	0.000	10.000
Delayed word recall	3.688	2.086	0.000	10.000
Total episodic memory (immediate + delayed)	8.427	3.769	0.000	20.000
Raven's progression matrices test (z-score)	0.353	0.797	-2.359	1.452
Numeracy skills test (z-score)	0.230	0.997	-1.216	2.527
Overall intelligence (Raven + Numeracy, z-score)	0.351	0.830	-2.205	2.077
Panel C: Mangrove variables				
% Mangrove coverage (within 30km of community location)	0.273	0.836	0.000	10.880
% Aquaculture pond coverage (within 30km of community location)	1.319	2.640	0.000	16.536
% Persistent mangrove coverage across 1999-2022 (within 30 km of community location)	0.184	0.694	0.000	8.524
% Persistent aquaculture pond coverage across 1999-2022 (within 30 km of community location)	1.061	2.364	0.000	15.002
% Mangrove converted to aquaculture pond between 1999-2022 (within 30 km of community location)	0.038	0.161	0.000	4.923
% Aquaculture pond converted to mangroves between 1999-2022 (within 30 km of community location)	0.064	0.143	0.000	0.935
Panel D: Individual and household controls				
Age	41.517	14.992	15	101
Married	0.761	0.427	0	1
Rural	0.475	0.499	0	1
Muslim	0.937	0.243	0	1
Household size	4.244	1.878	1	15
No formal education	0.082	0.275	0	1
Primary education	0.406	0.491	0	1
Junior high education	0.172	0.377	0	1
Senior high education	0.247	0.431	0	1
College/university education	0.093	0.291	0	1
Household head is male	0.831	0.375	0	1

Notes: Authors' calculations from the 2007 and 2014 rounds of the IFLS data and satellite sources for mangrove and aquaculture pond cover

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

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Mental Health			
	cesd10	**cesd10 (log)**	**cesd10 (inhs)**	**> median cesd10**	**>=10 cutoff**	
% Mangrove Cover	-0.629**	-0.110**	-0.135**	-0.039	-0.054***	
(within 30km of community location)	(0.277)	(0.050)	(0.062)	(0.028)	(0.019)	
Observations	25,270	25,270	25,270	25,270	25,270	
R-squared	0.635	0.624	0.620	0.602	0.579	
			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	-0.048	-0.069	-0.116	-0.025	-0.009	-0.024
(within 30km of community location)	(0.072)	(0.100)	(0.161)	(0.038)	(0.056)	(0.044)
Observations	24,656	24,656	24,656	9,628	9,628	9,628
R-squared	0.749	0.724	0.761	0.696	0.679	0.728
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. Columns (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 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 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	-0.616*	-0.058**	-0.056	-0.054
	(0.331)	(0.025)	(0.191)	(0.053)
% Mangrove cover x male	-0.642**	-0.051**	-0.178	0.006
	(0.305)	(0.021)	(0.180)	(0.050)
Observations	25,270	25,270	24,656	9,628
R-squared	0.635	0.579	0.761	0.728
		Panel B: By highest education level		
	CESD-10	**CESD score >= 10**	**total recall**	**overall intelligence**
% Mangrove cover x no formal education	-0.017	-0.019	-0.337	-0.078
	(0.440)	(0.030)	(0.359)	(0.165)
% Mangrove cover x primary school	-0.488	-0.048*	-0.066	-0.161*
	(0.421)	(0.029)	(0.237)	(0.097)
% Mangrove cover x junior high school	-0.709*	-0.061*	-0.074	-0.006
	(0.406)	(0.034)	(0.206)	(0.069)
% Mangrove cover x senior high school	-0.562**	-0.052***	-0.205	-0.021
	(0.234)	(0.018)	(0.165)	(0.037)
% Mangrove cover x college or above	-1.114**	-0.071**	0.025	0.073
	(0.448)	(0.029)	(0.183)	(0.060)
Observations	25,270	25,270	24,656	9,628
R-squared	0.635	0.579	0.761	0.729
		Panel C: By food insecurity status		
	CESD-10	**CESD score >= 10**	**total recall**	**overall intelligence**
% Mangrove cover x not food insecure	-0.631**	-0.054***	-0.132	-0.024
	(0.279)	(0.019)	(0.149)	(0.045)
% Mangrove cover x food insecure	-0.589*	-0.064***	0.108	-0.028
	(0.306)	(0.021)	(0.185)	(0.052)
Observations	25,262	25,262	24,648	9,626
R-squared	0.635	0.579	0.762	0.729
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 a dummy variable for whether CESD-10 score is equal or higher than 10. Column (3) focuses on total number of words recalled (immediate plus delayed). Column (4) reports a combined z-score measure of Raven and math tests for respondents under 40 years old. 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	-0.629**	-1.215***	-1.062***	-0.242	-0.253
(within 30km of community location)	(0.277)	(0.351)	(0.387)	(0.343)	(0.311)
Observations	25,270	19,870	22,614	5,338	2,594
Panel B: CESD score >= 10					
% Mangrove cover	-0.054***	-0.085***	-0.074***	-0.030	-0.037
(within 30km of community location)	(0.019)	(0.023)	(0.025)	(0.027)	(0.028)
Observations	25,270	19,870	22,614	5,338	2,594
Panel C: Total recall					
% Mangrove cover	-0.116	-0.029	-0.149	-0.230*	-0.092
(within 30km of community location)	(0.161)	(0.309)	(0.275)	(0.126)	(0.120)
Observations	24,656	19,344	22,028	5,250	2,566
Panel D: Overall intelligence					
% Mangrove cover	-0.024	-0.159*	-0.143*	-0.002	0.012
(within 30km of community location)	(0.044)	(0.082)	(0.075)	(0.045)	(0.043)
Observations	9,628	6,796	7,910	2,782	1,668

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	-0.323***	-0.036	-0.041	-0.020	-0.026***	
(1999-2022, within 30 km buffer)	(0.096)	(0.022)	(0.028)	(0.012)	(0.006)	
% Aquaculture persistence	0.112**	0.010	0.011	0.016***	0.009***	
(1999-2022, within 30 km buffer)	(0.044)	(0.011)	(0.015)	(0.005)	(0.003)	
% Mangrove converted to aquaculture	2.17***	0.266**	0.310**	0.147***	0.181***	
(1999-2022, within 30 km buffer)	(0.491)	(0.122)	(0.158)	(0.054)	(0.029)	
% Aquaculture converted to mangrove	-4.86***	-0.750***	-0.900***	-0.513***	-0.348***	
(1999-2022, within 30 km buffer)	(0.723)	(0.183)	(0.235)	(0.077)	(0.042)	
			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	0.067**	0.110***	0.175**	0.039**	0.064**	0.058***
(1999-2022, within 30 km buffer)	(0.033)	(0.041)	(0.068)	(0.019)	(0.030)	(0.022)
% Aquaculture persistence	-0.021	-0.097***	-0.117***	-0.014	-0.011	-0.011
(1999-2022, within 30 km buffer)	(0.019)	(0.024)	(0.037)	(0.011)	(0.018)	(0.013)
% Mangrove converted to aquaculture	0.051	-0.100	-0.069	0.021	0.154	0.102
(1999-2022, within 30 km buffer)	(0.210)	(0.195)	(0.367)	(0.107)	(0.121)	(0.105)
% Aquaculture converted to mangrove	0.541*	1.70***	2.27***	0.130	-0.162	-0.019
(1999-2022, within 30 km buffer)	(0.300)	(0.413)	(0.648)	(0.194)	(0.381)	(0.272)

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. Columns (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 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 community level. ***p<0.01, **p<0.05, *p<0.1.

Table 6: Mangroves and exposure to floods and other disasters

	Dependent variables:						
	individual 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	-0.007	-0.009	-0.005	-0.109	-0.771	0.363	0.482
(within 30km of community location)	(0.025)	(0.026)	(0.026)	(0.250)	(1.838)	(0.383)	(0.516)
% Aquaculture ponds	0.015	0.020*	0.021*	-0.015	-0.863	0.127	0.369
(within 30km of community location)	(0.010)	(0.011)	(0.012)	(0.184)	(0.929)	(0.204)	(0.267)
Observations	24,780	24,780	24,780	18,108	18,108	18,108	18,108
R-squared	0.612	0.598	0.619	0.747	0.587	0.649	0.636
Panel B: Land use change							
% Mangrove persistence	-0.074***	-0.086***	-0.077***	-0.146***	-1.93***	-0.010	0.163***
(1999-2022, within 30 km buffer)	(0.026)	(0.022)	(0.025)	(0.056)	(0.698)	(0.046)	(0.060)
% Aquaculture persistence	-0.004	-0.007	-0.004	0.003	-0.064	0.007	0.045
(1999-2022, within 30 km buffer)	(0.011)	(0.011)	(0.011)	(0.023)	(0.092)	(0.038)	(0.040)
% Mangrove converted to aquaculture	0.181**	0.240***	0.198**	0.278	6.54	-0.228	-0.251
(1999-2022, within 30 km buffer)	(0.077)	(0.079)	(0.082)	(0.336)	(5.24)	(0.340)	(0.558)
% Aquaculture converted to mangrove	-0.024	0.023	-0.024	-0.381	0.240	0.292	-0.125
(1999-2022, within 30 km buffer)	(0.173)	(0.171)	(0.181)	(0.391)	(1.57)	(0.576)	(0.594)
Observations	12,630	12,630	12,630	9,196	9,196	9,196	9,196
R-squared	0.01578	0.01444	0.01520	0.07173	0.03227	0.01439	0.04556

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. 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 7: Mangroves, income, employment, and consumption

	(1)	(2)	(3)	(4)	(5)
	Panel A: Income and Employment				
	income (last year)	worked for pay	employed last year	hours worked	
% Mangrove cover	0.181**	0.007	0.013	-1.294	
(within 30km of community location)	(0.070)	(0.021)	(0.017)	(1.346)	
% Aquaculture pond	-0.014	-0.002	0.016**	-0.098	
(within 30km of community location)	(0.031)	(0.009)	(0.008)	(0.466)	
Observations	13,039	23,894	23,890	16,772	
R-squared	0.544	0.362	0.364	0.415	
	Panel B: Consumption and nutrition				
	whether household purchases		**(log) expenditure on**		
	fish	protein-rich food	healthy food	total food	non-food
% Mangrove cover	0.020	0.022	0.152*	0.064*	0.012
(within 30km of community location)	(0.023)	(0.018)	(0.084)	(0.038)	(0.041)
% Aquaculture pond	0.019	0.013	-0.007	-0.002	0.028
(within 30km of community location)	(0.013)	(0.009)	(0.050)	(0.023)	(0.020)
Observations	23,872	23,898	23,872	23,872	23,872
R-squared	0.648	0.640	0.660	0.726	0.762
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 community level. ***p<0.01, **p<0.05, *p<0.1.

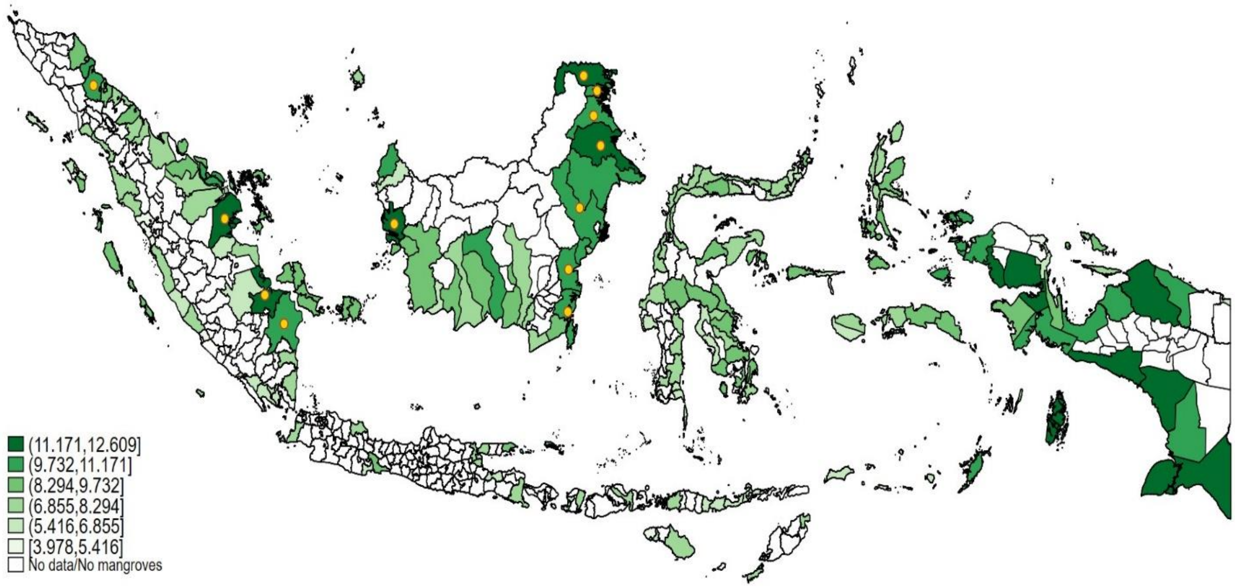
Table 8: Mitigation by biophysical mangrove restorability

	Outcome variable:			
	CESD-10	CESD score >=10	total recall	overall intelligence
	(1)	(2)	(3)	(4)
Panel A: Land cover model				
% Mangrove cover (within 30 km buffer)	0.204	-0.015	0.711	0.184
	(0.884)	(0.071)	(0.462)	(0.135)
% Aquaculture ponds (within 30 km buffer)	-0.223	-0.0009	0.012	-0.164**
	(0.363)	(0.033)	(0.299)	(0.079)
BRI	-0.003	-0.0001	0.023***	0.003*
	(0.007)	(0.0005)	(0.005)	(0.002)
% Mangrove cover x BRI	-0.014	-0.0007	-0.018*	-0.004
	(0.019)	(0.001)	(0.009)	(0.003)
% Aquaculture ponds x BRI	0.011	0.0004	-0.002	0.003*
	(0.008)	(0.0007)	(0.006)	(0.002)
Observations	12,635	12,635	12,328	4,835
R-squared	0.00770	0.00465	0.00735	0.01039
Panel B: Land use change model				
% Mangrove persistence	-1.38	-0.142***	1.36*	0.329**
	(1.04)	(0.051)	(0.781)	(0.153)
% Aquaculture persistence	-0.120	-0.002	0.046	-0.039
	(0.248)	(0.014)	(0.224)	(0.043)
% Mangrove converted to aquaculture	3.37	0.700**	-5.72	-2.20**
	(6.74)	(0.301)	(5.25)	(0.942)
% Aquaculture converted to mangrove	3.39	-0.072	-4.01	0.256
	(5.04)	(0.327)	(4.59)	(1.13)
BRI	0.006	0.0004	0.018***	0.002
	(0.008)	(0.0006)	(0.005)	(0.002)
% Mangrove persistence x BRI	0.019	0.002**	-0.024	-0.006*
	(0.019)	(0.0009)	(0.015)	(0.003)
% Aquaculture persistence x BRI	0.005	0.0002	-0.003	0.0006
	(0.005)	(0.0003)	(0.004)	(0.0009)
% Mangrove to aquaculture x BRI	-0.021	-0.010*	0.112	0.046**
	(0.131)	(0.006)	(0.104)	(0.019)
% Aquaculture to mangrove x BRI	-0.167*	-0.006	0.116	-0.007
	(0.095)	(0.006)	(0.088)	(0.024)
Observations	12,635	12,635	12,328	4,835
R-squared	0.01399	0.00915	0.00973	0.01403

Notes: This table reports the heterogeneous impacts of mangrove and aquaculture on mental health and cognitive outcomes, varying by Biophysical Restorability Index (BRI ∈ [0,100], higher BRI means easier to restore mangroves). Panel A uses percentages of mangrove and aquacultural pond coverage within a 30km buffer. Panel B uses percentages of land use persistence and transitions within a 30km buffer from 1999-2022. 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 variables except for BRI and 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.

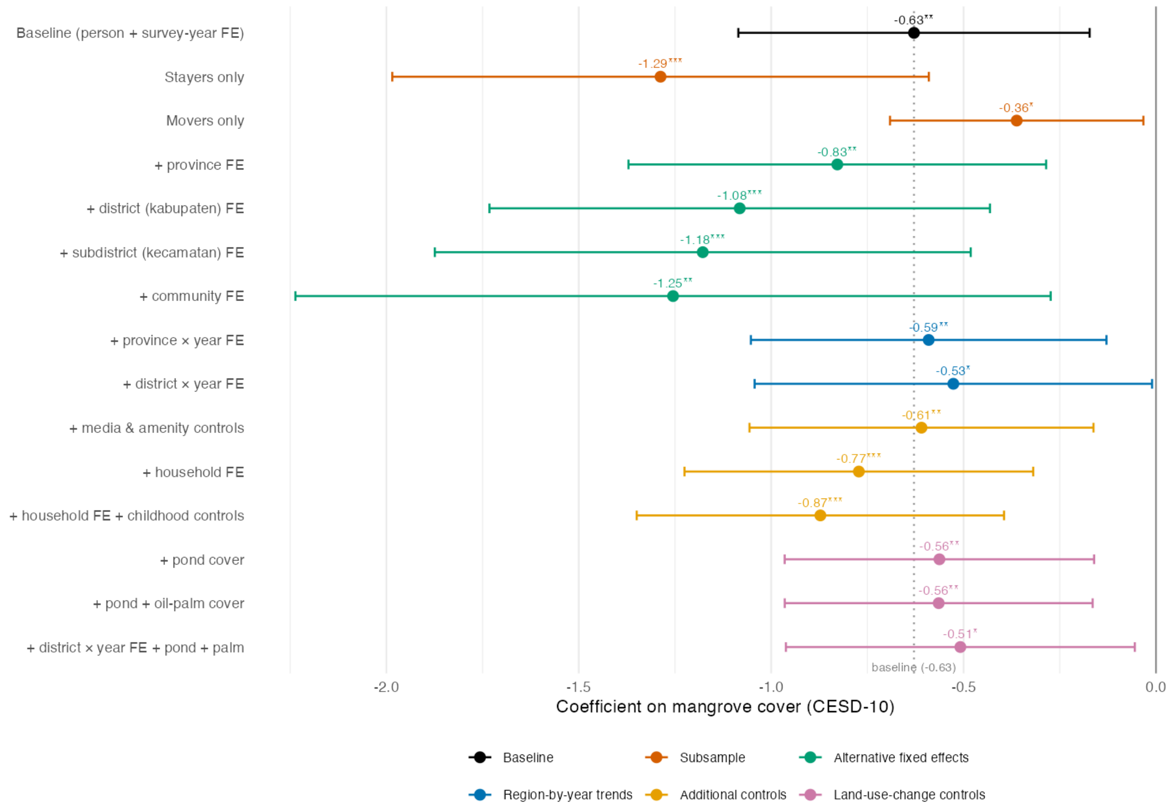
Appendix

Figure A1: Mangrove coverage across regencies in Indonesia in 2000



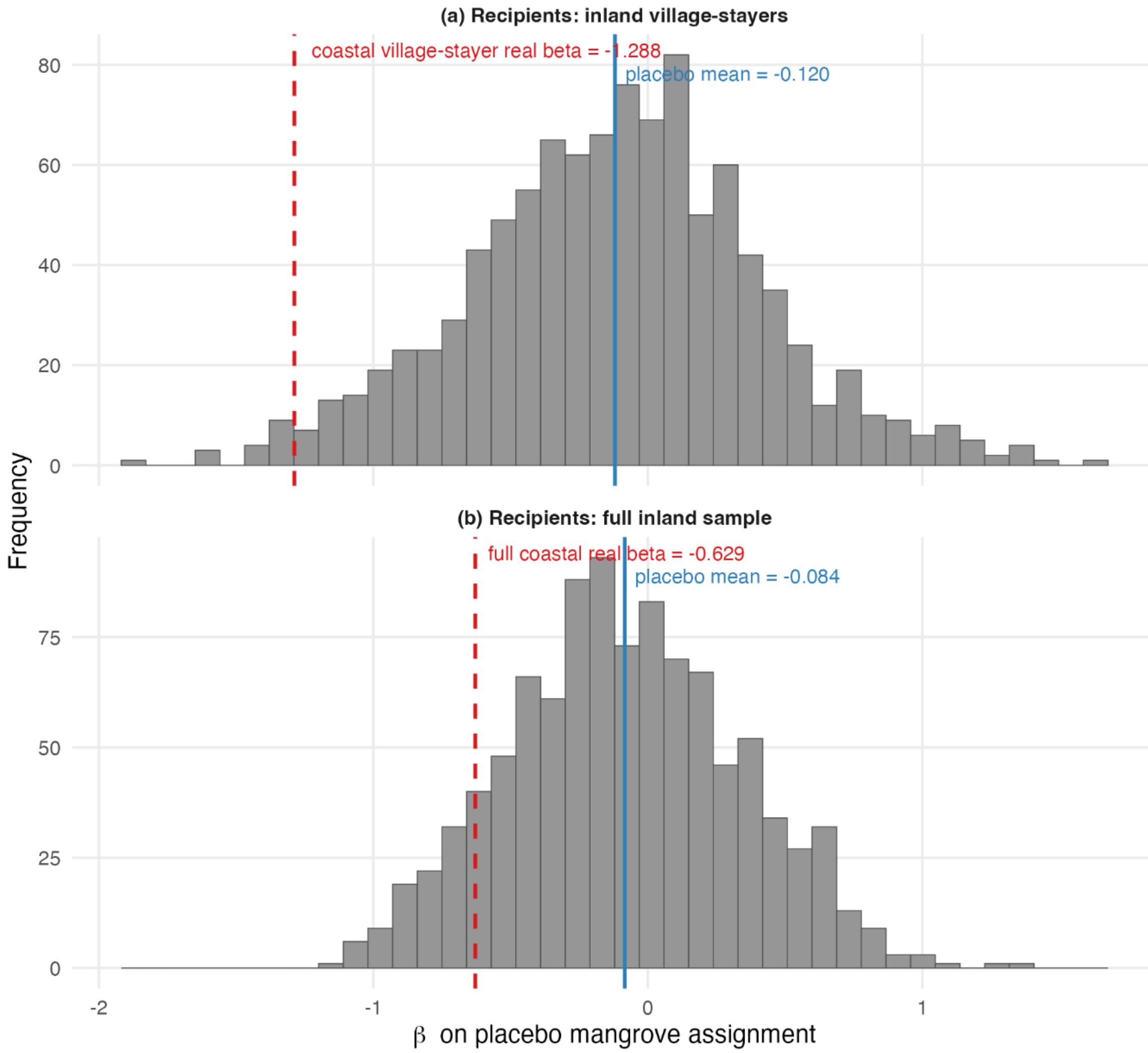
Notes: This map presents the natural logarithm of mangrove coverage in hectares for Indonesian regencies with a restoration potential exceeding 5 hectares as of the year 2000. Yellow circles identify the top 12 regencies with restoration opportunities exceeding 5,000 hectares. Note that data for 84 other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

Figure A2: Robustness checks – additional fixed effects and additional controls



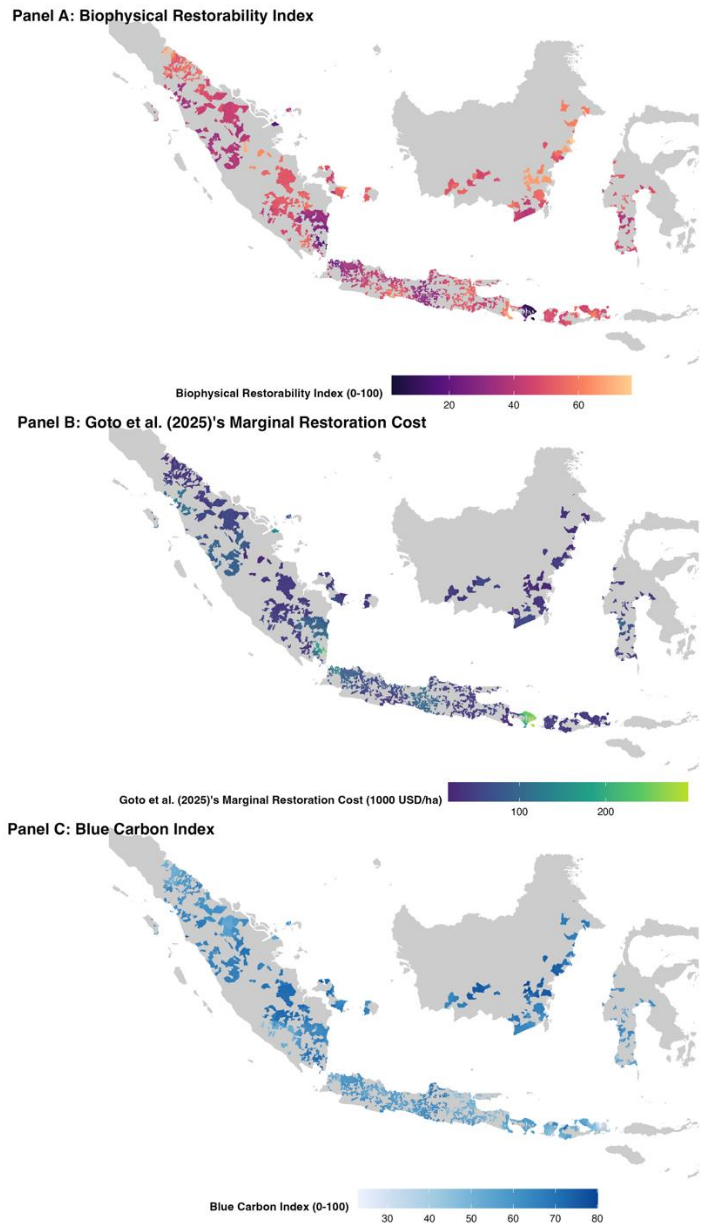
Notes: Each marker shows an estimated coefficient on mangrove cover (percentage of mangrove cover within a 30 km buffer) from a separate regression of the CESD-10 depression score, estimated on individuals in communities within 40 km of the coast. The baseline (top row) includes individual and survey-year fixed effects and is equivalent to the headline estimate presented in Table 2. The remaining rows, grouped by color, modify this baseline in the following way: Subsample: the baseline re-estimated separately for village stayers (who stayed in the same village between waves) and for movers (who moved out of the original village for wave 2014). Alternative fixed effects: province, regency (kabupaten), subdistrict (kecamatan), and community fixed effects, each added alongside with individual and survey-year fixed effects. Region-by-year trends: province-by-year and regency-by-year fixed effects are added alongside with individual and survey-year fixed effects. Additional controls: media-consumption and household-amenity controls (newspaper readership; household access to electricity, safe water, a private toilet, garbage disposal, and television); a specification replacing the individual fixed effect with a household fixed effect; and a household-fixed-effects specification adding childhood-circumstance controls (childhood health, schooling and resource constraints, early family stress, and reading materials in the childhood home). Land-use-change controls: aquaculture pond cover; pond and oil-palm cover jointly; and the latter combined with regency-by-year fixed effects. All regressions are weighted by the IFLS survey sampling weight and include the individual and household controls used in Table 2 (age, marital status, rural residence, religion, household size, education, and household-head gender). Standard errors are clustered at the community level. Horizontal bars denote 90% confidence intervals. Value labels report the point estimate with stars indicating statistical significance (*** p<0.01, ** p<0.05, * p<0.1). The solid vertical line marks zero; the dotted line marks the baseline estimate (-0.629).

Figure A3: Spatial placebo test using assigned coastal mangrove trajectories



Notes: This figure reports the distribution of placebo estimates from repeated first-difference regressions in which inland IFLS communities are assigned the mangrove cover trajectory of a randomly selected coastal community from the same province. Placebo recipients are individuals in communities located more than 40 km from the coast in both survey waves, which therefore have no local mangrove cover; the donor pool consists of coastal communities within 40 km of the coast, each with an observed mangrove trajectory. In each draw, every recipient community is randomly assigned one donor community from the same province and inherits that donor's mangrove cover in 2007 and in 2014, so that it receives a fictitious change in mangrove cover equal to the donor's actual change. The assignment is made at the community level and applied to all individuals in the community. We re-estimate the baseline specification in first-difference form on this placebo treatment, with the individual and household controls used in Table 2, weighted by the two-wave geometric mean of the IFLS survey sampling weight, and with standard errors clustered at the community level. The random assignment is repeated 1,000 times. The gray bars show the resulting distribution of placebo coefficients, and the blue solid vertical line marks its mean; the red dashed vertical line marks the corresponding estimated effect for coastal communities with actual local mangrove exposure. Panel (a) restricts both the placebo recipients and the coastal comparison to village stayers, defined as households that remain in the same IFLS community between survey waves (4,260 recipients in 260 communities). Panel (b) uses the full inland recipient sample and compares it to the full-sample coastal estimate (5,417 recipients in 684 communities).

Figure A4: Biophysical restorability index, marginal restoration cost, and blue carbon index



Notes: This figure presents the spatial distribution of mangrove restoration properties aggregated at the sub-district (Kecamatan) level for the Indonesian Family Life Survey (IFLS) sample. Panel A maps the Biophysical Restorability Index (BRI) on a 0 to 100 scale. Higher BRI means easier to restore mangroves. Panel B displays Goto et al. (2025)'s marginal restoration cost, in thousands of USD per hectare. Panel C plots the Blue Carbon Index, a normalized 0 to 100 scale estimating potential for blue carbon sequestration from mangrove restoration. We assign estuary-level characteristics to individual IFLS villages using spatial containment or nearest-neighbor matching and then calculate the unweighted sub-district averages. Shaded regions correspond to sub-districts containing at least one sampled village with proximity to restorable estuaries.

Table A1: Instrumental variable estimates

	Full sample			Village stayers		
	(1) OLS	(2) First stage	(3) 2SLS	(4) OLS	(5) First stage	(6) 2SLS
			Panel A. Depression score (CESD-10)			
Mangrove cover	-0.629***		-1.268***	-1.288***		-1.350***
(% within 30 km)	(0.277)		(0.362)	(0.424)		(0.411)
River Delta Area		0.642***			0.643***	
		(0.065)			(0.078)	
First-stage F-stat		98.5			68.0	
Observations (# individuals)	12,635	12,635	12,635	9,438	9,438	9,438
			Panel B. Clinical depression (CESD >= 10)			
Mangrove cover	-0.054***		-0.080***	-0.090***		-0.066**
(% within 30 km)	(0.017)		(0.023)	(0.027)		(0.029)
River Delta Area		0.642***			0.643***	
		(0.065)			(0.078)	
First-stage F-stat		98.5			68.0	
Observations (# individuals)	12,635	12,635	12,635	9,438	9,438	9,438

Notes: This table shows the instrumental variable estimates of the effect of mangrove cover on depression. Panel A uses the continuous CESD-10 depression score; Panel B uses an indicator for a CESD-10 score of at least 10 (clinical depression). Columns (1)–(3) use the full sample of individuals in communities within 40 km of the coast; columns (4)–(6) restrict to village stayers (individuals who remained in the same village between the 2007 and 2014 waves). Within each sample, we report ordinary least squares (columns 1 and 4), the first stage regression of mangrove cover on the instrument (columns 2 and 5), and two-stage least squares (columns 3 and 6). The endogenous regressor is mangrove cover (percentage of mangrove cover within a 30 km buffer); the instrument is an indicator for whether the community's nearest coastal landform is a river delta. The OLS estimate in column (1) reproduces the headline estimate in Table 2. All specifications are estimated in first differences (equivalent to individual and survey-year fixed effects with two waves), and each observation corresponds to one survey respondent. Regressions are weighted by the two-wave geometric mean of the IFLS survey sampling weight and include the individual and household controls used in Table 2 (age, marital status, rural residence, religion, household size, education, and household-head gender). Standard errors, clustered at the community level, are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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	-0.210***	-0.018***	0.183***	0.081***
(1999-2022, within 30 km buffer)	(0.080)	(0.006)	(0.063)	(0.015)
% Aquaculture persistence	0.011	0.003	-0.148***	-0.013
(1999-2022, within 30 km buffer)	(0.053)	(0.003)	(0.050)	(0.015)
% Mangrove converted to aquaculture	1.42***	0.143***	-0.388	0.160**
(1999-2022, within 30 km buffer)	(0.387)	(0.024)	(0.334)	(0.076)
% Mangrove converted to other land uses	-1.12**	-0.098***	-0.048	-0.321**
(1999-2022, within 30 km buffer)	(0.457)	(0.038)	(0.485)	(0.128)
% Aquaculture converted to mangrove	-3.69***	-0.223***	3.40***	0.076
(1999-2022, within 30 km buffer)	(0.980)	(0.057)	(0.853)	(0.335)
% Aquaculture converted to other land uses	-0.299	-0.041**	-0.558***	0.043
(1999-2022, within 30 km buffer)	(0.247)	(0.018)	(0.214)	(0.061)
% Other land uses converted to aquaculture	1.37***	0.066**	0.453	-0.126
(1999-2022, within 30 km buffer)	(0.390)	(0.027)	(0.365)	(0.086)
Number of Observations	12,635	12,635	12,328	4,835
R-squared	0.016	0.010	0.007	0.014

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	-0.025	-0.017	-0.016
(within 30km of community location)	(0.016)	(0.014)	(0.014)
Observations	22,496	22,496	22,496
R-squared	0.573	0.569	0.573
	Panel B: Standard of living and future economic outlook		
	Bleak economic outlook (inability to keep up with future living stds.)	inadequate std of living (adults and children)	bleak economic outlook and low social mobility
% Mangrove cover	-0.026	-0.005	-0.007
(within 30km of community location)	(0.025)	(0.023)	(0.012)
Observations	24,568	10,370	22,128
R-squared	0.614	0.607	0.562
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: Heterogeneous effects by blue carbon potential

	Outcome variable:			
	CESD-10	CESD score >=10	total recall	overall intelligence
	(1)	(2)	(3)	(4)
Panel A: Land cover model				
% Mangrove cover (within 30 km buffer)	-3.27**	-0.285**	0.249	-0.291
	(1.65)	(0.121)	(0.959)	(0.354)
% Aquaculture ponds (within 30 km buffer)	-0.402	-0.038	-1.60***	-0.147
	(0.490)	(0.037)	(0.397)	(0.138)
Blue carbon potential	0.003	-0.001	-0.013*	-0.006**
	(0.013)	(0.0009)	(0.008)	(0.003)
% Mangrove cover x blue carbon potential	0.047*	0.004**	-0.007	0.004
	(0.026)	(0.002)	(0.016)	(0.006)
% Aquaculture ponds x blue carbon potential	0.013	0.001	0.028***	0.002
	(0.009)	(0.0007)	(0.007)	(0.002)
Observations	12,635	12,635	12,328	4,835
R-squared	0.00825	0.00562	0.00506	0.01142
Panel B: Land use change model				
% Mangrove persistence	-1.50	-0.219	2.11*	-0.373
	(2.10)	(0.141)	(1.14)	(0.332)
% Aquaculture persistence	0.353	-0.008	-0.611	-0.040
	(0.431)	(0.029)	(0.387)	(0.098)
% Mangrove converted to aquaculture	7.84	1.11	-24.0***	-0.625
	(13.7)	(0.867)	(6.26)	(1.89)
% Aquaculture converted to mangrove	-13.8	-0.677	18.1**	0.205
	(9.53)	(0.604)	(8.84)	(2.37)
Blue Carbon Potential	-2.69e-6	-0.002**	-0.013*	-0.010***
	(0.013)	(0.0010)	(0.008)	(0.003)
% Mangrove persistence x Blue carbon potential	0.019	0.003	-0.031*	0.007
	(0.032)	(0.002)	(0.018)	(0.005)
% Aquaculture persistence x Blue carbon potential	-0.004	0.0004	0.008	0.0003
	(0.009)	(0.0006)	(0.008)	(0.002)
% Mangrove to aquaculture x Blue carbon potential	-0.092	-0.015	0.380***	0.012
	(0.212)	(0.013)	(0.099)	(0.030)
% Aquaculture to mangrove x Blue carbon potential	0.168	0.006	-0.284*	-0.0009
	(0.183)	(0.012)	(0.171)	(0.043)
Observations	12,635	12,635	12,328	4,835
R-squared	0.01364	0.00983	0.00900	0.01780

Notes: This table reports the heterogeneous impacts of mangrove and aquaculture on mental health and cognitive outcomes, varying by Blue Carbon Potential. Panel A uses percentages of mangrove and aquaculture pond coverage within a 30km buffer. Panel B uses percentages of land use persistence and transitions within a 30km buffer from 1999-2022. 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 variables except for Carbon and 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 A5: Mitigation effects of unconditional cash transfers

	Outcome variable:			
	CESD-10	CESD score >=10	total recall	overall intelligence
	(1)	(2)	(3)	(4)
Land cover model				
% Mangrove cover (within 30 km buffer)	-0.537**	-0.095**	-0.136	-0.019
	(0.244)	(0.042)	(0.151)	(0.049)
% Mangrove cover x UCT	-0.119	-0.005	0.051	-0.026
	(0.175)	(0.024)	(0.091)	(0.060)
% Aquaculture ponds (within 30 km buffer)	0.308***	0.059***	-0.069	-0.030
	(0.092)	(0.018)	(0.069)	(0.019)
% Aquaculture ponds x UCT	-0.074*	-0.013	0.003	0.011
	(0.039)	(0.008)	(0.031)	(0.013)
UCT receipt	0.284	0.054	0.004	0.012
	(0.184)	(0.034)	(0.124)	(0.054)
Observations	25,270	25,270	24,656	9,628
R-squared	0.636	0.625	0.761	0.729

Notes: This table reports the heterogeneous impacts of mangrove and aquaculture on mental health and cognitive outcomes, varying by Unconditional Cash Transfer (UCT) receipt status. We use percentages of mangrove and aquaculture pond coverage within a 30km buffer (Land Cover Model); interaction terms are constructed in levels before first differencing, identifying the effect for all units, including status switchers. 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 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 A6: Mitigation effects of social capital

	Outcome variable:			
	CESD-10	CESD score >=10	total recall	overall intelligence
	(1)	(2)	(3)	(4)
Land cover model				
% Mangrove cover (within 30 km buffer)	-0.525**	-0.053***	-0.136	-0.005
	(0.242)	(0.018)	(0.154)	(0.049)
% Mangrove cover x High social capital	-0.038	0.007	0.003	-0.029
	(0.070)	(0.006)	(0.110)	(0.025)
% Aquaculture ponds (within 30 km buffer)	0.263***	0.014**	-0.060	-0.019
	(0.091)	(0.006)	(0.071)	(0.020)
% Aquaculture ponds x High social capital	0.068*	0.006**	-0.014	-0.029***
	(0.038)	(0.003)	(0.029)	(0.009)
High social capital	-0.286**	-0.019	0.105	0.095***
	(0.137)	(0.012)	(0.092)	(0.033)
Observations	25,252	25,252	24,638	9,618
R-squared	0.63639	0.58009	0.76153	0.73011

Notes: This table reports the heterogeneous impacts of mangrove and aquaculture on mental health and cognitive outcomes, varying by a composite Social Capital index (high social capital = feels safe in village AND safe at night AND participates in community meetings). We use percentages of mangrove and aquacultural pond coverage within a 30km buffer (Land Cover Model). 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 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.