Quantifying the contribution of mangroves to local fish consumption in Indonesia: a cross-sectional spatial analysis

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Summary

Background Indonesia has lost more mangroves than any other country. The importance of mangroves for carbon storage and biodiversity is well recognised, but much less is known about what they contribute to the communities living near them who are called on to protect them. Malnutrition in Indonesia is high, with more than a third of children stunted, partly due to poor diets. Fish are nutrient-rich and are the most widely consumed animal source food in Indonesia, making the relationship between mangroves and fish consumption of great importance. Aquaculture is also tremendously important for fish production in Indonesia and has replaced large areas of mangroves over the last two decades.

Methods We performed a cross-sectional, spatial analysis in this study. We combined data on fish consumption for rural Indonesian coastal households from the Indonesian National Socioeconomic Survey with spatial data on mangrove forest and aquaculture area from the Indonesian Ministry of Environment and Forestry to create a cross-sectional spatial dataset. Using a mixed-effects regression model, we estimated to what extent living in proximity to different densities of mangroves and aquaculture was associated with fresh fish consumption for rural coastal households.

Findings Our sample included 6741 villages with 107 486 households in 2008. The results showed that rural coastal households residing near high-density mangroves consumed 28% (134/477) more fresh fish and other aquatic animals, and those residing near medium-density mangroves consumed 19% (90/477) more fresh fish and other aquatic animals, than coastal households who did not live near mangroves. Coastal households that lived near high-density aquaculture consumed 2% (9/536) more fresh fish, and those that lived near medium-density aquaculture consumed 1% (3/536) less, than other rural coastal households.

Interpretation Mangroves contribute substantially to the food security and nutrition of coastal communities in Indonesia. This finding means that the conservation of mangroves is important not only for carbon storage and biodiversity, but also for the communities living near them. Aquaculture does not appear to offer similar food security benefits.

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Introduction

Mangrove ecosystems provide a range of global and local benefits. They store three to five times more carbon per hectare than other ecosystems;[1] support biodiversity;[2] protect against coastal erosion, floods, and storm surges;[3,4] and support fisheries.[5] However, mangroves across the world are declining rapidly.[6] Indonesia is home to the world's largest mangrove area, but it has also lost the largest mangrove area over the last two decades.[7,8]

Mangrove conservation and restoration have been receiving increasing attention both globally and nationally in Indonesia, mainly because of the implications for climate change mitigation as well as their role in protecting coastlines from erosion, land subsidence, and saltwater intrusion.[9–11] Although the evidence base supporting the environmental importance of mangroves is growing, little is known about their contribution to the food security and nutrition of communities who live near mangroves. A better understanding of this contribution would provide a more complete picture of potential effects of mangrove deforestation and degradation on the health and wellbeing of local communities. In this paper, we focus on the importance of mangrove forests for local food security and nutrition through their role in supporting fisheries throughout Indonesia.

Despite its impressive economic performance over the last two decades,[12] Indonesia faces several nutritional challenges. Although rates of hunger have declined, stunting rates have been high and overweight and obesity have risen to high rates.[13] There are multiple causes of child stunting, but poor-quality diets characterised by low diversity and nutrient-poor foods are a key contributor. Animal source foods (ASFs) are particularly nutrient-rich and have been deemed a priority by nutritionists for improving Indonesian diets.[14] Fish is the most widely

Research in context

Evidence before this study

We used Web of Science, Scopus, and Google Scholar to search for journal articles and grey literature in English on the relationship between mangroves and fisheries from database inception until Jan 1, 2022. The search terms consisted of two parts. The first component captured mangroves ecosystems ("mangroves" OR "mangrove forests") and the second component included terms related to fish and other aquatic animals consumed for food ("fisheries" OR "aquatic foods" OR "blue foods" OR "food security" OR "fish consumption"). We found a total of 65 relevant papers. Most papers focused on the ecology of mangrove habitats for fish and other aquatic animals (n=47), providing evidence to suggest that mangrove ecosystems support fisheries and other aquatic animals. A smaller group of studies focused on ecosystem services derived from mangroves that support fishing livelihoods (n=18). However, we found no studies that had specifically investigated the importance of mangroves for local food consumption, food security, and nutrition.

Added value of this study

This is the first study to our knowledge to provide evidence linking mangroves with the food security and nutrition of mangrove-adjacent communities. We build on previous evidence that mangroves support fisheries by showing that not only do mangroves result in more fish, but also that these fish are widely consumed by coastal households. We estimate the quantitative importance of this contribution of fish from mangroves to coastal household consumption and show that it is quite substantial, and far outweighs the contribution of aquaculture to coastal household fish consumption.

Implications of all the available evidence

There has been increasing awareness about the important roles that mangroves play in carbon storage and in coastal protection. However, the benefits for local stakeholders who live near these mangroves is often overlooked, and because these benefits are diffuse, they might not be readily apparent. This study adds to mounting evidence on the importance of mangroves for fisheries to show that communities who live near mangroves gain an important dietary benefit. In Indonesia, they eat substantially more fish than other coastal households and more fish than households who live near aquaculture. These findings should give local communities an important incentive to conserve mangroves in their area and national policy makers an important additional reason to promote mangrove conservation.

consumed ASF in Indonesia, with an average consumption of 52 g per person per day compared with 31 g per person per day of all other ASFs combined, including meat, eggs, and dairy.[14] Fish and other aquatic animals (FOAAs) contain rich and diverse micronutrients, essential amino acids, and fatty acids important for children's growth and development.[15–18] Aquatic food systems are thus an important source of nutrient-rich foods in Indonesia.

The science of linking mangroves to fish is complex and there is debate in the scientific literature as to how much mangroves contribute to fisheries and through which specific pathways.[19–21] Despite the absence of a consensus on the specific mechanisms linking mangroves to fisheries and their quantitative importance, a global meta-analysis of studies on links between mangroves and fisheries found a substantial association between mangroves and fish catching across a range of countries and regions.[5]

We hypothesised that if mangroves support fisheries, then households residing near mangroves were more likely to consume fresh FOAAs than other coastal households because of the high transaction costs of exchanging these highly perishable foods. Aquaculture is also practiced widely in Indonesia's coastal areas, thus we also explored the contribution of aquaculture to fresh FOAA consumption. We used consumption data from a nationally representative socioeconomic survey from Indonesia and spatial data on mangrove and aquaculture area to test this hypothesis and to see whether households that lived close to mangroves or aquaculture ponds, or both, consumed more fresh FOAAs than other coastal households, controlling for other factors.

Interactions between mangroves and fisheries are biologically complex and, although scientists have made advances in understanding some of these interactions, much is still unknown. Perhaps the most widely accepted link is through the provision of nurseries for juvenile fish, which influences the survival and recruitment rates of individual fish.[22] Previous empirical studies have reported a greater biomass and an abundance of small and juvenile fish in mangrove habitats compared with non-mangrove areas.[23,24] Because of the structural complexity of roots within mangrove forests, these habitats offer places of refuge for young fish against predators,[25] while also serving as fish refugia for larger individuals, including predator species.[26]

Mangroves provide a habitat for aquatic animals within adjacent water columns (estuaries, rivers, and tidal creeks), on (eg, various epifuana) and within (eg, Terebellidae) living mangrove tissues, within associated sediments (meiofauna), and atop both sediments and leaf litter (benthic microfauna and macrofauna).[27] Mangroves have also been found to enhance the quality of nursery grounds in neighbouring seagrass habitats.[28]

Mangroves are also an important source of food for aquatic animals. The main contribution of mangrove ecosystems for fisheries production is likely from the primary productivity of phytoplankton prevalent in mangrove-associated water columns.[29] Mangrove flora themselves serve as both direct and indirect sources of food for various aquatic organisms who graze, scrape, and shred discarded mangrove litter (leaves, twigs, and fruits), which rapidly become colonised with bacteria and other microorganisms.[30] The protrusion of mangrove roots results in the accumulation of particles and leaf litter, which harbour colonies of small invertebrates that feed on these materials.[31] Crustaceans and other benthic organisms benefit from the availability of food resources derived from mangrove detritus and other organic matter, which can contribute to the survival and growth of individuals.[19,32] These species provide food to humans directly, but also indirectly, because other fish also prey on these species,[33,34] some of which are also consumed by humans.

Establishing the effects of mangroves on fish populations is a complex challenge. It is not always simply a matter of whether mangroves are present, but mangrove quality is also important. Local environmental factors influence the growth and quality of mangroves, as well as differences in tidal regimes.[5,35] In addition, the effect of mangrove forests might be affected by adjacent habitats such as seagrass, mudflats, and estuaries,[19,20] making it hard to single out the contributions of the mangrove forests alone. Furthermore, some species are almost exclusively found in mangrove areas, and others use mangrove forests at different stages of their lifecycles, making it difficult to identify which species are dependent on mangroves.[19]

Methods

Study design

We performed a cross-sectional, spatial analysis in this study. Given the biophysical complexities of trying to link individual fish species to mangroves, in this study we looked for indirect evidence of an association between overall fish consumption and mangrove presence. Although many of the species commonly consumed by households in the Indonesia dataset are known to be mangrove-dependent, such as shrimp (*Fenneropenaeus merguiensis* and *Penaeus monodon*), crabs (*Scylla* spp), and some finfish (*Atrobucca nibe* and *Lates calcarifer*), there are many other species for which the degree of mangrove dependence is still unclear. For instance, it is unclear whether populations of blue swimmer crab (*Portunus pelagicus*) in Indonesia have been reduced because of the loss of mangrove habitat (where juveniles spend part of their life history) or because of increased fishing pressure.[36] In addition, the quality of the National Socioeconomic Survey data in terms of species identification is low, because it classifies approximately 20% of fish consumed as other. Additionally, it is common for people to misidentify fish and to use the same local names for different species.[37–39] Furthermore, many species are both grown in aquaculture and can be found in wild mangrove areas. Our strategy was to aggregate all fresh fish together and examine them at a broader level, looking only at coastal areas, and examining whether households that live in areas with more mangroves eat more fresh fish than their coastal neighbours with no mangroves. Instead of focusing on the biological complexities of interactions between mangroves and fish that fisheries scientists and ecologists study at a microscale, we took advantage of our large dataset to explore broad patterns and associations. We focused only on fresh fish because it seems likely that because of their high perishability, there was more likely to be place-based consumption when fish are fresh than when they are dried and can be more easily bought and sold.

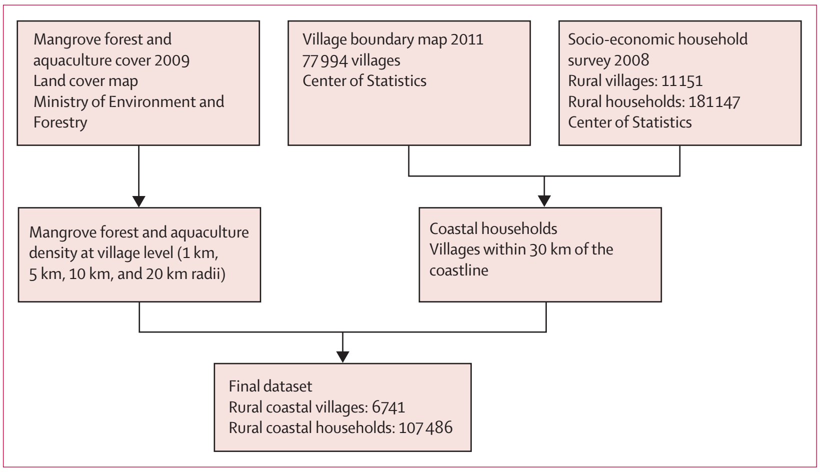


Figure 1: **Visual mapping and description of datasets and spatial information used in this study**

Data

We used socioeconomic and consumption data from the 2008 National Socioeconomic Survey (SUSENAS) of Indonesia, because 2008 was the last year for which village-level identification was possible from SUSENAS data (in later years, the smallest identifiable geographical unit was regency [an administrative division of Indonesia], making it difficult to identify whether a household was near the coast). We then matched the villages from the SUSENAS dataset to maps of villages from the Badan Pusat Statistik (published by Statistics Indonesia) to identify coastal villages. We took a subset of the SUSENAS dataset consisting only of rural coastal villages, which were defined as any rural village within 30 km of the coastline. A visualisation of how we created the sample can be seen in figure 1.

We used land cover maps from the Ministry of Environment and Forestry from 2011 (the year that was closest to 2008 for which land cover data were available) to estimate the area of mangrove forest and of aquaculture. Mangrove forests included both primary and secondary forest classes. Since we had no previous information at what scale mangrove or aquaculture

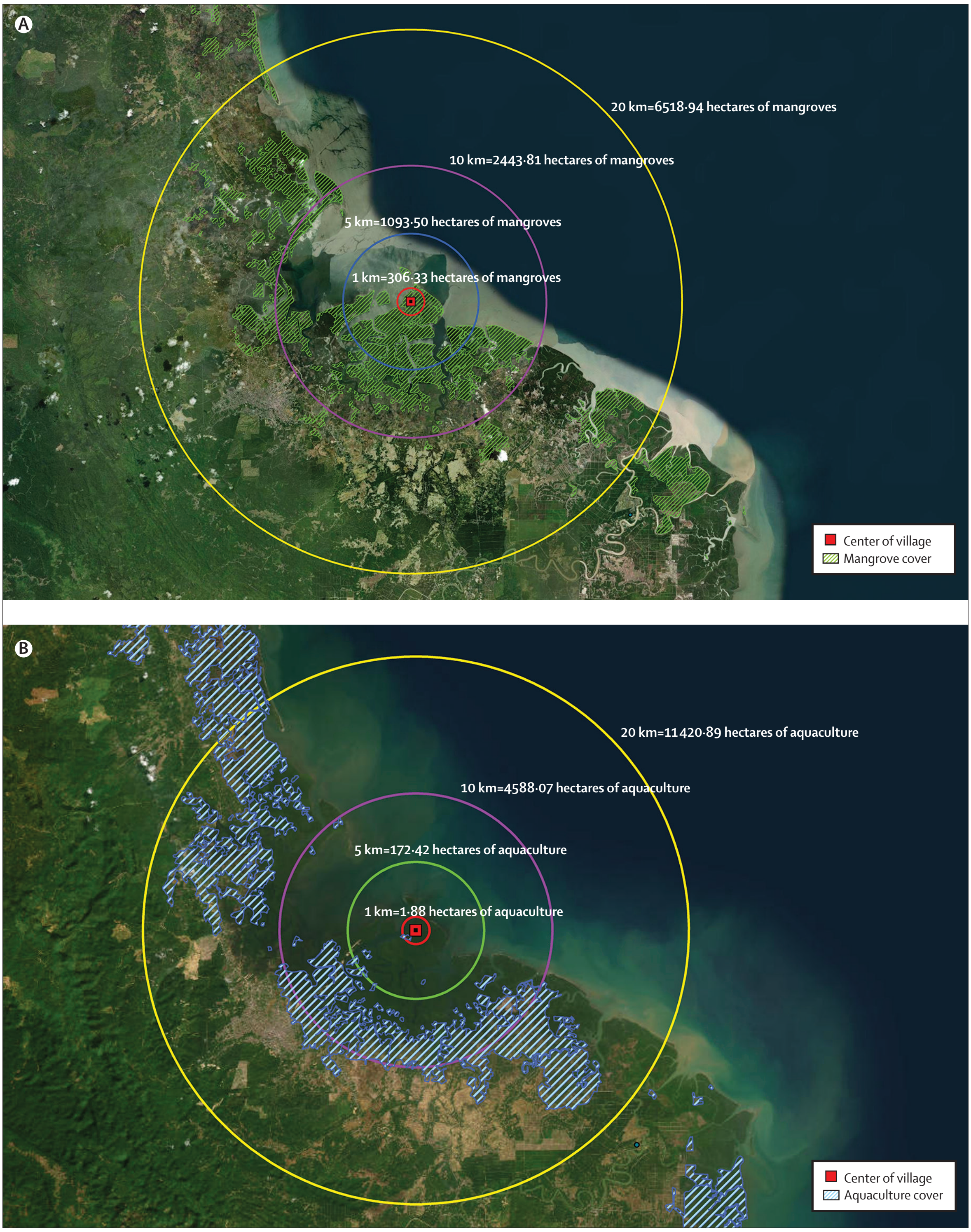


***Figure 2:* Example of different buffers around a village, and estimates of mangrove forest and aquaculture area within each buffer**
(A) Example of estimation of mangrove cover in different distance buffers around one village. (B) Example of estimation of area in aquaculture in different distance buffers around one village. The numbers in the figure correspond to the number of hectares of mangroves or aquaculture within each buffer. For example, there were 306 hectares of mangroves within a 1 km radius of the centre of this village and 1·88 hectares of aquaculture.

density would most affect fish consumption, we drew circular buffers of 1 km, 5 km, 10 km, and 20 km radii around the central point of each village to calculate the area of mangrove and aquaculture at these different spatial scales. Figure 2 shows an example of the different buffers around one village and the estimates of mangrove forest and aquaculture area within each buffer.

Because the distribution of both mangrove forests and aquaculture was highly non-linear (appendix p 2), we classed mangrove forest and aquaculture cover into low, medium, and high categories for each of the buffers by dividing the mangrove forest and aquaculture area distributions into terciles for each buffer. A low density was defined as the bottom third of the mangrove forest (aquaculture) distribution (excluding zero), a medium density was defined as the middle third of the distribution, and a high density was defined as the top third of the distribution.

The SUSENAS data record the amount food items, from more than 200 food items, that were consumed in the respondent's household in the 7 days preceding the survey. For our analysis, we included data on the consumption of various finfish, mollusks, and crustaceans. In total, 13 types of fish and four types of seafood (shrimp, squid, crab, and clams) featured on a predefined list, and other types of fish or species that were not listed, were recorded as other.

We calculated the total consumption of fresh FOAA consumed within each household and then estimated the consumption of FOAA in kg per adult equivalent using information on the individual characteristics of household members. Information on village and household characteristics was used to control for other factors that could influence the amount of FOAA consumed. We calculated the relative wealth asset index of each household using multiple components analysis.[40] The wealth asset index was composed of 15 assets at the household level (appendix p 3). Assets were weighted, standardised, and then summed together at the household level to form an aggregate score. On the basis of the calculated wealth score, households were classed as poorer, middle, and richer (divided based on their wealth asset scores; the top 20% were classified as rich, the second 40% were classified as middle, and the lowest 40% were classified as poor). The table presents the descriptive statistics for the variables used in the analyses.

See Online for appendix

	Outcome across households (N=107 486)
Fish and other aquatic animals consumed,* kg per week	0·53 (0·6)
Mangrove forest	
None	49 808 (46·34%)
Low density	18 901 (17·58%)
Medium density	19 048 (17·72%)
High density	19 714 (18·34%)
Aquaculture	
None	64 021 (59·56%)
Low density	14 278 (13·28%)
Medium density	14 379 (13·38%)
High density	14 808 (13·78%)
Household characteristics	
Number of household members	4·13 (1·82)
Female-headed household (female=1, male=0)	14 303 (13·31%)
Age of head of household, years	46·69 (14·07)
Married head of household (yes=1, no=0)	105 702 (98·34%)
Wealth status	
Poor (lowest 40% of wealth score)	42 894 (39·91%)
Middle (middle 40% of wealth score)	42 582 (39·62%)
Rich (top 20% of wealth score)	22 010 (20·48%)
Agricultural job (yes=1, no=0)	64 084 (59·62%)
Education level	
None	42 203 (39·26%)
Primary	32 177 (29·94%)
Secondary	29 016 (27·00%)
Tertiary	2090 (1·94%)
Distance of household to main road, km	6·58 (15·95)
Distance of household to coast, km	
5 km	40 832 (37·99%)
10 km	62 570 (58·21%)
20 km	90 550 (84·24%)
30 km	107 486 (100·00%)
Percentage of the sample of households from each island	
Sumatra	23 197 (21·58%)
Java	24 575 (22·86%)
Sunda	15 714 (14·62%)
Kalimantan	6663 (6·20%)
Sulawesi	29 302 (27·26%)
Maluku	5053 (4·70%)
Papua	2982 (2·77%)

Data are mean (SD) or %. *Consumption is adjusted to adult equivalent.

Table: **Descriptive statistics for sample of rural coastal households in Indonesia**

Regression analysis

To investigate the association between fresh FOAA consumption and mangrove and aquaculture density, we used a generalised linear mixed effects model, which accounts for the nested structure of the data. Households are situated in villages and villages are located on islands. A mixed-effects model accounts for the fact that the error terms for households within the same island or village might be non-independent because of unobserved factors. Because we included all seven major island groups in the dataset, we used fixed effects at the island level. However, the villages in the dataset are randomly selected by the SUSENAS survey and therefore could be viewed as a sample of a larger group of villages; thus, we used random effects at the village level in our model to account for the potential non-independence of the error terms for households within the same village.

We used the following regression model:

$$f_i = \beta_1 M_j + \beta_2 A + \beta_3 M_j A_j + \beta_4 X_i + \beta_5 r_j + \beta_6 M_j r_j + \beta_7 A_j r_j + \beta_8 c_j + \beta_9 Y + Zu + \varepsilon_i$$

where the dependent variable fi is the amount of fresh FOAA consumed per person in household i over the past 7 days. M is a qualitative variable indicating the density of mangrove forest cover in village j (representing no mangroves, or low, medium, and high mangrove densities), A is a qualitative variable indicating the density of aquaculture in village j (representing no aquaculture, or low, medium, and high aquaculture densities), X is a vector representing household characteristics including gender, age, education level, and marriage status of household head, the wealth status of the household, and the number of members in the household, r represents the distance to the nearest main road from the centre of village j, and c represents the distance to the coast from centre of village j. Y is an island fixed effect, and Zu represents the random effects by village. Both u and ε_i are normally distributed error terms with a mean of 0 and constant variance.

The dependent variable included only fresh fish and aquatic animals because we assumed that because of their perishability, fresh fish were more likely to be consumed locally. We re-ran the model including all types of fish (fresh and preserved) and the results were almost identical, which is probably because preserved fish contributed to only a small proportion of the overall fish consumption in coastal areas (11% of the total). The results from this model can be found in the appendix (p 4).

We ran the model in Stata version 17.0 for each buffer (1 km, 5 km, 10 km, and 20 km) for both mangroves and aquaculture and compared the log likelihood to identify which buffer gave the best fit. The results indicated a buffer of 20 km for mangroves and of 20 km for aquaculture would give the best fit, which is what we then used in the final model.

We included interaction variables between mangrove and aquaculture density and between each of these and household distance to the main road. Mangroves and aquaculture could have ecological interactions in which one affects the productivity of the other, either positively or negatively. Also, the effect of mangroves or aquaculture might affect fish consumption differently depending on how close or far the household is from a market, which is proxied in our model by household distance to the main road.

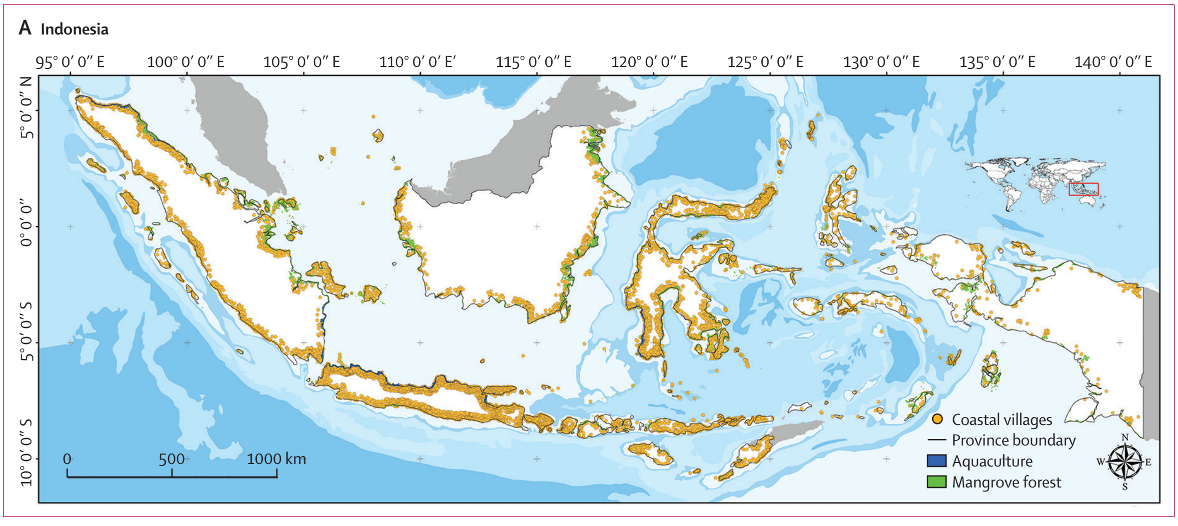
Figure 3A presents a national map of Indonesia showing the locations of the communities in the dataset as well as the location of mangroves and aquaculture. Figure 3B shows the same information, but at the island level. Because of the large differences in geography, ecology, economies, and culture across islands in Indonesia, we also ran the model for the individual islands maintaining random effects at the village level.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Our sample included 6741 villages with 108 894 households in 2008. The results of the model for the national sample of coastal villages can be seen in figure 4. Because the model used interaction effects, the coefficients could



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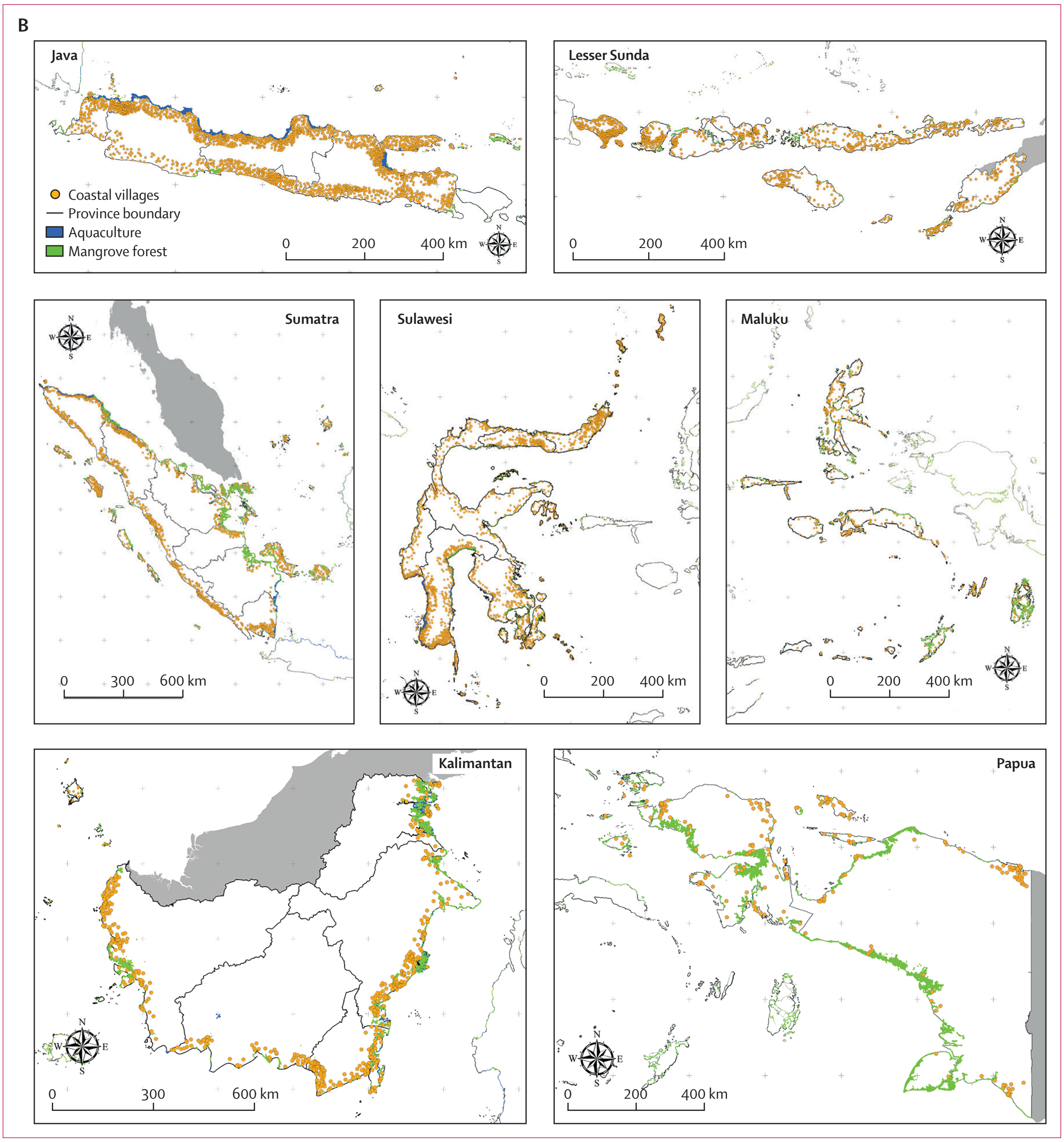

Figure 3: **Map of Indonesia and of major island groupings in Indonesia, showing mangrove forests, aquaculture ponds, and locations of communities included in the study**
(A) Map of Indonesia as a whole. (B) Map of major island groupings.

not be interpreted as marginal effects. We therefore reported the marginal effects of our main variables of interest in figure 4A and the coefficients in figure 4B. A table with the complete regression results can be found in the appendix (pp 5–7).

The results indicated that compared with those living in coastal areas with no mangroves, the presence of low or medium density mangroves was associated with an individual consuming an additional 19% (90/477) of FOAA (or 90 g more) per week. Those living in an area with a high density of mangroves consumed 28% (134/477) more FOAA (or 134 g more) than those living in coastal areas with no mangroves. Living in a village with low density or medium density aquaculture had a small negative association with fish consumption, whereas living near high-density aquaculture was associated with an additional 2% (9/536) of FOAA consumption (or 9 g more) per week.

Higher education was associated with more FOAA consumption; larger households consumed less

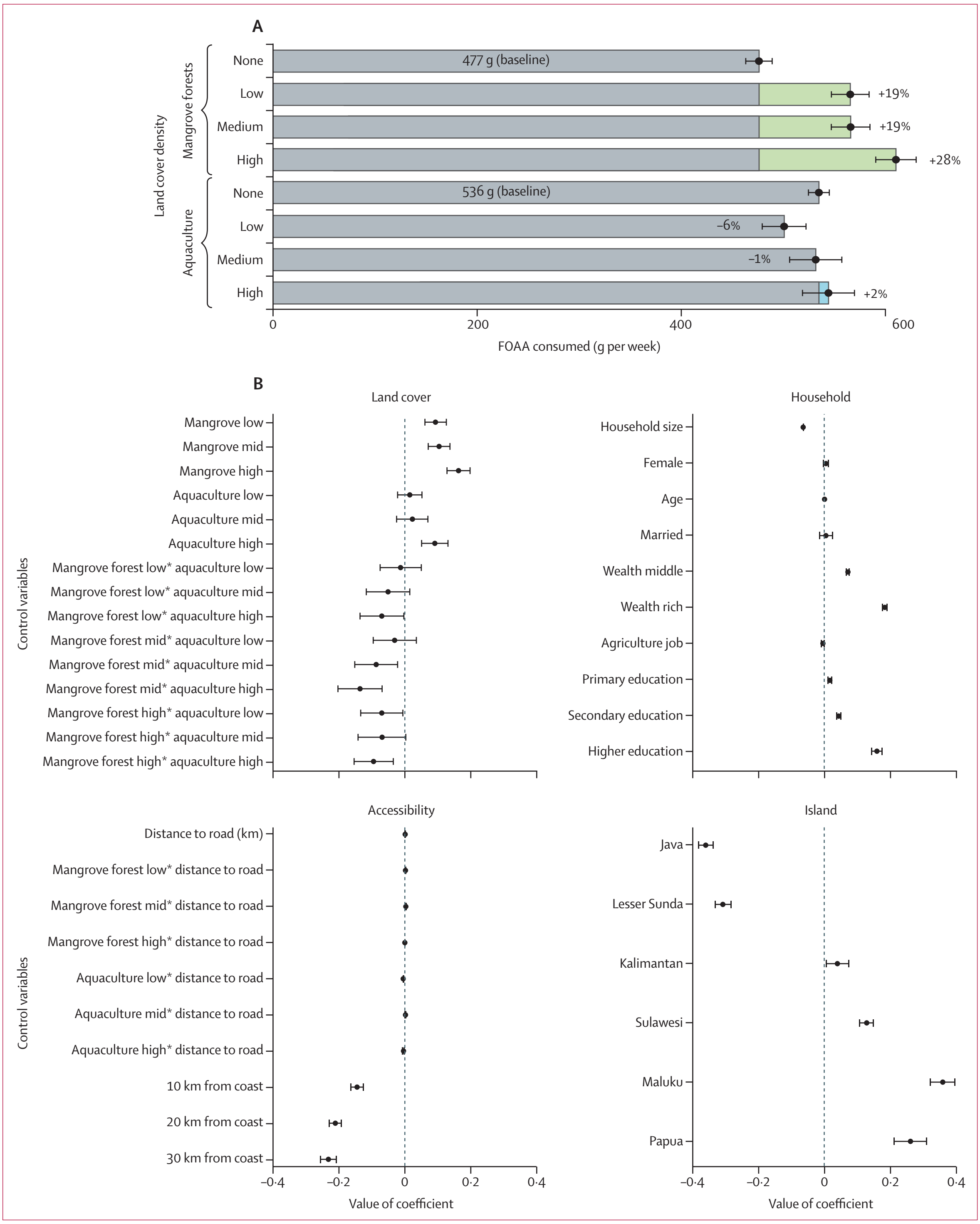

Figure 4: **Results of overall mixed-effects regression model for national sample**

The amount of FOAA consumed by density of mangrove forest and aquaculture compared with baseline (no mangrove forest or aquaculture) from the marginal effects of the model (A), and regression results of all coefficients (B). For land cover, the reference baseline for mangrove forest was no mangrove forest, and for aquaculture was no aquaculture. For household, household size and age were continuous; the reference baseline for wealth was poor, and for education was no education; and other variables were binary. For accessibility, the distance to the road was continuous; the reference baseline for mangrove forest was no mangrove forest, and for each distance from the coast, the reference baseline was 5 km from the coast. For each island, the reference baseline was Sumatra. FOAA=fish and other aquatic animals. *Interaction variables. Error bars represent 95% CIs.

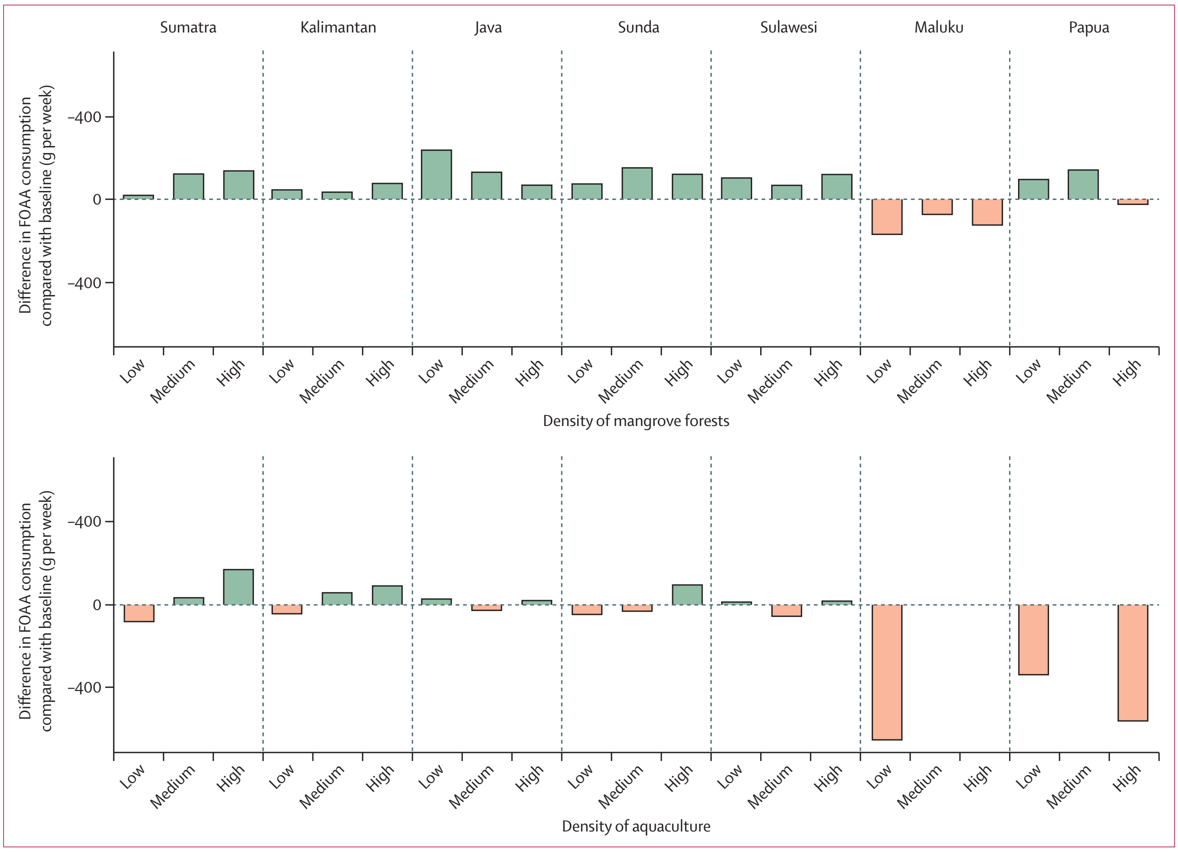

Figure 5: **Difference in amount of FOAA consumed**

Difference in amount of FOAA consumed (g per week) compared with the absence of mangrove forests and aquaculture. These results are derived from a mixed-effects regression model at the island level with random effects for villages. The results for marginal effects and their 95% CIs can be found in the appendix (pp 8–9). Note: interaction effects between mangrove forests and aquaculture were not used for Papua, Maluku, Kalimantan, and Sunda. Because of the small number of households in some of the density classes, marginal effects for these islands were not estimable with interactions. FOAA=fish and other aquatic animals.

FOAA per person; female-headed households consumed more FOAA per person; rich households consumed more FOAA per person than middle or poor households; and households living further from the coast consumed less FOAA per person. The results also highlighted the large differences in FOAA consumption across the various islands; using Sumatra as the baseline, households in Java and Sunda consumed less FOAA, whereas those in Kalimantan, Sulawesi, Maluku Islands, and Papua consumed more FOAA (figure 4; appendix p 2).

Figure 5 shows the differences in FOAA consumption for each land cover density category at the island level based on the marginal effects from the regression results for the mixed-effects model run for each island region. Some densities (low, medium, or high, depending on the island) of mangroves were associated with higher fish consumption for all islands, except for Maluku; and any density more than 0 of aquaculture was associated with higher fish consumption in Sumatra, Kalimantan, Java, and Sunda. The marginal effects for each level and their 95% CIs can be found in the appendix (pp 8–9).

Discussion

Our research identification strategy relied on the following assumptions: (1) that mangroves are important for fisheries; (2) that fresh fish are highly perishable and their exchange in markets entails transactions costs, which increase with distance from the place of capture; and (3) that most of the fresh fish that is consumed in coastal communities in Indonesia will probably be captured locally. Together, these assumptions imply that local conditions—namely, mangroves and aquaculture—will affect local fresh fish consumption. Our finding (figure 4B) that fish consumption decreases with distance to the coast lends support to assumption 3.

The results on the national level regression show quite a large effect of mangroves on fresh fish consumption overall in Indonesia. The average national consumption of fish in Indonesia was 52 g per day in 2016.[14] If we convert the estimates from our model to daily rates, average individual consumption in coastal households was approximately 76 g of fish per day, with those living near low-density and medium-density mangroves consuming an additional 14 g, and those living near high-density mangroves consuming an additional 21 g of fish. Since animal source foods are low in Indonesian diets, these effects are likely to have nutritional significance for households living near mangroves.

It could be the case that higher fish consumption near mangroves is related to the biophysical and geomorphological requirements of mangroves, which exist in calmer, lower energy (waves and currents) settings,[41] which are also conducive to small-scale fishing efforts. However, one study in Indonesia showing a negative effect of mangrove loss on fishing households' income of between 5·6% and 10·0% supports the idea that mangroves in and of themselves are probably beneficial for FOAA.[42]

We included aquaculture densities in the regressions with the hypothesis that aquaculture could both independently affect fresh fish consumption, and also interact with mangroves to affect fish productivity. Aquaculture is often portrayed as an important way to increase the production of fish to boost consumption of these important foods.[43] Additionally, aquaculture has also been one of the main drivers of mangrove loss in Indonesia over the last few decades.[44,45] The results from the national model showed a negative association between aquaculture at low and medium densities on fresh fish consumption and a small positive association on fish consumption at high densities. Note that this does not mean that aquaculture does not have an important effect on overall fish production; it is quite possible that aquaculture ponds produce fish, but that these fish are sold rather than consumed, thus not having an appreciable effect on direct consumption. The income from the fish that are sold could then be used to purchase other ASFs, such as chicken or beef or frozen and preserved fish. To investigate this possibility, we re-ran the model using aggregate per-week ASF consumption in adult equivalent as the dependent variable (all fish plus chicken plus beef), and the results do not support such a narrative; they show that those living near mangroves consumed between 13·0% and 22·2% more ASFs than other coastal households who did not reside near mangroves, and those living near aquaculture consumed either the same amount or 0·3% fewer ASFs than other coastal households not residing near aquaculture depending on density (appendix p 10).

Indonesia is the largest archipelago in the world, spanning 5100 km with many diverse ecological systems.[46] Even though there are mangroves present throughout all of its major islands (figure 3), the types of mangrove systems differ (eg, coastal, estuarine, and fringing), as do other biophysical factors, including the presence of adjacent reefs, seagrass, tidal patterns, and currents. Thus, even when densities of mangrove forest are the same, it is not surprising to see different effects on fisheries between different islands, probably due in large part to other ecological factors. Nonetheless, some ranges of mangrove forest density are associated with higher fresh FOAA consumption in all major island groups, except for Maluku. The absence of a positive association in Maluku might be because of the high relief of the local topography and bathymetry, the proximity of deep near-shore water, and the prevalence of deep-sea fishing in the region.[41,47] The data show that fresh FOAA consumption was by far the highest in Maluku, with the highest proportion of marine fish consumed of all islands. Aquaculture was negatively associated with fresh FOAA consumption at some densities on all islands.

Fish is mostly valued for its protein content but is also rich in micronutrients and essential fatty acids. Marine fatty fish are a well known source of long-chain polyunsaturated fatty acids, especially docosahexaenoid acid, a fatty acid product that has been associated with improved cognitive ability and brain function.[48] Marine fish consumption is associated with higher amounts of docosahexaenoid acid in human blood,[49,50] a lower risk of various health problems,[51–53] and better cognitive scores.[54,55] Consumption of fish has also been positively associated with the nutritional status of children, with a study in Zambia finding that children aged 6–23 months who consumed fish were less likely to be stunted.[56] Thus, a higher consumption of fish in areas with high mangrove density in Indonesia not only contributes to greater food security, but also probably contributes to better nutrition and the health of the communities that live near them.

This study has several limitations. Because it is a cross-sectional study, we are only able to estimate the association between mangrove cover and fish consumption, and not causality. Although pooling all the data on FOAA together provides a broad view of the relationship between mangroves and fish consumption, more could be learned by doing a similar analyses at a species level.

In addition, because of the limitations of our dataset, we were only able to include mangrove forest cover in our model, but not other geographical and ecological features that might be important, such as the presence of reeds, mudflats, wave intensity, and currents. Similarly, the data on aquaculture only shows the area under any form of aquaculture, but not what kind of aquaculture is practiced, in terms of species, techniques, or whether it is aimed at export or domestic markets. It is possible that some types of aquaculture have more positive effects on local consumption than can be seen with our data.

The data that we used on mangrove and aquaculture cover is not from the same year as the data on fish consumption; there is a 3-year gap, since neither dataset is collected annually. In addition, since the dataset is from more than a decade ago, it is possible that the relationships have changed over time. For example, as infrastructure has improved in Indonesia, it is possible that coastal communities might become more reliant on purchased ASFs that originate from longer distances and might be consuming fewer locally sourced foods. This study could provide a useful baseline for future research to examine how the influence of mangroves on food consumption might have changed over time.

Over the last decade, there has been increasing interest in Indonesia in conserving and restoring mangrove ecosystems both from the government sector and among non-governmental organisations.[11] With the adoption of Presidential Regulation 120/2020, expanding the Peatland Restoration Agency to the Peatland and Mangrove Restoration Agency, the Government of Indonesia has committed to restoring 600 000 hectares of mangrove forests by 2024, increasing the protection of existing mangroves, resolving coastal land tenure issues, and producing national policy reform around mangrove management.[57] Most of the discussions around these activities have focused on the contribution of mangroves to mitigate climate change through carbon sequestration and storage. Mangroves store more carbon than almost any other terrestrial ecosystem and can thus benefit not only Indonesia, but also the global community.[58] Although this is undoubtedly an important benefit, its importance for local communities living near mangroves is negligible. However, what we have shown here is that mangroves also have important benefits for communities who live near these ecosystems and who are often called on to protect them. The results from our analysis show that the communities who live in proximity to mangroves consume more ASFs than other coastal households in Indonesia because of their higher consumption of fresh fish. This result is statistically significant, and also of real quantitative importance, with individuals living near mangroves consuming 19–28% more fresh fish than other coastal households and 13–22% more ASFs in total. Mangroves play an important role in the food security and nutrition of the communities who live near them. Recognising this contribution and making it visible to all stakeholders can give local communities and local governments another important reason to protect them.

Contributors

AI conceived the study, developed the methods, and carried out the regression analysis. ML carried out the literature review, contributed to the methods development, and created the visualisation of the study mapping and the results. AMM created the dataset by merging data from the Indonesian National Socioeconomic Survey and spatial data from the Indonesian Ministry of Environment and Forestry and created the spatial buffers connecting the households with spatial features; and also created the maps and the visualisations of the spatial data. AI led the drafting of the original manuscript with contributions from ML, MN, AMM, and BMB. All authors reviewed and edited the manuscript, and all approved the final draft. AI and ML accessed and verified the underlying data reported in the manuscript.

Declaration of interests

The authors declare no competing interests.

Data sharing

To create the dataset used in this study, we merged data from the 2008 Indonesian National Socioeconomic Survey (SUSENAS) with data on land use from the Indonesian Ministry of Environment and Forestry (KHLK). We are not legally allowed to share the SUSENAS data, but it can be purchased from the Indonesian National Statistics Bureau on this website: https://silastik.bps.go.id/v3/index.php/site/login/. The KHLK data on land cover are available here: https://geoportal.menlhk.go.id/Interaktif/.

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