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A SOURCE–SINK ASSESSMENT OF SMALL-SCALE MARITIME VESSEL EMISSIONS AND MANGROVE CARBON STOCKS IN VANUA LEVU, FIJI.

CONTEXT

Worldwide, many countries have announced their intention to become carbon neutral by the period 2050-2060. Island archipelago nations such as Fiji heavily utilize maritime inter-island vessels. This activity generates substantial carbon dioxide that pollutes the atmosphere. With Fiji's diverse natural resources, mangrove forests could be used as a potential Nature-Based Solution (NBS) for sequestering CO_2 emissions from maritime vessels.

In this study, we aim to:

1. Estimate the quantity of anthropogenic greenhouse gas emissions (GHG) in Macuata and Bua Provinces originating from maritime (small boat) transportation that can be sequestered by mangroves;

2. Calculate carbon stocks in blue carbon mangroves within the Bua and Macuata Provinces

Figure 1 Map showing the surveyed villages in the Northern Division.

In Pacific Island Countries, fisheries are very important for livelihoods and food security, with fish consumption often exceeding 50 kg per person per year (Pratchett et al., 2011). In countries like Fiji, fishing activities depend heavily on fuel-powered boats, including for fisheries such as sea cucumber harvesting (Purcell et al., 2018). Improving fuel efficiency is important for both economic and environmental reasons. Many small-scale fishers use fuel daily, and high fuel cost can reduce household income. Good engine care, right boat speed, and good trip planning can help reduce fuel use and pollution (Gulbrandsen, 2012; Sterling & Goldsworthy, 2006). However, emissions from fishing vessels remain a major cause of concern and can be potentially offset through carbon sequestration in mangrove forest ecosystems.

Mangroves are among the most carbon-intensive ecosystems worldwide, with over 3 to 5 times higher carbon densities than most upland terrestrial forest ecosystems (Wang et al., 2025). Despite making up less than 1% of the world's tropical forest area, they contribute to more than 3% (24 Tg C/y) of the global carbon sequestration within the tropical forest biome (Bhomia et al., 2016).

Fiji has the third-largest mangrove cover in the Pacific, with over 90% of the forests concentrated along the coasts of the two major islands of Viti Levu and Vanua Levu (Cameron et al., 2021). Mangrove forests are, however, under growing pressure from both natural and anthropogenic stressors. Between the period 2001 and 2018, the country lost an estimated 1135 ha primarily due to tropical cyclones (Cameron et al., 2021), agriculture expansion, and infrastructure development (Avtar et al., 2021). Protecting and restoring mangroves in coastal areas such as Macuata and Bua can support fisheries, reduce carbon emissions, and improve food security.

Current climate and energy policies in Fiji mostly focus on cutting emissions from electricity, transport, and other big sectors. However, emissions from small-scale fishing are not given much attention, even though many coastal communities rely on fuel-powered fishing boats for daily living. In addition, there remains limited research on the potential of mangrove forests to offset carbon emissions from maritime vessels, despite their coexistence within the same coastal marine ecosystem.

This policy brief presents findings from a study done in Bua and Macuata provinces. The research looked at fuel consumption in fishing boats, greenhouse gas emissions, and energy use in fishing households. It examined the social and economic conditions of these communities and how they access lighting and cooking energy. In addition, the aboveground, belowground, and soil carbon stocks of mangrove forests were assessed in the two provinces.

Methodology

The study used a mixed-methods approach, with data collected from October to December 2024. Data were collected from 58 fishing boats using questionnaires and field observations. Information on engine size, fuel use, fishing activities, and household energy access was gathered. Emissions from small boats were estimated using IPCC 2006 default emission factors.

Square plots of 10m by 10m were placed at 10m intervals along a 100m transect that was laid perpendicular to the water edge. In each plot, tree diameter at breast height (dbh) was measured, trees, saplings, and seedlings were counted, and soil samples were collected at two depths (0-40 cm and 40-100 cm). Carbon stocks were determined using species-specific allometric equations. Overall, the results provide useful evidence that can inform policies aimed at improving fuel efficiency, supporting sustainable fisheries management, mangrove conservation and enhancement, and reducing emissions in coastal communities.

Key Findings

Socio-economic characteristics

Fishing emerged as a dominant livelihood activity for both provinces (Bua – 94% of household income and Macuata – 91% of household income).
Boat operators in both provinces were mostly middle-aged men, married and taking care of big households. This shows the strong role of men in fishing with boats and the importance of fishing for family likelihoods.
Average monthly income for households in Macuata province was FJ$804, but in Bua it was FJ$630. This difference may be because Macuata has more diversified income sources than Bua.

Energy access

None of the Bua province households had access to grid-connected electricity (EFL). 95.5% of households here have solar home systems (SHS), while another 4.5% have solar minigrids (See Table 1). For Macuata province, 66% of households have EFL, while the rest have SHS. There are no solar mini grids.

For lighting, Bua province has Solar Torch, Solar lantern or battery-operated torch. For Macuata province, the majority have electric tube lights and energy savers or LED lights as households have grid-connected electricity.

Interestingly, both provinces' households (91% in Bua and 86% in Macuata) use 3-stone stoves for all primary cooking.

TABLE 1: ENERGY ACCESS FOR BOAT OWNERS

VARIABLE	BUA (N=22)	MACUATA (N=36)
Electricity source – Grid (EFL) (%)	0	65.7
Electricity source – Solar Home System (%)	95.5	34
Solar mini-grids (%)	4.5	0
Primary cookstove – 3 stone fire (%)	90.9	86.1

LIGHTNING TYPE	BUA (N=22)	MACUATA (N=36)
Solar Torch (%)	77.3	27.8
Battery-operated Torch (%)	45.5	25.0
Electric Tube Light (%)	0.0	63.9
LED / Energy Saver Bulb (%)	9.1	50.0
Solar Lantern (%)	77.3	33.3

Boat Emissions

Majority of surveyed boats (91.38%) were used mainly for fishing. Only a small proportion were used for passenger transport only (3.45%) or for both fishing and passenger transport (5.17%).

On average, the annual fuel consumption of boats in Bua is 2,800 liters while in Macuata it is 3,300 liters per year per boat. Average yearly emissions were 7.63 tCO_2-e per boat in Macuata and 6.47 tCO_2-e in Bua. Out of the 58 boats surveyed, the total emissions were 444 CO_2-e each year. On average, each boat emitted about 7.65 tonnes of CO_2-e yearly.

Based on Maritime Safety Authority (MSAF) data, there are 504 registered small boats in Northern Division. Using an average emission of 7.65 tCO_2-e per boat per year, total emissions for the Northern Division are estimated at 3,856 tCO_2-e (3.86 thousand tonnes). This accounts for approximately 1.63% of total maritime transport emissions reported in Fiji's NDC 3.0 (GoF, 2025).

Most fishing boats in both provinces used 40 HP engines, so this was the most common engine size. In Bua, around 68% of the boats had 40 HP engines. In Macuata, about 92% of the boats used 40 HP engines. Average engine size in Bua was about 32.5 HP, while in Macuata it was about 39.2 HP. This shows boats in Macuata had slightly bigger engines compared to Bua.

Carbon stocks of mangrove forests by provinces

Carbon stocks were generally higher for the mangrove forests of villages in Bua compared to those in Macuata province. Mean aboveground carbon (AGC) was

96.18±27.18 t C/ha in Bua and 7.50±6.03 t C/ha in Macuata province, while belowground carbon (BGC) stocks were 71.25±20.74 t C/ha and 4.11±3.06 t C/ha, respectively. Likewise, mean tCO_2-e values for both aboveground and belowground components were higher in Bua (352.96±99.77 tCO_2-e/ha and 261.49±76.13 tCO_2-e/ha) than in Macuata (27.52±22.14 tCO_2-e/ha and 15.09±11.24 tCO_2-e/ha).

Soil carbon stocks were comparable between the two provinces, with mean values of 1986.79±219.86 tCO_2-e/ha in Bua and 1934.62±167.61 tCO_2-e/ha in Macuata. In both provinces, soil carbon density increased with depth (233.24±52.92 t C/ha in Bua and 204.14±54.41 t C/ha in Macuata in the 0-40 cm layer, and 308.12±24.83 t C/ha in Bua and 323.01±70.74 t C/ha in Macuata in the 40-100 cm layer).

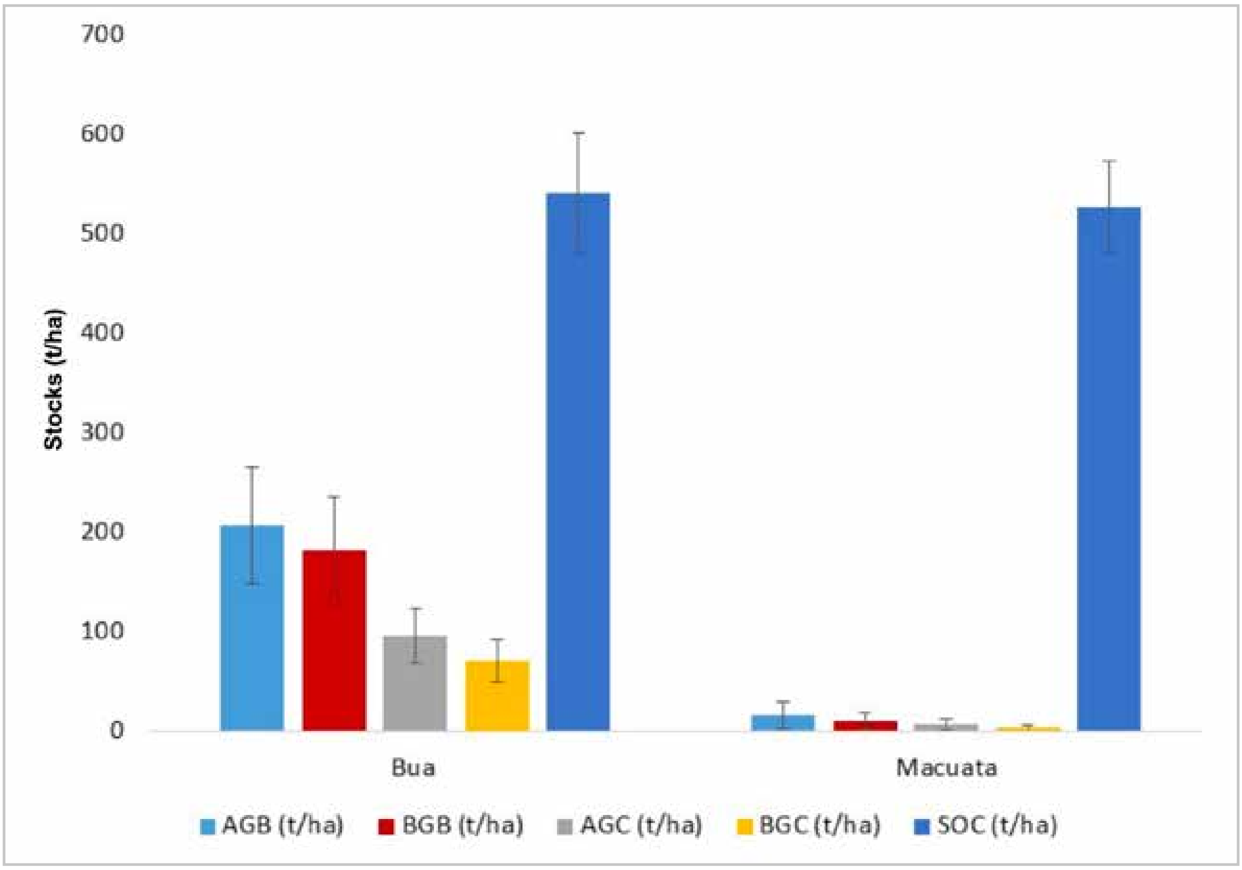

Figure 2 Biomass and carbon stocks of mangrove forests in Bua and Macuata

Carbon stocks of mangrove forests by species

Bruguiera gymnorhiza exhibited structural dominance in the mangrove forests with the highest basal area (20.05 m^2/ha) and tree density of 338.33 ind/ha. Individual species' contributions to carbon stocks were highly skewed. Over 93.2% of the total CO_2-e in the mangrove forests came from *Brugiera gymnorhiza*, which was followed by *Rhizophora stylosa* (4.5%) and *Rhizophora samoensis* (1.4%). *Milletia pinnata*, *Excoecaria agallocha*, and *Xylocarpus granatum* each contributed less than 1%, while *Barringtonia asiatica* and *Inocarpus fagifer* accounted for near-zero (0-0.01%).

B. gymnorhiza recorded a carbon stocks of 190.93 tCO_2-e/ha aboveground and 142.21 tCO_2-e/ha belowground. In contrast, relatively common mangrove species in Fiji and the Pacific, *R. stylosa* and *R. samoensis*, had much lower carbon densities (R. *stylosa* with 10.66 tCO_2-e/ha aboveground and 5.31 tCO_2-e/ha belowground, and R. *samoensis* with 3.23 tCO_2-e/ha aboveground and 1.80tCO_2-e/ha belowground).

Policy Recommendations

Based on the findings, the following recommendations are made:

1. Solar Mini-Grid Development for Remote Communities

Given the current energy access status, it is strongly recommended that solar mini-grids be installed for households in Bua. This system can also provide charging opportunities for electric outboard motors.

2.Assessment of Clean Cooking Technologies

More research is needed to understand how fishing communities use cooking energy. Clean cooking technologies suitable for places like Macuata and Bua should be studied so households can use cleaner energy instead of traditional fuels. As part of introducing clean technologies in communities, training programmes for users need to be included in the project/programme to ensure the project's longevity and sustainability.

3.Exploring Electric Fishing Boat Technology

The feasibility of using electric fishing boats should also be studied. A good example is the SPC project in Nausori where a village received an electric outboard motor that is charged using solar energy (SPC, 2022).

4.Including Artisanal Fisheries in National Emission Inventories

The national greenhouse gas reports in Fiji ought to incorporate emissions of small artisanal fishing boats. This can be used to enhance climate reporting and good policy planning.

5.Training Programs for Fuel-Efficient Fishing Practices

The support of government agencies should be applied in the form of training programs aimed at educating fishers on how they can maintain their boat engines, apply proper boat speed, and organize fishing trips more efficiently. Such measures can serve to minimize the use of fuel and also minimize emissions.

6.Protect high-biomass mangrove forests

Prioritize mature, carbon-rich mangrove forests like those of *B. gymnorhiza* in Bua province for conservation. Such forests can be designated as community-based protected areas to prevent logging, agriculture, and coastal development.

7.Restore degraded mangrove sites

Target areas with low tree density and regeneration, such as those in Macuata, for restoration. Planting native species, such as *Rhizophora*, where it grows best, and high-biomass species like *B. gymnorhiza*, where conditions allow, can enhance carbon sequestration benefits.

8.Integrate traditional and modern management

Integrate local ecological knowledge (*taboo* areas, *qoliqoli* stewardship) with scientific restoration, monitoring, and carbon accounting to enhance conservation outcomes.

9.Provide community incentives

Support alternative livelihoods and clean energy (solar, biogas) while linking mangrove conservation and enhancement to Payment of Ecosystem Services (PES) schemes, such as REDD+, which can reward good forest management practices.

10. Strengthen monitoring

Fuel use and emissions from small fishing boats should be checked regularly. Monitoring this can help the government understand energy use and make better plans for climate and fisheries management. Establish a national mangrove monitoring program to track forest structure, carbon stocks, and restoration success, guiding effective management decisions.

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The policy brief can be cited as: Prasad, R.D., Shah, S., Jreeta, Naikoyadai, V., Tamanitokula, A. (2026). Policy Brief No. 1 A source–sink assessment of small-scale maritime vessel emissions and mangrove carbon stocks in Vanua Levu, Fiji,