Fishery Technology 61 (2024) : 335 - 341

Assessment of Life Cycle and Environmental Impact Hotspots Associated with the Construction and Disposal of Fiberglass Reinforced Plastic Fishing (FRP) Boats in the Small-Scale Fishing Sector of India

Sreejith S. Kumar[1,2], Dhiju Das P. H.[1], Paras Nath Jha[1], M. V. Baiju[1], Leela Edwin[1] and Manju Lekshmi N.[1*]

[1] *ICAR-Central Institute of Fisheries Technology, P. O. Matsyapuri, Willingdon Island, Cochin - 682 029, India*
[2] *Kerala University of Fisheries and Ocean Studies, Panangad, Kochi, India*

Abstract

Fiberglass reinforced plastic (FRP) is a durable thermosetting plastic widely used in small-scale marine boat building. The average life span of FRP sheathed boat is seven years, while that of FRP boat is 30 years. Once their service life ends, these boats are mostly abandoned in the coastal areas, leading to significant environmental harm. Life Cycle Assessment (LCA) evaluates a product's entire life cycle, from raw material production to disposal, covering all intermediate stages. This study examines the LCA of boats made from FRP as a primary material and the wood/plywood boats sheathed with FRP, along the coast of Kerala, focusing on construction, use, maintenance, and disposal phases. The carbon footprint of FRP boats during their life cycle is 35.31 kg CO_2 equivalent, which is considerably lower than the 63.01 kg CO_2 equivalent for sheathed boats when normalised for a period of one year. Although FRP boats, require 2.4 times more materials like glass fibers and resins for construction than sheathed boats, their overall environment impact is lower due to their four times longer lifespan. The LCA findings show that resin compounds as the major contributors to environmental impacts. The study evaluated boat disposal methods in India, revealing that open burning of FRP boats generates 1253.58 kg CO_2 equivalent, while landfilling reduces it to 1065.3 kg CO2 equivalent, both posing environmental risks. In contrast, sheathed boats produce a much lower carbon footprint of 77.70 kg CO_2 equivalent when landfilled but have a substantially higher footprint of 596.67 kg CO_2 equivalent when burned. The results underscore the pressing need for sustainable disposal methods for the end-of-life FRP fishing boats to minimize ecological damage. The results of the study also highlight the importance of material selection and waste management in reducing the environmental footprint of boat construction and disposal. These insights are crucial for promoting sustainability in small-scale boat-building yards, offering a path forward for the industry to reduce its environmental impact while maintaining the durability and longevity of the fishing boats.

Keywords: Fibre-glass reinforced plastic, end of life boats, life cycle assessment, environmental impacts, carbon foot print

Introduction

Fishing fleets of India are classified into mechanized, motorized and non-motorized, in which small-scale fisheries sector operate both motorized and non-motorized. Boats having length 5-14 m which are either motorized or non-motorized falls under small-scale fishing crafts (McVeagh et al., 2010). The small-scale fisheries sector accounts for around 81% of India's total fisheries. These fisheries play a critical role in supporting coastal communities by contributing a significant portion of their livelihood income (CMFRI, 2017). In the small-scale marine fishing sector of India, Fiberglass reinforced plastic (FRP)is the predominant boat building material. FRP is a thermosetting plastic that utilizes

Received 5 July 2024; Revised 7 October 2024; Accepted 9 October 2024

*Email: manjulekshmi.n@icar.gov.in

glass fibers as a reinforcing material and is widely used across different production sectors for its robustness, stiffness, corrosion resistance, relatively low production and maintenance costs (Arduini, Di Tommaso, & Nanni, 1997; Grause, Mochizuki, Kameda, & Yoshioka, 2013). Its application in the global marine boat-building sector has been particularly significant for over 70 years, replacing wood as the primary material due to its superior resistance to physical, chemical, and biological damage (Pauchard, Chateauminois, Grosjean, & Odru, 2002; Guersel & Neser, 2012; Sunardi, Sukandar, Sulkhani, & Rahman, 2019).

FRP is used either as a primary construction material for boats which are found to have an average service life of more than 30 years (Eklund, Haaksi, Syversen, & Elsted, 2013) or as a laminate over wood with a service life of seven years or less (Baiju, Edwin, Pravin, Meenakumari, & Baiju , 2013; Lekshmi et al., 2023 b).The number of abandoned FRP boats in the marine environment has been increasing globally due to limited guidelines and regulations on disposal and lack of practical alternatives for recycling or reuse (Eklund et al., 2013; Somarajan, Kodungallur, & Nandakumar , 2018; Lekshmi et al., 2023a). The abandoned FRP boats in the marine environment cause various environmental impacts, including habitat loss, debris accumulation, chemical pollution, and navigational hazards (Turner & Rees, 2016). As a thermoset composite, the weathering of FRP acts as a source of marine plastic debris and ultimately, breaks down to microplastics, which, pose dangers to aquatic flora and fauna (Song et al., 2014; Belioka & Achilias, 2023). Improper disposal, such as landfilling/burial and open burning generates harmful persistent organic pollutants (POPs) like dioxins and furans, and releases heavy metals like copper and lead into the marine ecosystem (Lekshmi et al., 2023b).

Life Cycle Assessment (LCA) is a valuable tool that considers all the phases of a product's life, including raw material production, manufacturing, distribution, use, and disposal, along with all intermediate steps. According to ISO 14040-14044 standards, the primary objective of LCA is to facilitate the comparison of environmental performance of different products, helping to identify the best options for mitigation measures against pollution (ISO, 2006).

There is limited research on the impact of FRP debris from abandoned boats entering the marine environment during various phases of their life cycle, including construction and disposal. Therefore objective of the study is to assess the environmental impacts of FRP fishing boats using life cycle assessment (LCA), by examining different stages such as construction, use, maintenance, repair, and type of disposal. It compares the life cycles and impacts of two types of FRP boats in India's small-scale fishing sector: those made entirely of FRP and those laminated with FRP over wood or plywood, since data from studies like this is essential to develop scalable and economically viable recycling or repurposing methods for FRP materials in the fishing sector.

Materials and Methods

A pre-structured questionnaire, was used for collecting data on materials and quantities used, and also the details of construction of two types of boats, used for comparison. Data was collected between 2021 and 2023 from different categories of boat-building yards, including commercial, cooperative, and small-scale backyards, as well as from fishers, boat owners, and cooperatives along Kerala coast. The data collected included details of material flows, energy usage, and other factors at the boat building yards throughout the construction phase. This information was used as the inventory data for the construction phase of LCA analysis.

A representative size class of 7m L_{OA} (length Overall) boat was selected for the LCA analysis, since majority of the abandoned FRP fishing boats belongs to 7m L_{OA} in the marine environment along the Kerala coast (Fig. 1) (Lekshmi et al., 2023 b).

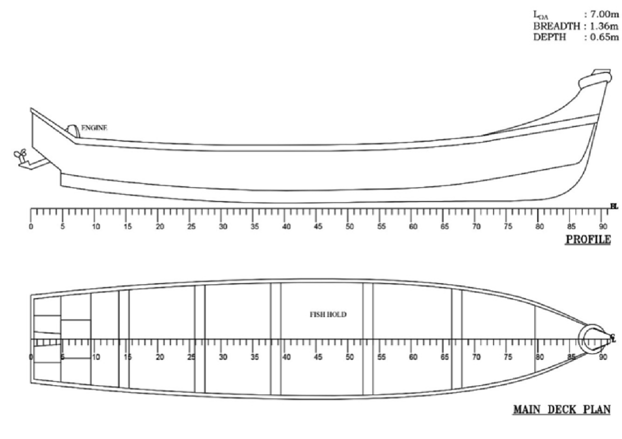

Fig. 1. Typical motorized 7m fishing boat deck layout

The LCA analysis involved three phases of the life span of the boat *viz.*, construction, usage including maintenance & repair and the disposal (Fig. 2). For the disposal of abandoned FRP boats, two common methods viz., landfilling or burial in beach soil and open/backyard burning was observed. Landfilling refers to the process of crushing the end-of-life boats and burying them in soil. Open burning, on the other hand, involves the uncontrolled combustion of the boats without any form of energy recovery (generation of heat or electricity from burning) or controlled emission procedures. These two scenarios were separately analysed in this study to determine their adverse environmental impacts on the marine ecosystem, simulating actual conditions.

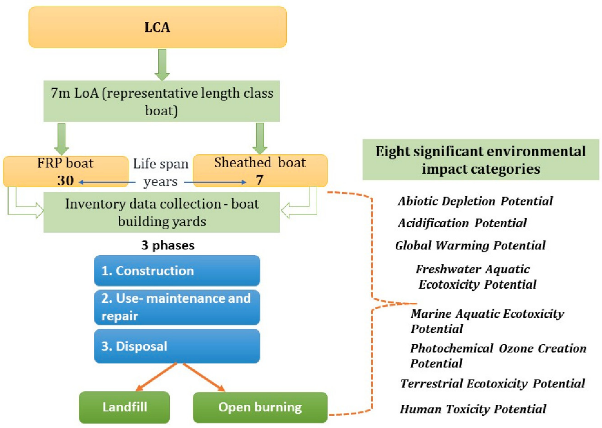

Fig. 2. Flow chart showing the flow of analysis for LCA

GaBi (Ver:6.0); which employs a variety of methods and databases to perform LCA analysis was used. The impact assessment was conducted using the CML method developed by Centre of Environmental Science, Leiden University Netherland, which translates emissions and resource use throughout the life cycle into impact scores for various environmental categories. The analysis considered the inputs and outputs of boats during their construction, use, and disposal stages. Often termed as "cradle to grave" approach, to understand the environmental consequences associated with construction and disposal practices of the abandoned boat (Fig. 3).

Eight key environmental impact categories were selected for the LCA during the construction, operation, maintenance, repair, and disposal phases of fishing boats. These include abiotic depletion potential, acidification potential (assessing the release of pollutants causing acid rain and ecosystem damage), global warming potential (measuring greenhouse gas emissions), marine and freshwater aquatic ecotoxicity potential (evaluating the toxic effects on marine and freshwater ecosystems), photochemical ozone creation potential (focusing on pollutants contributing to ground-level ozone formation), terrestrial ecotoxicity potential (assessing the impact on soil and wildlife), and human toxicity potential (quantifying the health risks from exposure to toxic substances) (AlShafi & Bicer, 2021).

The environmental potentials for the construction, maintenance, and disposal of a FRP boat was assessed over a lifespan of 30 years, denoted as X kg equivalent. For a sheathed boat, the environmental potentials are evaluated over a shorter lifespan of 7 years, denoted as Y kg equivalent. To compare the emissions on an annual basis, the environmental potentials for the FRP boat would be X/30 kg equivalent per year, while for the sheathed boat, it would be Y/7 kg equivalent per year.

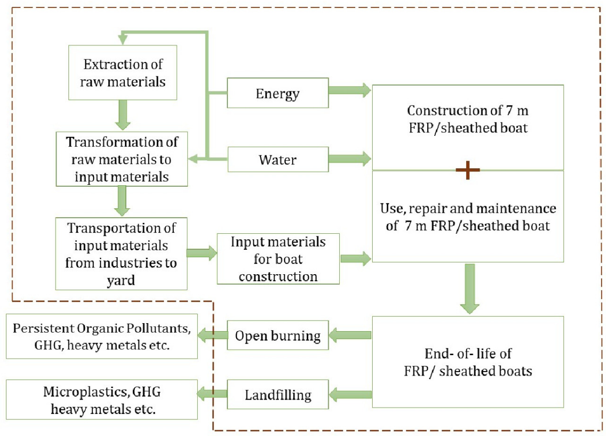

Fig. 3. Representation of the system boundary used for the study

Results and Discussion

Data pertaining to the analysis were collected from 10 different boat building yards in Kerala, including commercial, cooperative, and small-scale backyards yards. All the yards were equipped to construct boats using either FRP as the primary material or as a laminate over wood/plywood. In most yards, boats are constructed using the hand layup method, in which the glass mat layers are placed by human labours and the resin is applied using roller after placing of each glass mat layer. The design, quality and quantities of materials used are based on the preferences and decisions of the individual boat owner, leading to notable variations from yard to yard. Therefore, to ensure a comprehensive analysis, mean values of the data on the quantity of materials from each boat-building yards were calculated and used as input for inventory analysis (Table 1). This approach allows for a more accurate representation of the typical characteristics and construction practices (Table 1). To ensure the accuracy of this data, it was cross-checked with the existing literature. (Anmarkrud, 2009; Du Plessis, 2013; Das & Edwin, 2019).

Table 1. Inventory details of FRP and FRP sheathed boats

Item	Units	FRP	Sheathed
Glass mat CSM	Kg	22	9
Glass mat WR	Kg	15	7
Epoxy Resin	Kg	66	30
Gel coat	Kg	12	2
Pigment	Kg	1.2	0.5
Accelerator	Litre	2	0.8
Catalyst	Litre	0.2	0.08
Acetone	Litre	3	2
Electricity	KWH	2	1
Fresh water	Litre	50	50
Chalk powder	Kg	70	20
Wax	Kg	1	0
Wood	Kg	0	60
Copper nail	Kg	0	7
Paint	Litre	0	10

In FRP boat construction, glass fibers are utilized in the forms of chopped strand mat (CSM) and woven rovings (WR). The specifications for CSM include options like 300 and 450 GSM (grams per square meter), while WR as 610 and 900 GSM. The bonding agent for the glass fibers are either epoxy or polyester resin. This resin is combined with a catalyst and an accelerator before being applied over the glass mat layer using a roller.

Typically, the quantity of resin used is 1.8 times the amount of the glass mat. The curing process takes on an average 8 to 10 hours. Chalk powder is added to the resin as a filler, and wax is used as a releasing agent from the mold. For the outer layers, a gelcoat—a resin with a glossy finish mixed with pigment is applied. Acetone and fresh water are used for washing and cleaning purposes throughout the construction process. Energy consumption in boat building primarily involved electricity for lighting and operating small equipment used for cutting and shaping materials and all of these factors were considered for the analysis.

Primary observations and survey results showed the average lifespan of an FRP boat is around 30 years, while that of the sheathed boat was about seven years. The sheathing process involves applying a thinner layer of glass mat and woven rovings, primarily served as a protective coating rather than a core structural component in sheathed boats. The inventory analysis reveals that FRP boats require significantly more reinforcing materials, including 2.3 times more glass mat and woven rovings and 2.4 times more resin compared to sheathed boats. These materials are extensively used to increase strength and durability, resulting in a more robust structure capable of withstanding harsher conditions and offering a longer lifespan. This coating also provides necessary protection to the underlying structure, which is mostly wood or plywood, but does not contribute as significantly to the overall strength and durability as full FRP boat construction does.

FRP boats, with high material strength, typically require less frequent maintenance compared to FRP sheathed boats (Lekshmi et al., 2023b), which need a more regular maintenance to maintain the protective FRP layer. However, the extended lifespan of FRP boats (ie., 4 times) helps to mitigate their overall environmental impact when normalised. Despite using fewer materials, FRP sheathed boats thus tend to have high environmental impact potentials (Table 2). The impact potential of FRP sheathed boat construction is 1.7 times to 3.2 times high, in all impact categories, and this is primarily due to its lower usable life span.

The carbon foot print of FRP boats during construction, use, maintenance and repair of the boat is 35.31 kg CO_2 equiv., per year whereas for sheathed boat is 63.01 kg CO_2 equiv. per year.

The analysis of the environmental impacts of FRP boats reveals that resin compounds, including epoxy resin and gelcoat, are the primary contributors both in terms of quantity and impact potential across various categories (Fig. 4). This highlights the significant role of resin in determining the environmental footprint of FRP boats, affecting factors such as abiotic depletion potential, acidification potential,

Table 2. Comparison of environmental impact categories between FRP and sheathed boats during the construction and maintenance phase

Impact category	Units	Impact Factor for FRP boats (30y)	Impact Factor for Sheathed boats (7y)	Difference in impacts (times) between FRP and sheathed boats based on life span
Abiotic Depletion Potential	kg Sb-Equiv.	2.35E-04	7.09E-04	3
Acidification Potential	kg SO_2-Equiv	1.01E-01	2.75E-01	2.7
Eutrophication Potential	kg Phosphate-Equiv.	1.75E-02	3.82E-02	2.1
Global Warming Potential (GWP 100 years)	kg CO_2-Equiv.	3.53E+01	6.30E+01	1.7
Freshwater Aquatic Ecotoxicity Potential	kg DCB-Equiv.	2.54E-02	8.17E-02	3.2
Marine Aquatic Ecotoxicity Potential	kg DCB-Equiv.	1.40E+03	3.77E+03	2.6
Photochemical Ozone Creation Potential	kg Ethene-Equiv.	1.03E-02	2.86E-02	2.7
Human Toxicity Potential		2.02E+00	4.47E+00	2.2
Terrestric Ecotoxicity Potential	kg DCB-Equiv.	4.44E-02	9.63E-02	2.1

and global warming potential. Following closely behind resin, glass fibers, including glass mat and woven roving, also substantially contributes to the environmental impact of FRP boats.

In contrast, the composition of FRP sheathed boats presents a different environmental profile. Wood although being the major contributor in terms of quantity, its impact on global warming potential (GWP) is negative due to its carbon sequestration effect. Despite the positive effect of wood on GWP (-1.56E+01 kg CO_2 equivalent), resin (6.61E+01 kg CO_2 equivalent), glass fibers (7.46E+00 kg CO_2 equivalent) are significant in influencing the environmental footprint of FRP sheathed boats during the construction, use maintenance and repair phases.

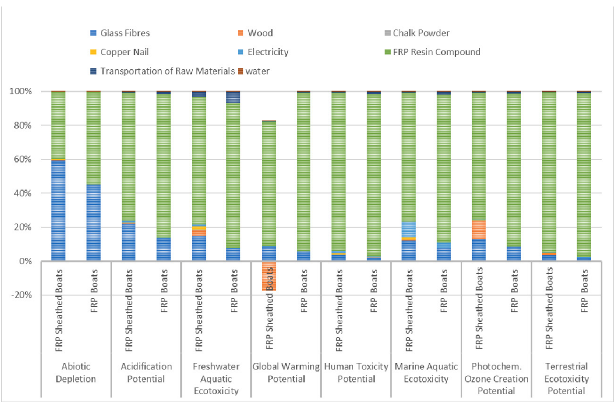

Fig. 4. LCA of 7m FRP and sheathed boat (construction and maintenance phase)

In India, fishers often discard abandoned FRP fishing boats by either open burning or landfilling, both methods lacking regulatory control, while lack the more regulated practices observed in European countries. Over their life cycle, FRP boats leave a carbon footprint of 1253.58 kg CO_2 equiv. when open burning is used for disposal, and a slightly reduced footprint of 1065.3 kg CO_2 equiv. when landfilled, indicating that both disposal methods have almost similar environmental impacts (Fig. 5). In contrast, for sheathed boats, landfilling results in a carbon footprint of 77.70 kg CO_2 equiv., while open burning has a significantly more adverse effect, with a carbon footprint of 596.67 kg CO_2 equiv.

Landfilling in Europe has been used sparingly, particularly in harbor construction (Eklund et al., 2013), and is recommended only as a last-resort recycling option (Somarajan et al., 2018; Önal & Neser, 2018) due to the severe environment impacts compared to burning. This has led some European countries to ban the practice (Dejhala & Legoviæ, 2018). In India, open burning releases hazardous substances, including glass fibers, persistent organic pollutants (POPs), and heavy metals into the environment, contributing to pollution (Lekshmi et al., 2023b). Similar practices in Nigeria (Odiegwu & Enyioko, 2022) have also shown the release of POPs and heavy metals, poising serious ecological risks (Singh & Turner, 2009; Turner, 2010).

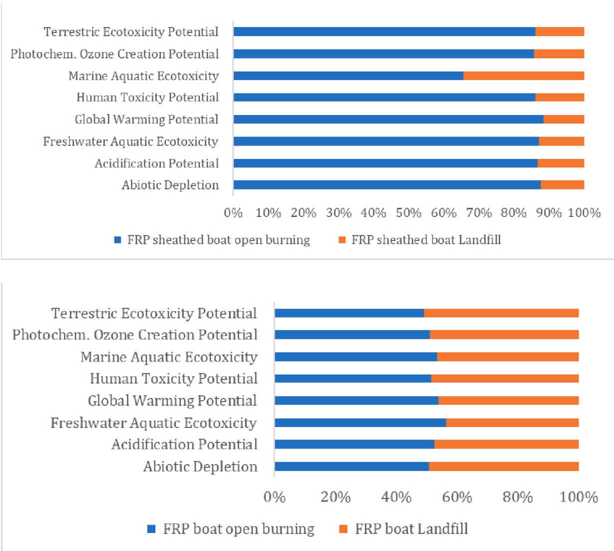

Fig. 5. Comparison of the disposal options of standard FRP and sheathed boat used in this study

Conclusion

This study examined the life cycle and environmental impacts associated with the construction, use, and disposal of Fiberglass Reinforced Plastic (FRP) boats and FRP-sheathed boats in the small-scale fishing sector. The findings reveal that while FRP boats require a significantly higher quantity of materials for construction, their longer lifespan of 30 years, compared to the 7 years of FRP-sheathed boats, results in lower overall environmental impacts when normalized to an year. Key environmental impact contributors, such as resin and glass fibers, significantly contribute to the carbon footprint during the construction and maintenance phases. Moreover, disposal methods such as open burning and landfilling generate severe environmental consequences, including the release of persistent organic pollutants (POPs) and greenhouse gases, with FRP boats having a higher carbon footprint compared to sheathed boats. Open burning of FRP boats poses the highest environmental threat. Thus, the study highlights an urgent need for sustainable disposal and recycling practices of FRP boats to mitigate ecological damage.

The research also emphasizes the importance of material selection and standard construction practices in reducing the environmental footprint. It also highlights the necessity for regulatory frameworks for the responsible disposal of end-of-life boats. Implementing such measures could significantly enhance sustainability in the small-scale fishing sector while maintaining the durability and longevity of fishing boats.

Acknowledgements

The authors thank the Director of ICAR-Central Institute of Fisheries Technology for providing facilities and guidance. Authors also thank National Innovations on Climate Resilient Agriculture (NICRA) for supporting the study. The fishers are acknowledged for their time, and cooperation for collection of data for this study. We thank the technical staff of the Fishing Technology Division of ICAR-CIFT for their support. We are also grateful to the editors for dedicating their valuable time for improving this manuscript.

References

AlShafi, M., & Bicer, Y. (2021). Life cycle assessment of compressed air, vanadium redox flow battery, and molten salt systems for renewable energy storage. *Energy Reports, 7,* 7090-7105. https://doi.org/10.1016/j.egyr.2021.09.161.

Anmarkrud, T. (2009). Fishing boat construction: Building an undecked fibreglass reinforced plastic boat. *FAO Fisheries and Aquaculture Technical Paper,* No. 507. FAO, Rome.

Arduini, M., Di Tommaso, A., & Nanni, A. (1997). Brittle failure in FRP plate and sheet bonded beams. *Structural Journal, 94*(4), 363-370. Htpps://doi.org/10.14359/487.

Baiju, M. V., Edwin, L., Pravin, P., Meenakumari, B., & Baiju, M. (2013). Fiberglass reinforced plastic (FRP) sheathed canoes for north east hill regions. *Journal of the Marine Biological Association of India, 55*(2), 88-90.

Belioka, M. P., & Achilias, D. S. (2023). Microplastic Pollution and Monitoring in Seawater and Harbor Environments: A Meta-Analysis and Review. *Sustainability. 15*(11), 9079. https://doi.org/10.3390/su15119079.

CMFRI. (2017). *CMFRI Annual Report 2016-2017.* CMFRI, Kochi.

Dejhala, R., & Legoviæ, D. (2018). Disposal of wornout fiberglass recreational boats. *Pomorski zbornik Posebno izdanje, 2,* 143–153. https://doi.org/10.18048/2018-00.143.

Das, D. P. H., & Edwin, L. (2019). LCA analysis: Case study of ring seine fishing systems of Kerala. In: Edwin, L., Thomas, S. N., Remesan, M. P., Ashraf, M.

P., Baiju, M. V., Lekshmi, M. N., & Madhu, V. R., (Eds.), *ICAR Winter school: Responsible fishing: recent advances in resource and energy conservation*. (pp. 167-176). ICAR- Central Institute of Fisheries Technology, Kochi.

Du Plessis, H. (2013). *Fibreglass Boats: Construction, Gel Coat, Stressing, Blistering, Repair, Maintenance* (5th ed.). Bloomsbury Publishing, London.

Eklund, B., Haaksi, H., Syversen, F., & Elsted, R., (2013). *Disposal of end-of-life plastic boats.* Nordisk Ministerråd, Copenhagen.

Grause, G., Mochizuki, T., Kameda, T., & Yoshioka, T. (2013). Recovery of glass fibers from glass fiber reinforced plastics by pyrolysis. *Journal of Material Cycles and Waste Management*, *15*(2), 122–128. https://doi.org/10.1007/s10163-012-0101-x.

Guersel, K. T., & Neser, G. (2012). Fatigue properties of fiberglass bolted, bonded joints in marine structures. *Sea Technology, 53*(11), 37- 41.

International Organisation for Standardisation [ISO]. (2006). *Environmental Management—Life Cycle Assessment—Principle and Framework.* (2nd ed.). ISO, Geneva.

Lekshmi, N. M., Kumar, S. S., Ashraf, P. M., Nehala, S. P., Edwin, L., & Turner, A. (2023 a) Occurrence and characteristics of fibreglass-reinforced plastics and microplastics on a beach impacted by abandoned fishing boats: A case study from Chellanam, India. *Marine Pollution Bulletin*, *192*, 114980. https://doi.org/10.1016/j.marpolbul.2023.114980.

Lekshmi, N. M., Kumar, S. S., Ashraf, P. M., Xavier, K. A. M., Prathish, K. P., Ajay, S. V, Edwin, L., & Turner, A. (2023 b). Abandonment of fibreglass reinforced plastic fishing boats in Kerala, India, and chemical emissions arising from their burning. *Environmental Monitoring and Assessment*, *195*, 1413. https://doi.org/10.1007/s10661-023-12033-8.

McVeagh, J., Anmarkrud, T., Gulbrandsen, O., Ravikumar, R., Danielsson, P., & Gudmundsson, A. (2010). *Training Manual on The Construction of FRP Beach Landing Boats*. FAO, Rome.

Odiegwu, C. L., & Enyioko, N. C. P. (2022). Effect of abandoned vessels on safety of mariners in coastal waters of nigeria. *International Research Journal of Modernization in Engineering Technology and Science, 4*(8), 2352-2370. https://www.doi.org/10.56726/IRJMETS29457.

Önal, M., & Neser, G. (2018). End-of-life alternatives of glass reinforced polyester boat hulls compared by LCA. *Advanced Composites Letters*, *27*(4). https://doi.org/10.1177/096369351802700402.

Pauchard, V., Chateauminois, A., Grosjean, F., & Odru, P. (2002). In situ analysis of delayed fibre failure within water-aged GFRP under static fatigue conditions. *International Journal of Fatigue*, *24*(2–4), 447–454.

Sunardi, Sukandar, Sulkhani Y. E., & Rahman, M. A. (2019, November). Repair technique for wooden fishing boats using fibreglass. *IOP Conference Series: Earth and Environmental Science*, *370*(1), 012081.

Singh, N., & Turner, A. (2009). Leaching of copper and zinc from spent antifouling paint particles. *Environmental Pollution*, *157*(2), 371–376. https://doi.org/10.1016/j.envpol.2008.10.003.

Somarajan, J., Kodungallur, S., & Nandakumar, C. G. (2018). Recycling of FRP Boats. *International Journal of Advanced Research in Engineering and Technology (IJARET)*, *9*, 244–252.

Song, Y. K., Hong, S. H., Jang, M., Kang, J. H., Kwon, O. Y., Han, G. M., & Shim, W. J. (2014). Large accumulation of micro-sized synthetic polymer particles in the sea surface microlayer. *Environmental Science & Technology*, *48*(16), 9014–9021. https://doi.org/10.1021/es501757s.

Turner, A. (2010). Marine pollution from antifouling paint particles. *Marine Pollution Bulletin*, *60*(2), 159–171. https://doi.org/10.1016/j.marpolbul.2009.12.004.

Turner, A., & Rees, A. (2016) The environmental impacts and health hazards of abandoned boats in estuaries. *Regional Studies in Marine Science*, *6*, 75–82. https://doi.org/10.1016/j.rsma.2016.03.013.